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PhD Dissertation

Analysis of impact of selected natural waste fibers and ashes on properties of mortars

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"Thank you" to my family for always believing in me. Thanks, Mom and Dad, for letting me chase my dreams. You always gave me good advice, letting me make my own choices while supporting me. Parents like you make me very lucky. "Thank you" Pratap has always protected me as a supportive spouse. Much obliged.

For myself

I couldn't have done this without my family, yet our life depend on our choices. Everyone has great potential. New challenges may arise, but by focusing on what we can control, we can overcome them. I forgot all of this for months, but I was able to look within and return stronger and ready for the next Chapter.

ABSTRACT

By conducting research on renewable, ecologically friendly building materials, this dissertation hopes to advance the field of building materials for the construction sector. The material is created using a biomass ash such as rice husk ash (RHA), sugarcane bagasse ash (SCBA), and limestone powder (LP) as SCM for cement substitute, as well as waste natural fibers such as jute, sisal, and synthetic fiber as polypropylene. Long-term objectives include developing innovative, locally sourced ecologically friendly building materials to increase construction efficiency, speed up development, and lower construction costs, fitting into the area related to the use of natural waste materials and they recycling, i.e. environmental protection and sustainable construction.

The first study was carried out to examine the physical, mechanical, and micro-structural properties of natural fibers from jute, sisal and polypropylene which are widely available in Asia. Then, we reviewed the comparison jute and sisal to polypropylene fiber as waste on mortar properties. The study, designed a formula for a fiber composite material with cement, cement lime and cement with Air entraining Plasticizing Admixture (APA) so that it could be formed using in practical. After that, testing used to check the impact of fibers on the behavior of the cement. The second part of study is done with replacement of cement with rice husk ash, sugarcane bagasse ash and limestone powder with amount 5%, 10 and 15%. Then, it is analyzed to obtain a prediction for the better materials enhancing mortar properties with all additives. The study, examined the mechanical performance of tested mortars, using air content, consistency, compressive strength, flexural strength and shrinkage. To obtain characterization of the micro components, testing is done using a Scanning Electron Microscope (SEM) and Mercury intrusion porosimetry (MIP). On the base on them the evolution of failure and damage of the material is observed by micro-cracks.

The results obtained from this study show that mortar samples performance is improved jute fibers and supplementary cementitious materials (SCM) addition. Furthermore, the addition of jute fiber increases the compressive and tensile strength compared to without fiber also enhancing all the properties on mortar with better crack resistance capability. The microstructural investigation confirmed better adhesion in jute composite fiber. The use of biomass ash enhance all the mechanical properties of mortar resulting is development of such materials which is more sustainable. The use of rice husk and bagasse ash shows improvement in both compressive and flexural strength with replacement level of 10%. With microstructural properties it can be seen than sugarcane bagasse ash is acting more like a filler materials and hence decreasing the cracks and voids in matrix. The carried out investigations showed the beneficial properties of mortars with the addition of natural waste materials such as jute fibers or ashes. Such materials can therefore be considered ecological and environmentally friendly

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Abbreviations

APA	Air entraining Plasticizing Admixture
CA	Cement mortar with APA
CL	Cement lime mortar
CM	Cement Mortar
EN	European Standards
LOI	Loss on Ignition
LS	Lime stone powder
MIP	Mercury intrusion porosity
OPC	Ordinary Portland cement
RHA	Rice husk ash
SCBA	Sugarcane bagasse ash
SCM	Supplementary Cementitious Material
SEM	Scanning electron microscopic
WA	Wood Ash

Chemical Abbreviations

Al_2O_3	Aluminium Oxide
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
C_4AF	Tetra-calcium Aluminoferrite
CaO	Calcium Oxide
CO_2	Carbon Dioxide
CSH	Calcium–Silicate–Hydrate
Fe_2O_3	Iron Oxide

K_2O	Potassium Oxide
MgO	Magnesium Oxide
Na_2O	Sodium Oxide
SiO_2	Silicon Dioxide
SO_2	Sulphur Dioxide
SO_3	Sulphur Trioxide
ZnO	Zinc Oxide

CHAPTER 1

INTRODUCTION

Researchers have recently been concentrating a lot on global warming. People are currently very concerned about environmental destruction. Studies and material design are becoming more focused on preventing environmental harm. The primary contributor to global warming is CO_2 emissions. The production of cement and steel, two widely used commodities in the building sector, uses a significant amount of energy. Along with the rising demand in the building industry, cement production is also rising. As a result, the building sector manages the depletion of numerous non-renewable resources. Millions of tonnes of mineral waste and carbon dioxide emissions are produced by this activity. Half of the greenhouse gases produced by this industry's total emissions are caused directly by the transport, production, and usage of materials during the construction phase. The goal of the research is to create substitute materials that will lower CO_2 emissions and other hazardous gas releases into the atmosphere. To reduce the environmental effects of building materials, it is usual practice to use additional cementitious materials or naturally occurring local raw materials, such as biomass waste. It is also intriguing to substitute locally accessible bio-based fibers for steel reinforcement in composite materials.

Natural waste has become increasingly popular as an additive or partial replacement in construction materials in recent decades after it became popular in automotive, aerospace, and sports applications. Their popularity is due to the fact that they have some unique properties that conventional-materials may not have. Utilization of natural materials, such as wood, agricultural waste, and plant fibers, is expanding significantly in industry and research. These materials are renewable, readily available, less dense, inexpensive, and have excellent mechanical properties, making them an attractive sustainable alternative to synthetic fibers in composite material production. Motivated by the desire to accomplish desirable material properties, such as good mechanical and durability crack resistance and good surface hardness, the investigation is conducted. Through extensive research, it has been determined that many natural fibers, including sisal, coconut, sugar-cane bagasse, hemp, and jute, have been documented to enhance the compressive and flexural strength of cement composites [1]–[3]. Natural fiber-reinforced composites are characterized by their lightweight nature and the use of stiff and strong fibers, resulting in a composite material that exhibits enhanced ductility and reduced stiffness [4]. Natural SCM alternatives to cement, including rice husk ash, sugarcane bagasse ash, wood ash, limestone, and clays, are also in high demand. In light of the escalating demand and utilization of cement, coupled with the prevailing waste management concerns, scientists and researchers are actively engaged in the pursuit of environmentally sustainable alternative binders and these materials are achieved after combustion, wasted, and thrown into the environment. The development of a nation depends not only on technology but also on infrastructure; concrete and mortar are mainly used materials and are the backbone of infrastructure. It is critical to develop low-cost construction materials to make adequate housing available to even the most impoverished populations.

The first step to implementing low-cost construction is to use low-cost materials and what can be better if it’s environmentally friendly. Most composites have two constituent materials one is matrix as surrounding and for holding a reinforcement and second is filler that give strength and stiffness to matrix. Glass, carbon, and aramid fibers are popular fibers for use in high performance composites. Because of their low density and excellent specific properties. Thermosets such as vinyl ester, unsaturated polyester, epoxy, phenolic, and glass dust are frequently used as polymer matrices for high performance composites; however, these materials are both environmentally hazardous and expensive therefore thermoplastics is suggested as an alternative because is cheaper and environmentally friendly materials.

Polypropylene (PP), a commodity plastic, is more commonly used in glass mat thermoplastic composite (GMT) for automotive applications [5]. Recently various studies and research are ongoing on natural composites which can be consider as long term used materials both in aspect of strength and sustainability. Straw and mud are the first used materials for making brick as composites. Use of naturals fibers and ashes in place of artificial and consider to be recommended though they have lesser strength compared to artificial but different improvement mechanism can be made to improve the properties of composites with natural additive. Due to rising social, ecological, and economic concerns as well as the rapid consumption of petroleum resources, industrial ecology, sustainability principles, and new environmental regulations, the next environmentally friendly composite materials must be developed in order to reduce greenhouse gas emissions. The production of natural fibers requires very little energy, and because they have high values, they can be incinerated for energy recovery at the end of their useful life.

Plant-derived fibers use carbon dioxide during their growth and can be concluded to have natural CO_2, which means that after being burned, they don't release additional CO_2 into the atmosphere [6]. The primary disadvantages of using natural fibers as reinforcement are their chemical and physical properties, such as fiber structure, cellulose content, cross section, and polymerization degree. Due to the presence of cellulose and lignin in natural fibers, they are water-absorbent, resulting in fiber expansion and a feeble bond between fiber interfaces in cement composites. Also, the strength, rigidity, and durability of natural fibers vary greatly from plant to plant, and variations in the cross-sectional area and length of fibers can ultimately lead to design and performance issues in composites. Natural fibers are also have thermally conductive properties when compared to most synthetic fibers, they are unstable and have processing and working limitations at 200°C temperatures. However it the demerits can be improve according to different research by surface treatments [7], [8].

The study includes the implementation on natural waste ash as replacement with cement and addition of bio fibers to enhance the reinforcement properties of mortar. Many studies and research are being carried out with polymer composites with different addition of materials a rare work has been carried out with both natural materials addition to single composites, so the aim of experiment is to find the benefits of new composite with natural additive.

CHAPTER 2

MORTAR IN CONSTRUCTION

Mortar is a bonding agent that is typically made by combining cementing or binding material example cement and lime and fine aggregate like sand, sawdust etc. with water. Mortar is used holding various building components to as bricks, stones, and so on and it is also used to make different a decorative design in masonry structures. Mortar has been used since the dawn of time. The Egyptians used lime mortars over 2000 years ago. To improve the other characteristics or properties of mortar components such as additives and admixtures are frequently added to mortars EN 16572 2015 [9]. Mortar's binding property plays a distinct and vital role in masonry construction. To perform its function, mortar must be able to retain certain characteristics. It must be able to mature within the ambient weather conditions during the first few days after placement, which can range from hot to freezing and wet to dry. It must also provide a structure with the ability to accommodate movements caused by temperature and moisture variations, as well as resist rain penetration, frost damage, and sulphate attack. The visual appeal of masonry is frequently a primary consideration. Depending on the application, a mortar that matches or mixes with the color of the stone construction may be preferred. The color of mortar materials such as sand, masonry mix, plaster cement, Portland cement, and lime has an effect on the look of mortar joints. Following that is the texture of the mortar joint surface. The texture and thus look of mortar joint surfaces are determined by sand gradation, the uniformity of the mortar during tooling, the type of jointer used in tooling joints, and the impact of the cleaning operation.

2.1. Plaster mortar and masonry mortar

The goal of this work is to examine the current level of knowledge in relation to the preservation of a particular class of materials, namely mortars and plasters. The terms "mortar" and "plaster" are frequently used interchangeably, although mortars are used in masonry to unite stones, bricks and other building materials, whilst plasters are used to render both the inside and outside of walls. Here, when we speak to "mortars and plasters," we mean a general word for artificial stone materials comprised of binder and aggregates that are used in masonry settings as a bedding mortar or for protection (such as render and plaster), as well as ornamental mortars.

The term "plaster" can refer to a number of different combinations, depending on the binder and aggregate employed. Technical jargon distinguishes between renders and plasters, the latter of which are combinations of one or more binders with aggregate (and maybe other admixtures). Plaster and render are further words for internal and external finish formulations, respectively.

Since mortar plays an important role in load transfer, the mortar properties required for masonry connections differ from those required for general mortar applications. In addition to mortar's strength and durability, the efficacy of masonry is significantly influenced by mortar's strength and durability. If the mortar degraded or deteriorated, the load-bearing capacity of masonry connections and general applications would decrease.

The heterogeneity in masonry mortars and plasters may result from variations in composition, technical execution, and/or exposure to the environment and other deterioration causes. Since mortar and plaster issues and behaviors can differ from place to place, a precise examination is necessary. Plaster mortars are more fluid than masonry mortars, which is the primary distinction between the two forms of mortar other than function. The differences in water content or admixture content between the two types of mortar are typically linked to changes in the desired consistency. There are several grades and varieties of plaster mortars, as well as different rendering techniques.

The technical specifications demand specific characteristics for both masonry and plastering mortars, based on their designated use and classification. According to the EN 998-1[10] standard, plastering mortars can be categorized into several categories, including general purpose, lightweight, colored, one layer for external usage, rehabilitation, and thermal insulating. There exist three fundamental features that are necessary: compressive strength, capillary water absorption, and thermal conductivity. Furthermore, there are several additional features that may be deemed necessary, including as binding, water through capillaries absorption, water vapor permeability, penetration of water, and reaction to fire.

As per the specifications outlined in EN 998-2 [11], which pertains to mortars used in masonry construction, bricklaying mortars can be categorized into three types: general purpose, thin layer, and colored. The essential characteristics that must be considered include bond strength, water absorption, water vapor permeability, and thermal conductivity. In order to conduct tests on hardened mortars in accordance with EN 1015 [12] (Methods of test for mortar for masonry), it is necessary to ensure that all specified properties are present. Furthermore, it is advisable to conduct tests on fresh mortar to assess its properties, such as consistency (measured using a flow table or plunger penetration), air content, workable life, and water-soluble chloride content.

Plastering material or mortar is made out of cement, water, and sand, with additional ingredients added as needed. For instance, the mortar used for masonry work, such brick repair, has a different composition than mortar used for interior, exterior, and ceiling construction. Plaster is mostly used for finishing work both inside and outside, thus the features that are needed for it depend on how it will be used. For instance, outdoor plaster requires higher resilience to weather than internal plaster mortar.

A substantial portion of the study is devoted to altering mortars with various additives to enhance their qualities while partially substituting waste materials for reinforcements, fillers and binders. The mortar's tensile strength and particularly its ductility are improved by dispersing the fiber reinforcement within it. The cracking zones and crack width of the fiber-reinforced mortar are smaller than those of a traditional mortar. In actual use, fiber-reinforced mortar is preferred over traditional mortar, particularly for masonry structures in seismically active areas. As fillers and binders as well utilizing agricultural waste ashes as cement substitutes is one of the most efficient ways to reuse waste to stop these negative effects caused by cement manufacture.

Exemplary Muthukrishnan's study [13] demonstrates that 20% RHA has a larger silica concentration and a lower specific surface area, which improves RHA's pozzolanicity as a mortar additive. Furthermore, it has been shown that the inclusion of this particular substance results in an enhancement of the compressive strength and other mechanical properties of the mortar, when compared to a control sample with an equivalent water-to-binder ratio.

2.2. Cement mortar and cement-lime mortar

Both cement-lime mortar and cement mortar are frequently used mortar in construction. With this study, we're looking into the many additive qualities of cement lime mortar and cement mortar's various properties.

Cement mortar are the most common use in masonry structure compare to cement- lime mortar. Cement is most valuable when used to create mortar for masonry and concrete projects. The most prevalent type of cement used globally is portland cement. The most useful ingredient in concrete is portland cement, a binding agent. Economically speaking, given the energy required to produce it, it is a somewhat expensive building material. The high energy requirements for cement mining, manufacturing, and transportation, as well as the resulting air pollution and greenhouse gas emissions, are environmental concerns.

Composition mortar, "compo" mortar, guarded mortar, and gauged mortar are further names for lime-cement mortar. This mortar is typically used in plastering and masonry. Of course, additional mortars can be classified by binder, such as sand-lime, gypsum, or cement-clay, depending on their use. Masonry mortars are classified by composition and compressive strength: M1, M2.5, M5, M10, M15, and M20. In other strength classes, the manufacturer can declare different values.

Depending on the needs of the project, the mixture contains varying amounts of cement, lime, and sand. Commonly used composition is 1 part cement, 1 part hydrated lime and 6 parts sand by volume work well for the majority of jobs (C: L: S is 1:1:6). An appropriate mixture would consist of 1 part cement, 2 parts lime, and 9 parts sand for enhanced workability. Because it combines the benefits of outstanding workability with early strength, lime-cement mortar is the most ideal. Although it shouldn't be used for any work below the damp course level, it should be used up within an hour after mixing. Cement lime mortar are mostly used for making the mortar homogeneous or more workable and durable. It is composed of the oxide or hydroxides of calcium. It helps to minimize the cracks on drying. Adding water can make lime paste less dense and lime paste fills up sand spaces, it stands to reason that adding too much water will also make mortars less dense. Even a mortar with the highest density is too stiff to be used and needs additional water to be usable.

Plain cement mortar is more durable than lime mortar, but it can be challenging to deal with since it feels either too stiff or too moist to the mason. Additives that give the mortar more "plasticity" are frequently used to improve workability, however admixtures may have a negative effect on durability. In the past, this was accomplished by adding hydrated lime; however, chemical admixtures known as "plasticizers" are now frequently utilized, either with or without hydrated lime. Exemplary in place of lime an air entraining plasticizing admixture can be used. The durability and adherence of mortar can be negatively impacted by the improper application of these admixtures, though.

Given the previously stated requirements, the present study focused primarily on the examination of consistency and air content in waste-based modified mortars. The parameters of compressive strength, flexural strength, and shrinkage were evaluated for hardened mortars.

CHAPTER 3

STUDY OF THE LITERATURE

3.1. Introduction

The purpose of the literature review and state of the art in this chapter is to provide a comprehensive and exhaustive summary of the research findings on environmentally friendly construction materials.

The construction materials focused on the qualities and performance characteristics of natural fibers in cement, SCM, and fiber cementitious composite materials. In addition, additives such as jute, sisal, and polypropylene as fiber and SCM such as sugarcane bagasse ash, rice husk ash, and limestone are investigated in cement-based composites. At both the micro parameters and the mechanical properties of such composites were studied. The first section will begin with a broad overview of mortar and concrete with fibers, including varieties, applications, and property enhancement by addition. The second part will provide a comprehensive overview of the characteristics of supplementary cementitious materials (SCMs), including their application, preparation, microstructure, fineness, and reactivity. Additionally, it will examine the impact of various additives on the strength of mortar and concrete, as well as their effect on dry shrinkage.

3.2. Natural fiber

Plant fibers, including bamboo, coir, jute, sisal, and cotton, are made up of cellulose, hemicellulose, and lignin. The exact makeup of the fibers differ depending on the types [8]. Flax, hemp, jute, sisal, hemp, and kenaf fibers are some of the most often used natural fibers. They have been widely investigated and employed in many applications, and their qualities and availability are rising attention and relevance among both researchers and industrial uses [14]. Determination of thesis natural fiber-based mortar together with polypropylene comparable additive in form of synthetic fibers. The research seeks to organize the findings from results reported in literature to discover trends relating mechanical properties to be useful from a future sustainable materials in construction industries and its implementation perspective.

3.2.1. Composition and chemical structure of selected natural fibers

Cellulose, hemicellulose, and lignin are the primary constituents of natural fibers. Cellulose is a polymer composed of glucose units. It is a robust, crystalline molecule devoid of branches. cellulose is resistant to hydrolysis, but chemical treatment can break down some of this resistance [15]. Hemicellulose is composed of glucose, mannose, glucuronic acid, and xylose, and it functions as a low molecular weight polysaccharide polymer with an amorphous, branching structure. Hemicellulose is hydrolyzed by dilute acid or base, which releases the cellulosic material's binding structure [7].

Table 1 illustrates the average quantity of chemical ingredients for a variety of fiber types. Cellulose is a major structural component of practically all green plant cell walls, particularly in many natural fibers.

Table 1 .Chemical composition of natural fibers

Fiber	Cellulose (wt. %)	Hemicellulose (wt.%)	Lignin (wt.%)
Bagasse	55.2	16.8	25.3
Bamboo	26-43	30	21-31
Flax	71	18.6-20.6	2.2
Jute	61-71	14-20	12-13
Kenaf	72	20.3	9
Hemp	68	15	10
Abaca	56-63	20-25	9-12
Sisal	65	12	9.9
Coir	32-43	0.15-0.25	40-45
Oil palm	65		29
Pineapple	81		12.7
Rice husk	35-45	19-25	20
Wheat straw	38-45	15-31	20-24

Source: [16]

Even within the same plant, the chemical composition of various fiber varieties varies. Additionally, it varies according to its growing region, climate, age, and soil conditions. The chemical composition of a fiber is determined by its growth period, botanical classification, and height. Similarly, the chemical components of a plant can vary within the same region. Root and stem cores contain more lignin than fibers [3].

3.2.2. Review on physical and mechanical properties of natural fibers

3.2.2.1. Physical properties of natural fibers

Jute fiber is a member of the malvaceae family, which is derived from corchorus vegetation. Jute fiber is composed of cellulose up to 64.4%, hemicellulose up to 12%, lignin up to 11.8%, and water up to 10%, in addition to water-soluble components (1.1%), and wax (0.5%). When jute fiber is exposed to sunlight, its hue ranges from yellow to brown with differing degrees of grey. As a result of its composition and rigidity, this fiber is utilized in the production of low-impact building materials. [17], [18].

Sisal belong to Agavaceae family and is derived from the Agave Sasayama and is a leaf fiber Leaf fibers run lengthwise which providing strength and stiffness. Approximate 200-250 leaves is produce by sisal plants which compose of approx. 4% fiber, 8% dry matter, 0.75 cuticle ,and 87.25% water [19].

Few of Physical properties of natural fibers are mentioned in Table 2. According to Seongwoo Gowns, raising the volume part caused the paste to have a larger air content with both jute and kenaf plant fiber for a given fiber length. This was owing to the higher porosity caused by both the increased fiber volume and the increased quantity of entrained air bubbles. At a constant fiber volume fraction, however, the combinations with longer fibers (except for the 10-mm-long jute fibers) had less air content than those with shorter fibers. This is most likely due to a reduction in entrained air bubbles caused by fewer long fibers with the same fiber volume fraction [20]. Naraindas Bheel investigates the workability qualities of jute fibers using slump analysis. The study found that the highest slump value observed was 60 mm when the volume percentage of fibers was 0%. Furthermore, it has been shown that an increase in the amount of jute fiber leads to a reduction in the slump of newly produced concrete. The decline in workability may be ascribed to the augmentation in the specific surface area of the component, resulting in an amplified need for cement mortar to adequately cover its surface area. Consequently, there was a reduction in the water quantity necessary to achieve the desired workability of reinforced concrete when using jute fibers [21].

The addition of fibers to the mortar reduces its workability; to make it work, a superplasticizer is advised. In general, the surface area, length, and surface shape of the fiber influence the workability of fiber-reinforced mortar. The addition of natural fibers to mortar and concrete, on the other hand, enhances workability due to high water absorption due to the presence of lignin in natural fibers [22].

Wongsa, Ampol investigated the workability of geopolymers mortars incorporating natural fibers (Sisal fibers and Cotton fibers) was examined using flow table analysis in comparison to the control geopolymers mortar (CGM). These results showed that using entire fibers considerably reduced the workability of mortars. Geopolymers mortars containing SF and CF had flow values of 22-54% and 55-97%, respectively, which were lower than CGM (132%). This was owing to the fibers' rough surface, porosity texture, and uneven stripes. With an increase in fiber content, the fresh geopolymers mortar stiffened [23]. Similarly, Priyadharshini and Ramakrishna discovered that increasing the amount of sisal fiber component (0, 1.5, and 2.5% by weight of cement) reduced workability while improving cohesiveness of cement-based composite [24].

Flávio de Andrade Silva discovered that the addition of sisal fiber promotes drying shrinkage. When compared to the control, the composite showed a 40% increase in drying shrinkage. A 5% difference was found when measuring shrinkage parallel and perpendicular to the fiber, indicating that fiber orientation had little effect on composite shrinkage. The primary factors influencing the drying shrinkage of the cement matrix are the porosity of the cement matrix and the characteristics of the capillary system in the hydrated cement paste, including its size, shape, and continuity. The inherent porosity of the fibers at the microstructural level facilitates an increased influx of moisture into the matrix, hence leading to elevated levels of drying shrinkage [25].

3.2.2.2. Mechanical properties of natural fibers

Mechanical qualities are affected by various aspects, including fiber length [26], composition [27], [28], orientation [29], and production technique. As a result, comparing their composite characteristics is difficult since the materials, production processes, circumstances, and analytical variables do not immediately correlate. This literature review focuses on the mechanical characteristics of composites such as flexural strength, compressive strength, and tensile strength.

Lertwattanaruk and Suntijitto (2015) [30] proposed using natural fiber cement sheets as an alternative, increasing the value of reused agricultural industrial resources. The experiment was carried out with cement mortar comprising coconut coir fiber and oil palm fiber, which was shaped into cement sheets. The findings of the trials revealed equivalent effects in physical and thermal properties. The apparent porosity of the natural fiber cement sheets increased while the bulk density decreased. The composite's compressive and flexural strength decreased with the addition of fibers soil-the mix proportions.

K. C. M. Nair [31] In his a study conducted the impact of fiber orientation on the tensile properties of composites made from sisal fiber reinforced polystyrene was examined. Two forms of orientation composites were developed, namely randomly oriented fiber composites and unidirectionally oriented fiber composites. The modulus of longitudinally oriented fiber composites exhibits a 40% increase compared to randomly oriented fiber composites when subjected to a fiber loading of 10%.

Kedou and Fsikiotini [17] researched the usage of natural fibers in cement mortar and discovered that adding fibers to mortars appears to enhance the flexural strength of mortar when compared to the references mortar. Kelp fibers in cement mortars increase the strength by 28%, followed by a mixture with coconut fibers that increases by 24%. Jute fibers increase cement mortar strength by around 16%. Jute fibers, on the other hand, appear to triple the strength of lime mortars, whereas kelp and coconut provide increases of 77% and 90%, respectively. The compression behavior of the mixtures was quite different. The compressive strength of cement mortars exhibited a reduction of around 15%. In contrast, it is noteworthy that lime reinforced mortars exhibited a threefold rise, despite the limited duration of the tests conducted at a mere 28-day age. This relatively short timeframe may not guarantee the complete carbonation of mortar samples at a significant depth. Upon comparing the results, it is evident that cellulose-rich fibers, such as jute and kelp, have a detrimental effect on the compressive strength of cement mortars, while exhibiting an enhancing effect on lime mortars. In contrast, coconut fibers, characterized by their elevated lignin content, exhibit compatibility with cementitious materials, but their interaction with lime-based materials is limited.

Kundu et al. [32] examined a cost-effective method for manufacturing sewage pipes using jute fiber reinforced concrete. During the experiment, jute fibers were subjected to cutting and chemical treatment in order to achieve a uniform distribution of jute fibers inside the cement matrix. The investigation revealed that the load-bearing capability of sewage pipes reinforced with jute fibers exceeded that of concrete pipes without reinforcement. This finding suggests that natural fibers, such as jute fibers, have the potential to serve as effective reinforcements for cement-based constructions.

Pavan et al [33] investigated the shear behavior of fiber reinforced brick masonry. Masonry shear strength and post-peak behavior were evaluated. Natural fiber reinforced composites applied to masonry have received little attention. The work presented in this context investigates the strength of brick masonry utilizing natural fiber reinforced polymer composite (NFRP). Jute is a natural fiber, and jute fiber reinforced polymer composite is used to reinforce masonry.

Table.2 summarizes the key physical-mechanical parameters of frequently used natural fibers as compiled by several publications [Faruk 2012[16]], [Hattallia 2002[34]], and [Hoareau 2004[35]]

Table 2. Physical-mechanical properties of natural fiber

Fiber	Tensile strength (MPa)	Young‘s modulus (GPa)	Elongation break (%)	Density (g/cm3)
Bagasse	290	17	0	1.25
Bamboo	140-230	17-Nov	0	0.6-1.1
Flax	325-1035	27.6	2.7-3.2	1.5
Jute	393-773	26.5	1.5-1.8	1.3
Kenaf	930	53	1.6	
Hemp	690	70	1.6	1.48
Abaca	400	12	10-Mar	1.5
Sisal	511-635	9.4-22	2.0-2.5	1.5
Coir	175	6-Apr	30	1.2

Source: [16]

K. M. Rao, [36] Has also investigated the behavior of cement boards reinforced with 8% waste Kraft pulp modified with silica fumes as SCM. The results showed that adding 3-6% silica fume by cement weight could slightly improve flexural strength while adding more than 6% Silica Fume resulted in a slight decrease in strength when compared to the control specimen.

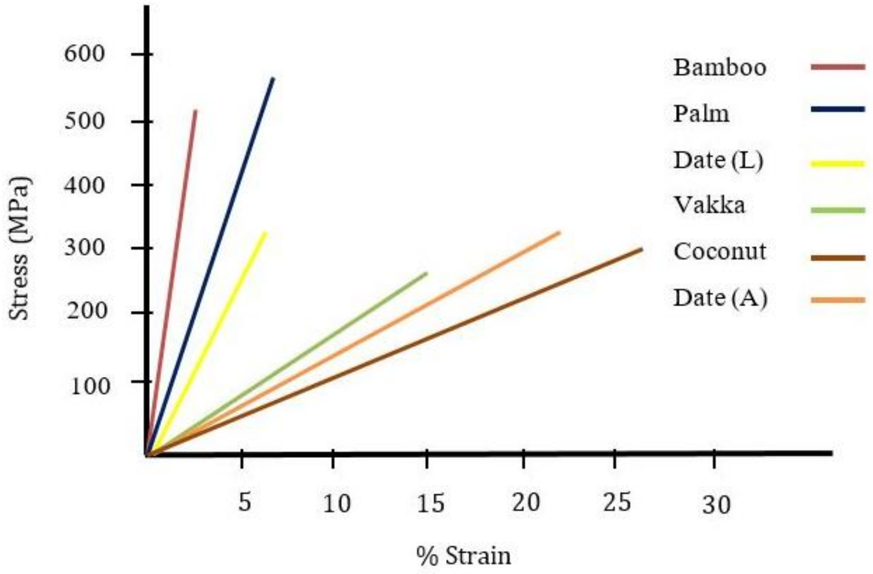


Figure 1. Stress verses percentage strains of various fibers [37]

3.3. Review on polypropylene fibers

Polymers and ceramics are common matrix materials, with plastics being particularly popular because to their widespread availability and inexpensive cost. Plastic is originated from the Latin term "plasticus," which referred to anything that could be shaped/molded into a desired shape (Plastics Europe: Association of plastic makers, 2018; Plastics europe, 2017). This is also true for thermoplastics, which have high melt flow indexes as well as sufficient strength and stiffness values. However, the plastic family has developed significantly, with each variety having unique features and applications. As a result, plastics are becoming increasingly popular due to their demonstrated ability to satisfy a wide range of criteria in a variety of sectors. The thermoplastics and thermosets are the two primary groups of plastics.

Polypropylene is a flexible thermoplastic material made by polymerizing monomer units of propylene molecules into very long polymer molecules or chains in the presence of a catalyst under precisely regulated heat and pressure [38]. Polypropylene is one of the fastest growing commodity thermoplastic classes, with a market share increase of 6 to 7% every year. Only polyethylene and polyvinyl chloride yield more volume than polypropylene. Polypropylene's low cost and favorable features lead to its rapid rise [39].

3.3.1. Physical and mechanical properties of polypropylene fibers in cement matrix

3.3.1.1. Physical properties of polypropylene fiber

Few artificial fibers are also showing the better results than natural fibers for an example with steel and glass fibers and plastic fibers [22], [40].

Panthapulakkal et al [41] investigated the tensile characteristics of a hemp/glass fiber reinforced hybrid composite with varying glass fiber loading. Because glass fiber has a higher strength than hemp fiber, the tensile strength of the composite rose as the glass fiber content increased. With glass fiber loading ranging from 5 to 15%wt, the tensile modulus of hybrid composites increased by 6-17%.

The polymers of interest in this literature study include and polypropylene (PP). Table 3 lists its main mechanical features. Polypropylene is one of the most often utilized thermoplastic polymers in the production of natural fiber composites [42].
Its mechanical qualities convincingly support its use as a major matrix material.

Some of the advantages of polypropylene include [42]:

- low dimensional stability,
- high thermal degradation temperature,
- high recyclability

Małek, M [43] study the effects of polypropylene fiber When compared to ordinary concrete, the addition of PP fibers to the reference mix diminishes its workability. In practice, a decrease in slump cone was found for plain concrete reinforced with polypropylene fibers derived from the same plastic packaging. The air content of the cement glass composite remained consistent regardless of polypropylene fiber percentage and was equivalent to 4.0 0.5%. The addition of fibers had no effect on the amount of air in the mixture. Other researchers discovered a similar relationship between decreased workability and increased polypropylene fiber concentration [22], [44].

Ranjbar, N [45] studied The effect of polypropylene fiber content on the flow reduction of geopolymer composites in their fresh state was investigated. The flow of pure geopolymers paste is relatively high and tends to flow by gravity, as seen. When static, the addition of low fraction, 1-3% fires into geopolymers paste appears harsh, however the stiffening effect of the fibers begins to decrease under vibration. However, the overall addition of fiber increases shear resistance to flow, resulting in a decrease in flow ability. Similarly Xu, Yangchen [46] investigated The influence of fibers on the flow of mortar mixes was studied, and it was discovered that the presence of polypropylene fiber in cement mortar diminishes the flow ability with all percentage blends. A greater proportion of polypropylene fiber, on the other hand, reduces flowability. In conclusion, the effect of polypropylene fiber on either flow or working capacity is substantially lower than that of the reference cement mortar.

Thanon, Daethar [47] studied the physical property dry density and found that The addition of polypropylene fibers resulted in a reduction in the mass of the hardened mortar, which was expected due to the low specific gravity of fiber, which reduces the overall density of mortar; thus, the higher volume fraction 0.8% PP fiber revealed a 4% reduction in density. Polypropylene fibers were introduced into cement mortars with the goal of strengthening the composite material while lowering its weight. Rajaei, Shahin [48] found similar results stating that the addition of fibers resulted in a little decrease in density. This is due to the decreased density of the polypropylene fiber in comparison to the overall density of the combination. Adding 0.5% and 1% (by volume of mix) PPF, for example, resulted in a 2% and 4% reduction in density, respectively, when compared to the reference mix.

Another factor that may explain for the lower density of fiber-reinforced mixes is the higher entrapped air caused by the addition of fibers. Because PPF is hydrophobic, air bubbles can form at the fiber-paste contact, increasing the void content of the mixture.

3.3.1.2. Mechanical properties of Polypropylene fiber

Some researchers even demonstrated that recycled polypropylene is less porous and has a greater density than virgin polymer. Furthermore, its flexural and mechanical characteristics are equivalent. Polypropylene-based natural fiber composites outperformed polypropylene alone in terms of tensile and flexural strength [5], [39], [40], [49].

S. Kakooei [50] Investigated the influence of polypropylene fibers on reinforced concrete structural attributes. The effect of varied amounts of polypropylene fibers content on concrete qualities was explored in their study by evaluating permeability, electrical resistivity, and compressive strength. They discovered that the compressive strength of concrete rose proportionately to the volume ratio of PP fiber. They determined that the inclusion of PP fibers slowed the deterioration process by lowering permeability, limiting the amount of shrinkage and expansion of concrete, which can considerably alter the structure's lifespan. They also determined that the electrical resistivity of concrete with fiber ratios of 1 and 1.5 kg m-3 was greater than in other samples.

Shrinkage cracks can be an aesthetic and durability issue because water, chlorides, and other harmful substances can enter those cracks, causing premature deterioration and damage. Thus, controlling shrinkage cracks is critical for increasing service life and lowering repair costs. These cracks reduce load carrying capacity and allow aggressive agents to penetrate the mass, reducing constructions' long-term durability. Fibers limit shrinkage due to the matrix bond and specifically control plastic shrinkage cracking at early ages. Adding fibers to concrete does not affect evaporation rate, but it does increase strength and strain capacity during early age shrinkage against tensile cracking. the researchers found that that fibers, particularly synthetic fibers, have a beneficial effect on the plastic and autogenous shrinkage of cement composites [51]–[53]

N. Banthia [54] Evaluated the effect of PP fiber geometry on concrete plastic shrinkage cracking. Four distinct volume fractions of PP fibers, three monofilament and one fibrillated fiber type, were introduced to diverse concrete overlay compositions. They came to the conclusion that PP fibers are quite good in controlling plastic shrinkage cracking in concrete. The inclusion of fibers reduced total crack area, maximum crack width, and crack number. They also indicated that when the fiber volume fraction grows, so does the efficiency of fiber reinforcement.

S.Singh [55] Studied the pull-out behavior of PP fibers from cementitious matrix. Polypropylene strips 50 mm long with a rectangular cross-section of 1.25 x 0.2 mm were employed. They observed that as embedded length increases, the fiber abrasion effect becomes more pronounced, resulting in a rise in pullout load in the frictional sliding zone of the pullout. The scientists also determined that when the surface of the fiber was mechanically indented, the binding strength between PP fibers and cement matrix rose by a factor of three with the optimal amount of dent modification.

M. Del Zoppo [56] investigated the behavior of polypropylene (PP) and steel fiber-reinforced in masonry prisms. The effect of the type and amount of fiber in the mortar mix, as well as the thickness of the surface layer, on the flexural behavior of masonry prisms was investigated in this study. A three-point loading test was used to evaluate the flexural behavior of masonry prisms. The results of the tests show that masonry prisms retrofitted with a fiber reinforced mortar as a surface layer significantly increased flexural strength. Furthermore, the results show that using steel fiber is more efficient than using PP fibers.

The durability of polypropylene fiber reinforced fly ash concrete was also investigated [57]. The fibrillated PP fiber was mixed into the concrete in various volume fractions. By changing the control Portland cement concrete, mixes containing 15% and 30% fly ash as cement replacement in mass basis were created. They came to the conclusion that the impact of PP fiber on compressive strength and elastic modulus was negligible. Porosity, water absorption, and sorptivity coefficient values rose when fly ash and fiber content increased in all concrete compositions. They also determined that the addition of PP fiber and fly ash in concrete, whether individually or in combination, decreased drying shrinkage. When compared to concrete without fibers, the freeze-thaw resistance of PP fiber concrete was found to be somewhat higher.

Using 1% carbon steel fiber (SF) and 0.1% polypropylene fiber, Sagar and Parikh [58]conducted an empirical study on the influence of hybrid fiber (HF) introduction into fresh as well as mechanical properties of SCC (PPF). In the fresh state, the results showed that PPF had a greater influence on limiting the workability of the SCC than carbon SF.

Similarly fibrous material can be good sound absorbing materials. Zani [59] proposed using recycled polyester fibers to create sound-absorbing non-woven materials. The authors claimed that increasing the diameter, thickness, length, and content of fibers improved the non-woven fabric's sound absorption coefficient.

Madhavi [39] tested different non-woven fabrics containing natural and synthetic textile fibers in another study. The results showed that the sound absorption coefficient was good at medium and high frequencies, but it was lower at low frequencies.

3.4. Biomass ash as supplementary cementitious materials (SCM)

There are different types of Supplementary cementitious materials we will be mainly focusing on the literature review on materials taken in studies.

The growing worldwide energy demand, along with the objective of providing 100% carbon-neutral fuel by 2050, has motivated the search for alternative energy sources. Biomass is widely known as renewable and, owing to CO_2 neutral conversion, does not contribute to the greenhouse effect, making it an ecologically beneficial energy source. Biomass is defined as organic material derived from plants, such as wood, straw, and bagasse. In recent decades, there has been a fast growth in the use of biomass as a biofuel in heating and power generation .The combustion of biofuel results in the generation of ashes classified as biomass ash, often known as wood ash (WA) [60], [61].

The growing worldwide energy demand, along with the objective of providing 100% carbon-neutral fuel by 2050, has motivated the search for alternative energy sources. Biomass is widely known as renewable and, owing to CO_2 neutral conversion, does not contribute to the greenhouse effect, making it an ecologically beneficial energy source. Biomass is defined as organic material derived from plants, such as wood, straw, and bagasse. In recent decades, there has been a fast growth in the use of biomass as a biofuel in heating and power generation .The combustion of biofuel results in the generation of ashes classified as biomass ash, often known as wood ash (WA) [62], [63]. The chemical and supplementary cementing materials, to improve the concrete's properties. Performance mix design. Natural materials, byproducts, and industrial waste from other manufacturing processes are all included. Several efforts have been made to develop sustainable binders by using SCMs as partial replacements for cement in concrete and mortar such as slag, fly ash (FA), palm oil fuel ash (POFA), silica fume (SF), rice husk ash (RHA), wood ash, sugarcane bagasse ash ,ground granulated blast furnace slag (GGBFS), metakaolin (MK), and others. These SCMs have been widely used as pozzolanas materials in concrete and have demonstrated a significant effect in improving the mechanical and durability properties of concrete [64].Also, to enhance the different physical and mechanical of mortar and concrete mix additions of fibers additive both natural and artificial are considered beneficial in aspect of environmental and economical construction. According to Mehta [65] the main ways to reduce CO_2 emissions are to use less cement in concrete and mortar mixtures, use less concrete for new structures, and use less clinker in the cementing material.

In addition, the usage of limestone powder as SCM in Portland cement in concrete helps to conserve the environment since the use of limestone in cement manufacture decreases CO_2 emissions while enhancing concrete characteristics when compared to using conventional Portland cement. Limestone cements are strong enough but use less water than regular Portland cements. The use of limestone powder increases clinker response and hydraulic potential utilization. Portland limestone cements, according to [66] offer competitive concrete characteristics and improve concrete corrosion performance.

3.4.1. Review on composition of supplementary cementitious materials (SCM)

C-S-H, portlandite, ettringite (AFt), and calcium aluminate monosulfate (AFm) phases are formed during the hydration of cement systems. Through pozzolanic reaction, the silica in the SCMs combines with portlandite ($Ca(OH)_2$) to generate more calcium-silicate-hydrate (C-S-H). The added C-S-H strengthens the cementitious matrix and results in a denser microstructure. SCM also enhances cementitious matrix resistance to alkali-silica reaction (ASR) and deicers. A SCM's chemical composition and material properties can influence the kinetics of its response.

Blast-furnace slag, silica fume, calcined clays, and coal fly ash or wood ash are the most used supplemental cementitious ingredients. Wood ash has extremely comparable physical properties and chemical makeup to coal fly ash [67]. As seen in Figure 1, SCMs have a lower calcium concentration than typical Portland cement, resulting in differences in reaction products. This has an impact on the strength and longevity of cement systems.

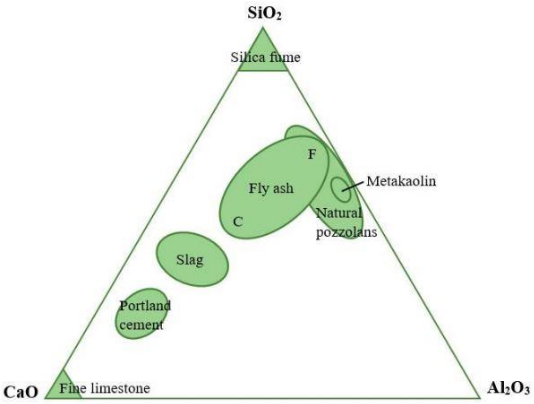


Figure 2. Depicts the change in chemical, compositions between different types of SCM using ternary diagram [68].

3.4.2. Review on physical and mechanical properties of supplementary cementitious Materials (SCM) in cement matrix

There are two kinds of waste additives that can be employed in building materials: artificial and natural. The use of artificial additives to improve the characteristics of mortar and concrete is a widespread but costly practice. To improve the sustainability of building, it is vital to use materials that are both cost effective and environmentally friendly. The majority of artificial additives utilized are produced using vast amounts of resources and are the primary source of carbon dioxide emissions into the environment. The research focuses on natural waste additives that are not only environmentally friendly but also economically useful. As previously discussed, there are various natural additives that improve the properties of concrete and mortar. This study includes SCM materials that can be good replacements for cement to improve mechanical properties based on a literature review. The findings show that these materials can be good replacements for cement, which ultimately reduces the harmful effect of cement use and production on the environment.

3.4.2.1. Review on physical properties of supplementary cementitious materials (SCM) in cement matrix

The Physical properties of SCM depends on characteristics like fineness, particle shape and size, and color mainly depend on the combustion temperature products [69]. The subchapter focused on the reactivity of the SCM materials on mortar and concrete on aspect of physical properties.

The Fineness of the RHA, according to Meheta [70], has an effect on the pozzolanic activity and workability of concrete. It also has an impact on the water content and the additive requirement in concrete. The majority of RHA particle sizes vary from 4 to 75m. Aside from particle size distribution, RHA particles have a very high specific surface area, which is heavily influenced by the porous structure of RHA particles. The influence of RHA particle size on pore structure through refinement and chain the development of unfavorable crystals formed during the hydration process [71] .Because of filling or densification of the microstructure, hardening of mortar or concrete is linked to higher fineness of RHA when used in the cementitious system.

Combustion process also effects the physical properties of SCM materials, uncontrolled temperature during combustion leaves unburnt carbon residue with affects its properties [49]. According to Zain et al. (2011) [72], the carbon content of RHA should be low. According to Cordeiro et al, RHA with a high residual carbon rate (loss on ignition) is deemed a low-quality pozzolanic material. Moreover, the presence of large amounts of residual carbon in ash influencing negatively on the strength of mortar or concrete. According to Cordeiro et al. (2009) [73], when grinding processes are used, the homogeneity and pozzolanic activity of RHA can be increased with residual carbon content of up to 12%.

Color is another important physical property of pozzolanic material. When SCBA is completely burned at a higher temperature, it appears grey, whereas it appears black in the presence of significant LOI. Similarly, RHA shows as white or grey for samples with low LOI and black for samples with high LOI. Cement's soundness reveals its resistance to expansion after hardening. The highest permissible limit for cement soundness is 10 mm. SCBA blended cement specifications with 5% to 25% cement replacement level (CRL) experienced reduced expansion.

For example, 5% SCBA blended cement-based specimens expanded by 1.14 mm, which is smaller than that of control concrete (1.61 mm) [18], [74].

According to [75] the increase in water requirement could also be attributed to the irregularly shaped SCBA particles producing friction and hence lowering workability [76] RHA is believed to be more porous, which increases water requirement and so lowers workability. Bahurudeen et al. [77] employed flow value as an indicator for the change in water requirement of control and SCBA blended specimens, and discovered that increasing the amount of SCBA increases the water requirements. Additionally by The elimination of fibrous particles from raw SCBA reduced the water required. Carbon content in RHA tends to increase water demand, while SCBA has a similar pattern [78].

Kartini et al. (2010), and Marthong (2012) [79], [80] found that paste containing RHA requires more water to achieve standard consistency than samples without RHA, and that the water demand increased as cement replacement with RHA increased. This was attributed to RHA's porous nature, which results in a huge surface area. According [81] Le (2016), the adsorptive nature of cellular RHA particles, along with their extreme fineness, increases their specific surface area, needing more water.

Concrete consistency measures its wetness and is a metric that shows whether or not concrete is workable throughout the whole process of transport, placing, and finishing without segregation. According to Le et al., the adsorptive nature of RHA's porous structure, which results in a larger surface area, and its high fineness are the reasons why the paste containing RHA requires significantly more water to achieve the standard consistency than the sample without RHA, Furthermore, there is a direct relationship between the proportion of cement replacement and water consumption: the greater the RHA, the greater the water demand. For example, at a 15% cement replacement level, the water consumption for normal consistency is 48% more than that of the control mixture [82].

Furthermore, the pozzolanic reaction of SCM with the $Ca(OH)_2$ product of cement hydration increases additional strength. Aside from the strength provided by these materials, SCM is used to fill the skeleton of concrete, enriching the macro/micro-structure, and reducing permeability [83]. High-performance materials in construction have long piqued the interest of a wide range of industries. A significant number of researchers have demonstrated the incorporation of various types of SCMs, either as ingredients in blended cement or as separately batched constituents in mortar and concrete mixtures, yielding encouraging results regarding the mechanical and durability properties of mortar and concrete [84].The concrete pore system, which includes air voids, capillary pores, and gel pores, significantly contributes to the properties of concrete; the pore structure plays an important role in affecting the mechanical, durability, and transporting liquids agents' properties of concrete (Duan et al., 2013).

Agricultural residues are available and exhibit good reactivity at a low cost, according to [89], because of its chemical composition with larger amount of amorphous silica in biomass ash. When silica (SiO_2) is add together to cement, it reacts with CaO during the hydration process, producing silicate hydrate phases that improve the mechanical properties and durability of concrete and mortar. According to the standard, biomass materials used as cement replacement. The rice husk ash with good amount of amorphous silica can be obtained through controlled process and its properties varies accordingly [90] RHA produce from open filed contains high carbon content which affects its performance and results in low reactivity [91]. Similarly production of sugarcane is higher in countries like China, India, and Bangladesh which leading to dumping of remaining waste to the environment this waste can be burnt and reuse ash SCM due to presence of high silica containing with waste residue.

3.4.2.2. Review on mechanical properties of supplementary cementitious materials (SCM) in cement matrix

Fly ash is a residual substance that is generated as a consequence of the burning of coal. It is one of the several ash leftovers that are produced during this process (Senapati et al., 2014). Fly ash consists of small, spherical glass particles that possess hollow interiors. Fly ash has a substantial calcium composition and exhibits a pronounced reactivity with water, even in the absence of lime supplementation. [85] Investigated the inclusion of FA on HSC using 0%, 20%, and 40% cement mass replacements. The results concluded that the development of compressive strength of the concrete was consistently lower than the control mix at all ages for all FA replacements. The conclusion was that Fly ash mixtures not only had lower strength than the control mixture, but that increasing the Fly ash content reduced the porosity of composites containing SCM, which could be ascribed to the low w/b ratio, the packaging effect of SCM, and the pozzolanic reaction of SCM with cement hydration products. Strength even more. This result may be attributed to FA's extremely slow pozzolanic reaction. [86] Investigated the effect of silica fume (SF) with 5% and 10% replacement and Metakaolin (MK) with 5%, 10% and 20% by cement mass replacement. The porosity is investigated by using mercury intrusion porosimetry, the findings revealed that the decrease in porosity with age is caused by the addition of MK and SF

Beulah M. and Prahallada M. C [87] examined the impact of metakaolin as a substitute for cement in high performance concrete when exposed to HCl corrosion. Cubes were fabricated using different water cement ratios (0.3, 0.35, 0.4, and 0.45) and then subjected to compressive strength testing for 150x150x150 mm cubes. Additionally, the % weight loss was determined for 100x100x100 mm cubes. The cubes underwent a curing process in a hydrochloric acid solution with a concentration of 5% for durations of 30, 60, and 90 days. The researchers reached the conclusion that the residual compressive strength experiences a decline as the water binder ratio increases after 30, 60, and 90 days of immersion. This phenomenon may be attributed to the presence of a porous transition zone, which promotes the development of ettringite at elevated water levels [88].

C. m. Ravikumar [89] [89] evaluated the impact of partial pozzolanic material replacement in mortar mixtures. The experimental investigation focused on examining the strength and durability characteristics of several pozzolanic materials, including fly ash, rice husk ash, silica fume, calcined clay (Grog), and ground granulated blast furnace slag. These ingredients were used in the modification of an ordinary Portland cement (OPC) mortar mix. The inclusion of 12% pozzolanic material in cement mortar mixes has shown that pozzolanic materials has the capacity to serve as substitutes for cement, since they exhibit favorable attributes such as strength, durability, and sustainability.

Hossain et al. (2016) [90] resented examination of the advancement of sustainable binders by the utilisation of pozzolanic materials as a partial substitute for cement. These materials include slag, fly ash, palm oil fuel ash, metakaolin, silica fume, rice husk ash, and several others. The use of SCMs, in mortar and concrete compositions is of significant importance due to its ability to influence various characteristics. The results indicate that the refinement of the pore system and enhancement of the pozzolanic reaction are seen when partially replacing SCM in mortar and concrete. The concrete shown notable enhancements in terms of reinforcing corrosion, chemical and sulphate resistance, as well as reductions in chloride and carbon dioxide penetration.

The building industry and urbanization expansions have led to a significant rise in the demand for natural fine aggregates. This surge in demand has resulted in the depletion of natural resources and the degradation of the environment. Incorporating waste mining materials as a partial substitute for fine aggregate in concrete mixes is a compelling option that may help save fine aggregate for future generations. Numerous recent research have been done to investigate the use of diverse waste materials as partial substitutes for fine aggregate. [91], [92] .

Numerous scholars have conducted studies on the impact of integrating organic and inorganic additives into the lime matrix, focusing on their mechanical properties. These studies have consistently found that the inclusion of additives serves as a form of secondary reinforcement, leading to enhanced bond strength between lime particles and fine aggregate within the matrix. The incorporation of additives into the lime matrix enhances fracture resistance by promoting stronger adhesion between lime particles, expedites the hydration process, and augments the lime mortar's resistance to water absorption and the entrapment of air inside the lime matrix [93]–[96].

Another incentive for using waste as SCM materials lies in the use of raw materials obtained from building and demolition waste. The predominant source of trash comes from the dismantling of concrete buildings, accounting for 12-40% of total waste, and the disposal of ceramic materials from industry operations, which contributes to 8-54% of waste generation. The main method used for recycling these waste materials involves their conversion into construction aggregates [97]. The use of recycled ceramic aggregate derived from brick waste and manufacturing operations has shown favorable characteristics in enhancing the mechanical durability of plaster mortars intended for architectural heritage rehabilitation and restoration purposes. Furthermore, a resolution to this issue is the reduction of natural resources used in concrete and their substitution with recycled materials. This approach also mitigate the volume of waste deposited in landfills. Materials such as discarded glass, recovered plastic, wood ash, and rice husk ash are viable options for use into concrete and mortar compositions.

According to [98] portland cement can be partially replaced with two types of supplementary cementing materials: fly ash and silica fume. They investigated the effect of curing and supplementary materials on concrete deterioration and reinforcement corrosion when exposed to a 3.5% Na_2SO_4 solution. The results show that incorporating fly ash or silica fume into concrete helped to refine the pores system in the cementing matrix, reducing the easy penetration of sulphate ions into concrete. Pozzolanas materials chemically react with CH at normal temperatures in the presence of water to form components with cementitious properties, despite having little or no cementitious content. It is also frequently used as a low-cost substitute.

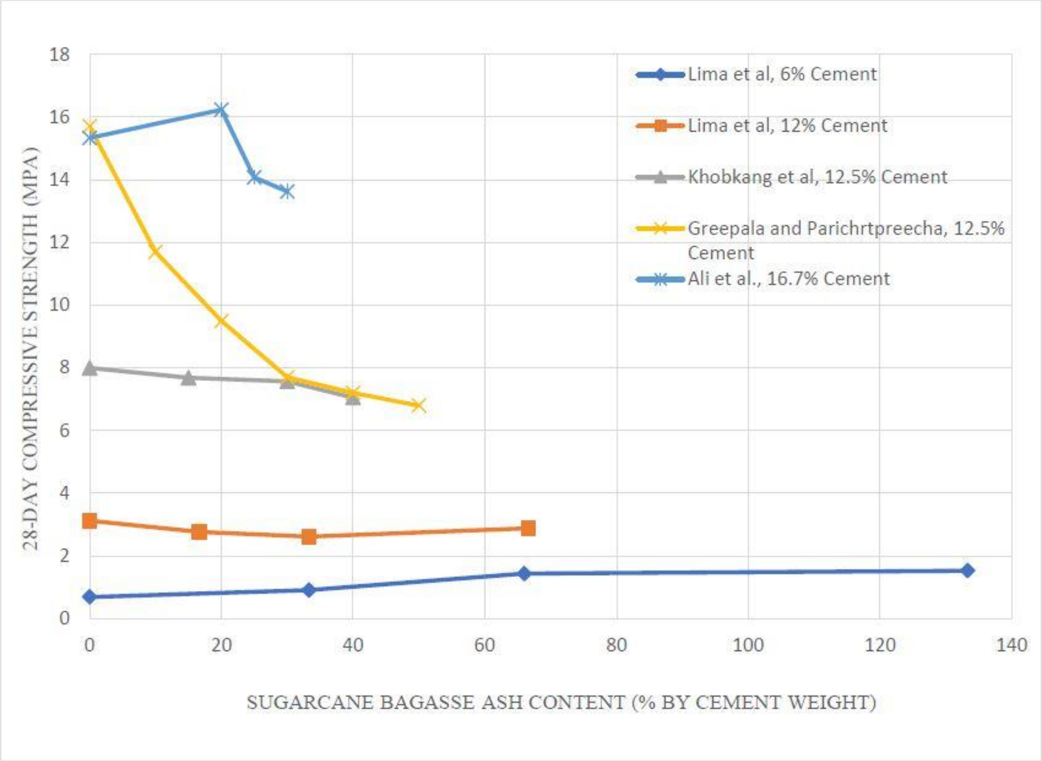


Figure 3. Compressive strength values according to researchers using SCBA in cement [99]–[101]

Figure 3 indicates that the 6% cement content blocks from Lima et al. (2012) have the lowest compressive strength and the 16.7% cement content blocks from Ali et al. (2016) have the highest compressive strength. The strength rises with amount of cement content in the blocks, as predicted.

Figure 3 provides additional evidence that, apart from the study conducted by Lima et al. (2012) which utilized a 6% cement mixture, all other investigations consistently indicate a reduction in the compressive strength of the blocks as the content of sugarcane bagasse ash increases. Additionally, the findings demonstrate that there is an improvement in compressive strength for both 6% and 12% cement mixes when the percentage of bagasse ash surpasses 60%.

V. Priyadarshini [102] evaluated The effect of 30% cement replacing in hollow concrete blocks by weight in 10% increments was evaluated. Silica fume was used as an independent variable in the research investigation and was introduced into a singular batch of bricks. The experimental results of the compressive strength test indicate that bricks including a 10% replacement of bagasse ash and silica fumes as an admixture had the highest performance. Water absorption was also improved when the ash content of sugarcane bagasse exceeded 10%. A cost analysis was also performed in this study, which demonstrated that sugarcane bagasse ash hollow concrete blocks could achieve a profit ratio of 63.7% on sales when compared to ordinary concrete blocks.

Concrete using biomass ash like sugarcane bagasse ash has better mechanical qualities. Sugarcane bagasse ash, which is composed of mostly SiO_2, may partially substitute cement in concrete and mortars [103]. To substitute cement in cementitious matrices, natural ashes have high pozzolanic properties and function as fillers owing to their smaller specific area. As cement costs rise, alternate binder ingredients like sugarcane bagasse ash, which is cheap to produce, are being employed more [104]. Sugarcane bagasse ash might partially replace concrete and mortars. Romildo [105] examined the proportion of amorphous particles in pizzeria and industrial sugarcane bagasse ashes. The amount of amorphous material and chemical composition from XRD and XRF tests show that sugarcane bagasse ashes from industry with a 15% cement substitution perform better in compressive strength testing. According to the results of the XRD and XRF tests, both types of ashes studied can be classified as pozzolanic materials under Brazilian law. The addition of a small amount of OPC was always beneficial to the increase of the strengths [106] Berenguer et al. 2016. Multiple variables, such as excessive combustion temperatures, insufficient calcination, and crystallinity, have a direct effect on the pozzolanic activity of SCBA. Despite exhibiting pozzolanic characteristics, the solid combustion by-products (SCBA) produced by power plants may contain higher levels of carbon and crystalline phases than particles generated by regulated combustion processes, such as those conducted at 600°C. However, it is possible to recalcine

SCBA extracted from furnaces in a laboratory setting under strict control. This procedure has the potential to generate pozzolanic ash with a lower carbon content that can be used as a cementitious material. In addition, the recalcined SCBA has better mechanical properties than its untreated counterpart [103].

Mr. Lavanya and colleagues examine the compressive strength of concrete with the partial substitution of cement with sugar cane bagasse ash. The present study aims to evaluate the use of sugar cane bagasse ash as a partial substitute for cement in traditional concrete. The experiments were conducted following the guidelines set by the Bureau of Indian Standards (BIS) to evaluate the stability of self-compacting concrete (SCC) when a maximum of 30% of cement is replaced with different water cement (W/C) ratios. The researchers claim that the inclusion of SCBA enhances strength across every case. From the findings, it can be inferred that including Bagasse ash as a substitute for up to 15% of cement, while maintaining a water-to-cement ratio of 0.35, has the potential to enhance the overall strength of concrete [107].

Kawade [108] utilized the sugarcane bagasse ash (SCBA) as a partial substitute for cement . Various percentages of SCBA replacement, namely 10%, 15%, 20%, 25%, and 30%, were examined in concrete mixtures of M20, M30, and M40 grades. The findings revealed that the inclusion of 15% SCBA replacement in ordinary Portland cement (OPC) resulted in enhanced compressive and flexural strength of the concrete. Furthermore, it was observed that a 15% replacement ratio yielded the most advantageous outcomes across all concrete properties.

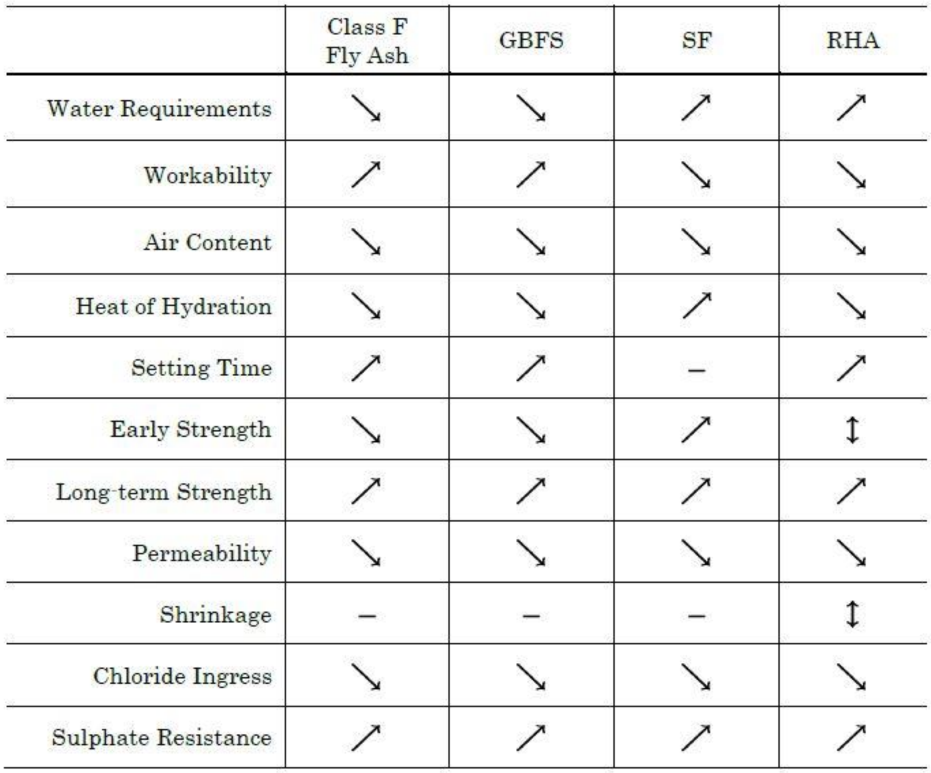
Asma Abd Elhameed Hussein et al [109] investigated compressive strength and microstructure of sugar cane bagasse ash concrete .The OPC was replaced with several proportions of bagasse ash, namely 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The aim was to examine the impact of sugar cane bagasse Ash on the workability, compressive strength, and microstructure of the Interfacial Transition Zone (ITZ) in concrete. The findings conclude that the incorporation of SCBA in concrete, up to a maximum replacement level of 20%, led to an enhancement in the compressive strength of the concrete throughout all periods. The maximum compressive strength was seen when the SCBA replacement level was set at 5%. The thickness of the ITZ saw a significant reduction with the rise in bagasse ash replacement level up to 15%. However, it remained narrower compared to conventional concrete. At a substitution level of 15% with bagasse ash, the interfacial transition zone exhibited homogeneity, and there was no discernible separation between the coarse aggregate and the paste matrix. Based on the results obtained from this investigation, it was observed that there is a direct correlation between the incremental enhancements of concrete's workability. Material replacement increased compressive strength by 20% across all time periods. After 28 days, compressive strength increased 25% and 30%. Adding 30% SCBA to self-compacting concrete (SCC) improved microstructural characteristics. A thinner interfacial transition zone (ITZ) indicated a more refined pore structure and denser matrix than the reference combination.

G. Sivakumar [110] conducted research on the preparation of natural cement using sugarcane bagasse ash. They used 10% weight as a partial substitute in ordinary Portland Cement (OPC) in their study. The compressive strength of the sample was determined, and it was observed that the cementious material in bagasse ash plays a role in early hydration. Bagasse ash's pozzolanic activity results in the formation of more C-S-H gel, which increases strength; as a result, bagasse ash is a feasible cement replacement material.

S. A. Zareei [111] investigated utilization of rice husk ash (RHA) as a partial substitute for cement in high strength concrete including micro silica. Incorporating RHA up to 25% led to an enhancement in compressive strength. Specifically, the compressive strength increased by 6.9% after 7 days and 6.8% after 28 days. However, it is important to note that further replacement ratios may yield contrasting results. Similar behavior was seen in the case of tensile strength, the maximum improvement was observed at 6.8% RHA, followed by a subsequent decline. The conventional method of curing for a duration of 28 days has been shown to be sufficient in terms of achieving the desired levels of compressive strength and resistance to chloride penetration. Extended curing, lasting up to a duration of 90 days, has shown efficacy only in enhancing the resistance to water absorption.

In their investigation, [79] discovered that higher proportions of RHA substitution lead to a decrease in compressive strength. Nevertheless, the requisite compressive strength was achieved with the replacement of 10% of Rice Husk Ash (RHA) for cement. The substitution of RHA in place of cement not only enhances compressive strength, but also enhances the durability characteristics of normal or conventional concrete compositions. According to Le et al. (2014) [109] and Foong et al. (2015) [112], observed that the splitting tensile strength after 28 days of curing exhibited an upward trend with an increase in the content of rice husk ash (RHA) up to a replacement level of 15% by weight of cement. The increase in splitting tensile strength was recorded as 17.65% and 28% in the respective studies. However, beyond the 15% RHA replacement level, the splitting tensile strength showed a decline and reached approximately 5.88% of the control specimens when the RHA replacement level reached 20% by weight of cement. In contrast, the splitting tensile strength is about 10% of the compressive strength.

Table 3. Qualitative description of the effect of Fly Ash, GBFS, SF, and RHA as SCMs on different properties of mortar. [113]



	Class F Fly Ash	GBFS	SF	RHA
Water Requirements	↘	↘	↗	↗
Workability	↗	↗	↘	↘
Air Content	↘	↘	↘	↘
Heat of Hydration	↘	↘	↗	↘
Setting Time	↗	↗	–	↗
Early Strength	↘	↘	↗	↕
Long-term Strength	↗	↗	↗	↗
Permeability	↘	↘	↘	↘
Shrinkage	–	–	–	↕
Chloride Ingress	↘	↘	↘	↘
Sulphate Resistance	↗	↗	↗	↗

Early-stage autogenous shrinkage is affected by a number of variables, including as the amount of supplementary cementitious materials (SCMs), the degree of internal restriction introduced by aggregates, fibers, chemical admixtures, and curing conditions. There has been a considerable increase in the contribution of autogenous shrinkage to the total shrinkage phenomena as a result of the usage of high early strength, high performance, and/or blended binder concretes with decreased water-to-cement ratios [114].

Drying shrinkage can be reduced by establishing a minimum required water cement ratio in the mix, using the highest possible fraction of aggregate and the maximum aggregate size, proper curing and placement on site, avoiding the use of admixtures that increase drying shrinkage, such as admixtures containing calcium chloride, using expansive cement, and using shrinkage reducing admixture that can decrease the surface tension of the pore solution. Mineral admixtures, such as silica fume, ground granulated blast furnace slag, GBFS, and fly ash, are among the other internal factors influencing drying shrinkage. When used in the right proportions, silica fume and GBFS significantly contribute to lowering drying shrinkage by strengthening the concrete's pore structure and making it more resistant to deformations via extra pozzolanic reactions [115] (Li and Yao, 2001).

Adding fly ash to a combination reduces drying shrinkage by lowering water content [116], [117]. Pozzolanic admixtures may reduce concrete and mortar macroscopic shrinkage by partially replacing cement. Unreacted pozzolan particles may behave as micro-aggregates or void-fillers, preventing moisture loss. Kumar et al. [39] Discovered that using fly ash as a cement replacement up to 60% reduced drying shrinkage by 39%. A 0.4 water-to-cement ratio (w/c) reduced this. Substituting cement with fly ash with low lime content may slow concrete hydration, reducing drying shrinkage. A little amount of evenly distributed nano-silica reduces drying shrinkage. Farzadnia et al [118], [119] measure measured drying shrinkage stresses in a 25x25x25 mm^3 prismatic sample. Following ASTM C157, measurements were taken in a climatic chamber at 23^{o}C and 50% relative humidity. The article found that 1% nano-silica reduced drying shrinkage by 7.6% in 28 days as a partial cement replacement. The administration of a large amount of nanoparticles with high specific surface areas might cause volumetric deformation, particularly shrinking during early development. Due to the rapid hydration process and narrow pore structure, capillary tension is high. According to Kovler and Zhutovsky adding more belite (C_2S) and less alite (C_3A) or celite (C_4AF) to ordinary Portland cement (OPC) may reduce autogenous shrinkage. However, changing cement mix to reduce autogenous shrinkage would affect paste compressive strength. Autogenous shrinkage is reduced by cement's high gypsum content, which causes autogenous expansion [120].

The conclusion can be drawn with literature review that to reduce greenhouse gas emissions and energy consumption, cement usage must be reduced, and natural and local materials used. Additional study is needed to develop mix design methodologies for low cement content natural fiber-reinforced composites, as identified in the literature review. Recent literature focuses on developing environmentally friendly building materials. Natural fiber and a substitute for cement can be used. However, issues remain as natural fiber-reinforced composites are dispersed and water-sensitive. Since cellulose is hydrophilic, its fibers' characteristics depend on water. Recently, scientists have studied using natural fibers to enhance cement-based building materials. Fibers in the material reduce environmental impact. This research helps in selecting and developing environmentally friendly construction materials. Impact with minimal cement and natural fibers increases composite strength. Most researchers state the use of 1% use of natural fiber and a maximum of 20% use of SCM for positive results. The state of the art shows that more study is needed to generate natural fiber and SCM properties in cement-based composites. In the light of this, there was a motivation to take up the topic of the dissertation. It was analyzed how the additions of natural waste materials, fibers (jute and sisal) and ashes (rice husk ash, sugarcane bagasse ash), affect the properties of mortars.

CHAPTER 4

AIMS AND SCOPE OF THE THESIS

The objective of this research is to provide a valuable contribution to the disciplines of civil engineering and materials science through the development and production of environmentally friendly and sustainable building materials without compromising the important properties of materials.

According to the literature assessment, ecologically friendly building materials are needed now. Alternatives to environmentally damaging materials is to include local and natural materials. Using innovative building materials and renewable energy can reduce hazardous emissions. Utilizing the local available waste materials as additive in mortar is the main focus of research.

To this end, thesis consists of two parts:

1. Literature review.

The conclusion can be made from literature review that construction is a substantial contributor to nonrenewable resource depletion of CO_2 emissions. Recently, scientists have studied using natural waste on cement-based building materials. Many renewable art researchers have investigated natural waste as additives in cement-based materials with positive results and continued formulating materials with low cement content, improved local materials, and natural fibers as reinforcement. Thus, using natural fibers as reinforcement and natural SCM as cement replacement in building materials can create new, renewable construction materials that lessen environmental effect.

2. Research conducted.

Firstly, is to successfully use natural fibers as reinforcement to enhance is properties of mortar.

- for physical properties air content and consistency is investigated with fresh mortar

- for mechanical properties compressive strength and flexural is investigated with hardened mortar
- shrinkage during hardening of mortars with fibers
- investigation of the effects of fibers on the structural parameters of mortar , MIP and SEM analysis is done

And secondly, replacing the part of cement with natural SCM materials to decrease the maximum use cement is done in the research. Similarly

- for physical properties air content and consistency is investigated with fresh mortar
- For mechanical properties compressive strength and flexural investigated with hardened mortar through standard mechanical tests.
- shrinkage during hardening of mortars with SCM additions
- SEM and MIP are used to study the impact of SCM on mortar microstructural characteristics and the interaction of ashes with OPC matrix.

The investigations also incorporate polypropylene fibers and limestone powder as comparative additives. Comparing natural and manmade materials helps comprehend their effects on external environments uses.

In the dissertation work the following thesis statement is accepted that: **Natural waste fibers (jute and sisal) and ashes (of rice husk and sugarcane bagasse) influence on properties of mortars, both mechanical and physical, including structural features. Moreover, the optimal content of these additives may have a beneficial effect on some properties.**

CHAPTER 5

TESTING METHODS

Background

This chapter describes the experimental methodologies and methodology used to achieve the research objectives. These include discussions of testing methodologies as well as experimental laboratory activities. In order to analyze outcomes of strength tests Statistica is used. It is an advanced analytics software package created by StatSoft that is now maintained by TIBCO Software Inc. Statistica. Specifically ANOVA is used for analysis of strength.

The standard (p) value in ANOVA analysis is considered to be less than 0.05 for the strength beneficial parameters. The compressive strength values according to the additive content and strength variation with respective days can be seen in annex A and annex B.

The additives were mixed into OPC mortar, lime-cement mortar and APA cement mortar, and tested against a control sample. The OPC specimens were stored in water for 2, 7, 28, 56, and 90 days, whereas the cement- lime specimens were kept in water for 7 days before being moved to the drying humidity cabinet for compressive and flexural strength tests, and the drying shrinkage test specimens were kept in air humidity camber for 28 days after demoulding. In order to enhance some mechanical and physical effects, the additives were modified and then tested again under the same experiments with 5, 10, and 15% of SCM with OPC replacement and 1% and 2% addition of all fibers to mixes as reinforcement.

The mortar block was cast using a steel mold. The dimensions of the casting mold were 40x40x160mm according to standard EN 1015-11:2001. The cement and sand were mixed for about 2 minutes before the water was added and mixed for 3 minutes by the mortar mixing machine. The mortar paste is then poured into three layers in the mold to be vibrated with the bar. This vibration aids in the release of the mortar’s entrapped air bubbles. Finally, the mould head is secured, and it is ready for curing for at least 24 hours at 20 +-5 C. (room temperature). The moulds are removed 20 to 24 hours later, and the prismatic specimens are placed in water with appropriate curing properties. The cement lime samples are cured in water for 7 days before being moved to humidity cambers for the remaining days of curing. All samples are cured in a receptive process for 90 days. Air entraining plasticizer (APA) cement mortar is mixed differently than regular cement mortar. All dry ingredients are poured into the mixer and mixed for 1 minute, and the APA solution is first mixed with water in the amount of 0.5% of the cement weight, and then the entire water substance is poured into the mixer and blended for the next 2 minutes. The addition of APA improves the homogeneity of the paste. The mortar are now ready for immediately-after tests for fresh properties. After curing the samples, the hardened properties test is performed at 2, 7, 28, 56, and 90 days.

The next step was to investigate the mechanism behind each additive's performance in shrinkage reduction. More experiments were chosen and used for this purpose, depending on the expected behavior. Among these tests are drying shrinkage and microstructural analysis. Each type of mixture had three samples to obtain more accurate data, and the averages were calculated to determine the final result.

5.1. Test of consistency

The EN 1015 [121] standards are the most important series of mortar test methods which includes consistency as one of the parameters. The tests for mortar consistency are divided into two categories: flow tests and penetration tests. The flow test will be discussed in detail below. Penetration tests determine the depth of penetration of an object of a specific mass released at zero (quasi-static) or a finite height (dynamic) above a mortar sample. As a plunger, the penetrating object has a cone shape. Several procedures in this thesis make use of the CEN-standardized plunger penetration apparatus. The analysis of the consistency of mortar is discussed in both methods for reference mortar and mortar with additives.

The consistency of mortar is measured by the flow table according to standard EN 1015-03 [121] it is the most widely used tool for determining mortar consistency. It is made up of a circular plate that is lifted and then dropped from a certain height. Slump and flow tests work on the basis that a sample is poured or scooped into a conical or cylindrical frustum, which is then carefully lifted, allowing the material to deform under its own weight. In all methods, the outcome of the test was determined by calculating the average of three measurements. The experiment was conducted using a Novikov's cone apparatus Figure 4 a in accordance with the established PN-B-04500 standard [122] (mortars physical and mechanical tests). Three layers of mortar mix were sequentially added to a conical vase. Each layer was compacted using a tamping rod. The top layer of mortar was then levelled to achieve a smooth surface. Subsequently, a needle-shaped plunger with a predetermined weight was released from a specified height, causing it to penetrate the mortar cone. The depth of penetration was measured using a Vernier scale.

The consistency using flow table testing was conducted in accordance with the EN 1015-3:2000 standard [123]. The specimen was arranged in a circular cylindrical container in two distinct layers and compressed inside each layer to eliminate any empty spaces. Subsequently, the surplus mortar was removed by using a trowel's straight edge, which was drawn over the upper surface of the mould in a sawing motion. The object measured 5 mm and was seen to occur 25 times during a duration of 15 seconds. The measurement of length is conducted using a Vernier scale in two orientations in order to ascertain the flow diameter as seen in Figure 4b.

a) b)

Figure 4. Testing of consistency a) Novikov cone apparatus, b) Flow table apparatus

5.2. Test of air content of mortars

The assessment of air content in mortar, in combination with the Féret and Bolomey models, enables the prediction of mechanical strength of mortars based on their density. The findings indicate that the traditional approach, use a regular aerometer, tends to overestimate the proportion of air content and hence underestimate the density of the mortar.

The assessment of air content is determined by assessing the compressibility of air bubbles. The conventional apparatus consists of a single-liter container in which mortar is arranged in two layers and compressed using basic tamping, as outlined in the air content measurement guidelines for concrete established in standard PN-EN 413-2:2016-11 [124], as seen in figure 5. The measuring system delivers the air content in % immediately. The determination of air content involves the calculation of the mean value derived from three separate samples.

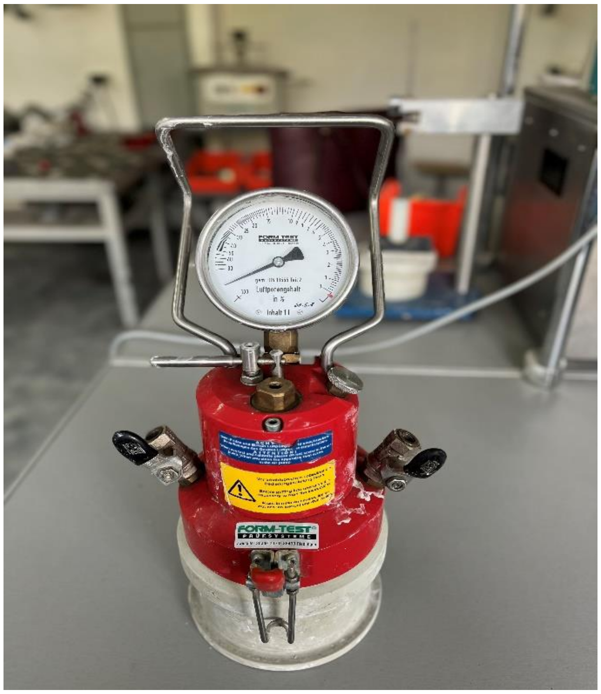


Figure 5. Aerometer for the determination of air content in mortar

Mechanical property is influenced by several factors, including the heating rate, exposure time, temperature levels, aggregate type, form and size of the specimen, age of the specimen, and moisture content. The consideration of mechanical qualities, including compressive strength, flexural strength, elastic modulus, and stress-strain response in compression, has significant importance in the design process aimed at enhancing fire resistance. Mechanical properties include ultimate tensile and compressive strength. These were determined using a universal MTS tensile testing machine outfitted with a load cell with a capacity of 10 N. These properties are discussed in depth in the sections that follow.

5.3. Test of compressive strength

In addition, the physical and mechanical properties of mixes containing new admixtures were investigated. Compressive strength measurement of mortar mixes is a major contributor to this list because it is the most important engineering property of cementitious construction materials. Compressive strength experiments were conducted on mortar composites including plain, fiber, and ash additives in order to find the modulus of elasticity, compressive strength, and to examine stress-strain curves. The modulus of elasticity (E) is determined by dividing the change in stress by the change in strain within the linear elastic range of the specimens. The stress-strain curves also include the measurement of compressive strength and its related strain. The compressive strength of the mortars was assessed according to the EN 1015-11:2001 [125] standard test, using a mould with dimensions of 40x40x40mm. The prismatic specimens were removed from the moulds after a period of 24 hours and subjected to a curing process in water for durations of 2, 7, 28, 56, and 90 days. The lime-cement sample, both with and without fibers and ashes, had a water-curing period of 7 days. Subsequently, it was transferred to a humidity chamber where it was maintained at a temperature of 20 ±2^{o}C and a relative humidity of 50–60%. This specific environmental condition was necessary owing to the presence of lime, which necessitates a dry environment. The mean of six measurements, determined using the coefficient of variation, is the average value of the test result.

5.4. Test of flexural strength

The hardened mortars were subjected to destructive testing using the bending tensile strength test in order to assess their fundamental flexural characteristics. Bending tensile strength tests were conducted on air-cured lime samples and water-cured cement samples, on mould with dimensions of 40 mm x 40 mm x 160 mm, at intervals of 2,7, 28, 56, and 90 days. The experiments were conducted using universal testing equipment with the specifications stated in the PN-EN-1961 standard method [126]. The flexural strength of three prismatic specimens was assessed using the coefficient of variation, a commonly used statistical metric of data dispersion. The calculation included determining the ratio between the variability of a certain property when subjected to a particular material or technical component, and the average value of that characteristic.

$$CV = \sigma/A \tag{1}$$

Where CV—coefficient of variation; σ= standard deviation of the results derived from measuring a given property without technological or material changes and with set changes; A—arithmetic mean value of all results derived for a given property (with technological modifications and without).

Figure 6. Universal machine for testing of
Flexural and Compressive strength

5.5. Test of the dry shrinkage of hardened mortars

The measurement of drying shrinkage was conducted in accordance with the standard PN-EN 12617-4:2004 [127]. The specimen, measuring 40x40x160 mm, was removed from the mould after a duration of 24 hours. Subsequently, it underwent a curing process inside a climatic chamber, maintained at a temperature range of 20+-100 C and a relative humidity of 50–60%. The collection of data occurred at specific intervals of 3, 7, 21, and 28 days subsequent to the preparation of the sample. The feasibility of doing earlier tests on CL mortars was hindered by their limited initial strength. The measurement of the sample's change in length was conducted using a modified Graf Kaufman Apparatus, as seen in Figure 7. Throughout the duration of the test, spanning from day 1 to day 28, the samples were consistently maintained in a horizontal position inside the apparatus. This approach was used to mitigate any potential issues associated with the manipulation or displacement of the samples. Also, it is important to note that the act of inserting and withdrawing the sample from such apparatus may result in potential harm to early age samples. These samples are often characterized by having low compressive and flexural strength.

Figure 7. Measuring of dry shrinkage by Graf Kaufman Apparatus

5.6. Scanning electron microscoping

In research projects, microstructural phase analysis was used to investigate the mechanisms and arrangements behind some shrinkage reducing/compensating admixtures. Scanning electron microscopy (SEM) and thermal analysis were used in the current study for these purposes. SEM is a powerful imaging technique that can produce high-resolution images of the surface morphology of a sample. SEM works by scanning a small area of a sample surface with a high-energy electron beam. The interaction of this primary electron beam with the atoms in the sample causes energy loss due to repeated random scattering and absorption. This interaction generates a variety of signals; however, the detection of secondary electrons (SE) is used to generate images.

As a result of their low energy, SE originate within a few nm of the sample's surface, producing images with excellent topographic contrast and detail to a maximum of 1 to 5 nm in size. Scanning electron microscopy (SEM) was conducted using the TESCAN Mira3 Oxford Instruments type electron microscope to observe the morphology and determine the chemical element composition. The research was conducted on fracture surfaces that were coated with a carbon coating to enhance conductivity.

We used cement mixes, lime-cement mixes, and cement with APA admixture with other materials in this work (sisal, jute, polypropylene, rice husk ash, sugarcane bagasse ash and limestone powder). As a result, identifying the various materials is required for the study of microstructure development on different surfaces. Atoms in the sample scatter them elastically. This effect is determined by the atom's atomic number. The greater the atomic number, the greater the number of backscattered electrons emitted, resulting in a bright zone.

5.7. Microscopic intrusion porosimetry (MIP)

There are only a few techniques for determining the pore structure of hydrated cement paste. Mercury intrusion porosimetry is a popular technique (MIP). Based on the passage of a non-wetting fluid, namely mercury, into the interconnected pore structure while the pressure is gradually increased. The Washburn equation is used for the determination of pressure by considering the dimensions of the entrance pore. The interpretation of the MIP curve has arisen due to the inherent limits of the technology and the necessary assumptions involved. [128]. The most important difference is that MIP measures the pore entry size rather than the actual pore size. This effect is significant in cement paste because many pores can only be accessed through a smaller pore. In the literature, this effect is known as the ink-bottle effect. The MIP (mercury intrusion porosimetry) technique facilitates the identification of open pores that possess accessible entrances, such as capillaries, through which mercury can penetrate. In addition to the analysis of pore distribution, the experimental data includes measurements of several other characteristics: the overall surface area of the pores, the predominant diameter of the pores, the tortuosity of the pore structure, as well as the open porosity, apparent density, and true density. The MIP approach was employed during each phase of the ageing studies conducted on the Autopore IV 9500 device, focusing on pore sizes ranging from 6 to 4500 nm. The calculations of the tested parameters were conducted under the assumption of the following constants: a contact angle of 140 degrees between mercury and the sample, a surface tension of mercury equal to 0.485 Nm-1, and a density of mercury equal to 13.54 g/cm$_3$.

CHAPTER 6

MATERIALS

6.1. Introduction

Several new additives have been selected or designed for use and study in the current project. These new admixtures were classified as natural additives (plant based) and synthetic, with natural fibers surface treated by the manufacturing company. Air- entraining plasticizer admixture (APA) is used to make the paste homogenous and keep plasticizing the mortar. The goal was to investigate various mechanisms of shrinkage reduction, improving mechanical properties microstructural properties. Air content, consistency, flexural, compressive strength and dry shrinkage are investigated.

Natural fibers have gained popularity due to their low cost, low health risk, and flexibility. Also synthetic fibers possess numerous advantages including significant properties such as improved tensile strength, reduced water absorption, and decreased density. For consideration to see the effects of both fibers natural such as jute and sisal and polypropylene as synthetic fiber were observed. In the field of research, the substitution of Ordinary Portland Cement (OPC) is being studied through the utilization of natural Supplementary Cementitious Materials (SCMs), such as sugarcane bagasse ash and rice husk ash. Additionally, the effects of other SCM materials, such as limestone powder, are being investigated. As was mentioned in the previous chapter, a thorough study is being carried out on the usefulness of fiber reinforced mortar with different types of fibers for and its use.

6.2. Basic components

The objective of this study is to investigate the behavior of various fibers and supplementary cementitious materials (SCM) in mortars composed of cement (C), cement-lime (CL), and cement with APA (CA). The determination of the mortar composition was based on the regularly used proportioning techniques utilized on building sites for various applications, including masonry mortars, plasters, and renders. The selection of compositions was conducted in order to examine the impact of fibers on mortars commonly used in regular applications. The volumetric ratio for cement to sand in cement mortar and cement mortar with air-entraining admixture (APA) was 1:6, whereas the volumetric proportion of cement to lime in cement-lime mortar was 1:1:6. The selection of this ratio is based on its historical significance and demonstrated effectiveness in the context of both masonry mortar and plaster applications. In this investigation, a naturally occurring quartz sand with a particle size of up to 2.0 mm was used. The water absorption of aggregates exhibits variability based on the specific aggregate type and is closely related to the quantity of water used for cement hydration. This is due to the fact that aggregates in a state of water absence may take in a portion of the introduced water, while damp aggregates can introduce additional water into mortars. Prior to beginning the mixing process, it is essential to ascertain the water uptake and moisture level of the aggregates being used. Subsequently, the quantity of water measured should be adjusted in line with the predetermined mix proportions, guaranteeing that the hydration of cement may occur at the intended water-to-binder ratio. The volume of water within each mortar was selected in order to attain a comparable and predetermined consistency, as determined by Novikov's cone measurement [39]. The binders used in the composition consisted of conventional Portland cement CEM I 42.5 and lime. The qualities may be seen in Tabs 4 and 5.

Table 4. Chemical composition of CEM I 42.5 Grade I

Chemical Components (%)									
SiO_2	Al_2O	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on ignition	Insoluble residue
18.9	3.8	3.9	63.3	1.2	2.9	0.15	1.05	3.17	1.89

Table 5. Chemical composition of Lime

SiO_2	Al_2O	Fe_2O_3	CaO	MgO	SO_3	Na_2O
0.7	-	-	90.2	1	0.7	0.15

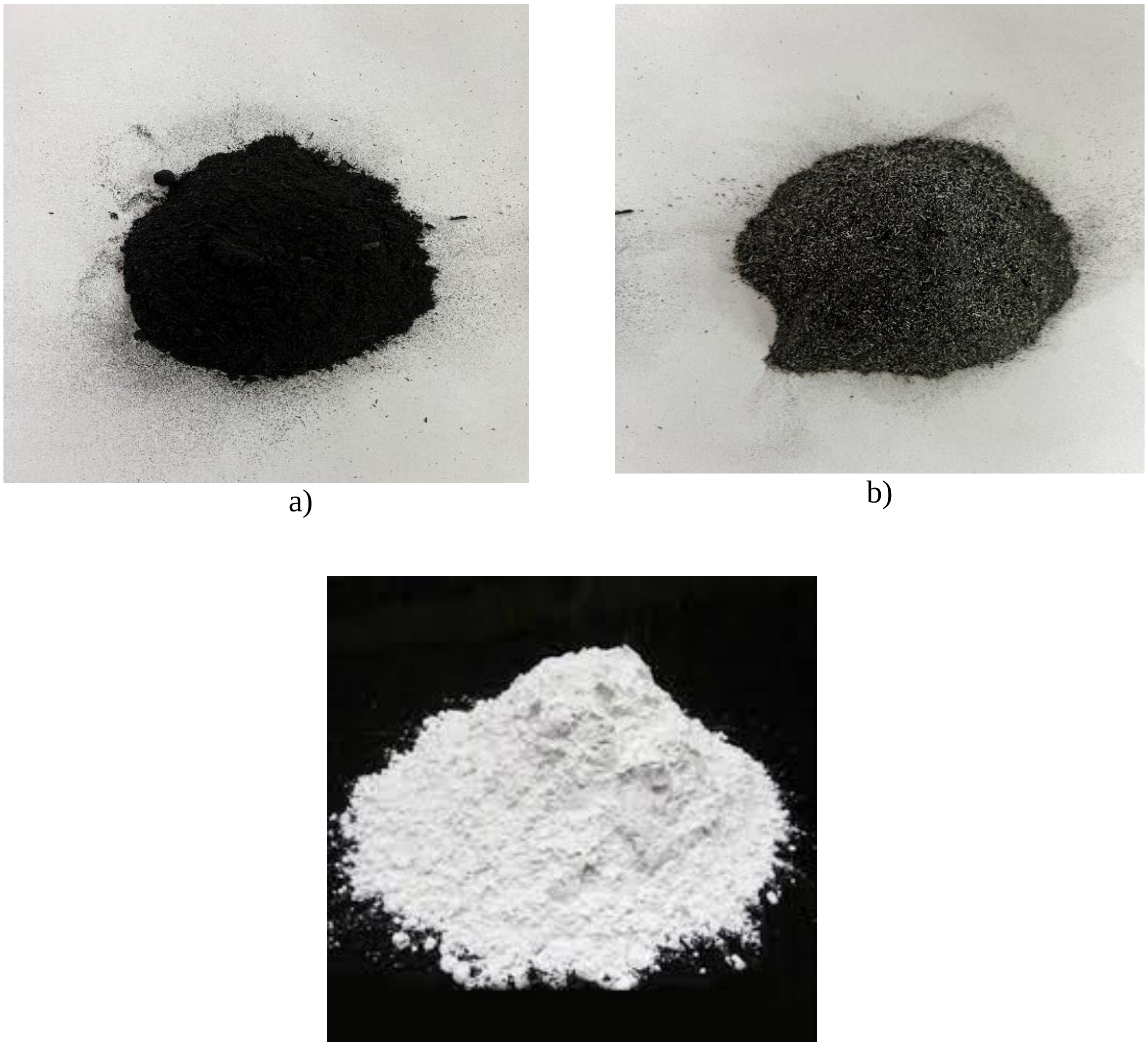
The cement mortars were treated with an air-entraining plasticizing additive (APA), a commercially available admixture, at a concentration of 0.5 percent, which falls within the recommended range of 0.25% to 0.75%. The consideration of the quantity in research is undertaken at a rate of 0.5% in order to ensure the necessary uniformity is maintained. This aqueous solution of naphthalene resin and surfactant has a density of 1.040 -0.03 g/cm 3 and less than 5% mass alkali and up to 0.1 percent chlorides. It gives cement particles in the cement paste a homogenous charge that repels each other, developing the mortar. It also increases cohesion, avoids segregation, and lowers water tension at the surface, resulting in homogeneous air microspore distribution through the mortar volume.

6.3. Waste additives

The present study focuses on the application of various waste additives. The topics covered can be categorized into two distinct groups: one regarding SCM, and the other involving fibers. The SCM utilized in this study includes sugarcane bagasse ash, rice husk ash, and limestone powder. As for the reinforcement fibers, jute, sisal, and polypropylene are evaluated. To completely understand the beneficial effects of incorporating these materials into the properties of different types of mortar.

Table 6 .Chemical composition and Physical Properties of ashes

Materials	SiO_2	Cao	Al_2O_3	Carbon (%)	Specific gravity (gm/cc)	pH
SCBA	63.1	1.3	0.8	42	2.43	6.2
RHA	65.3	0.74	0.58	14	2.43	6.2



a)

b)

c)

Figure 8. Supplementary Cementitious Materials a) Sugarcane bagasse ash (SCBA), b) Rice husk ash (RHA), and c) Limestone powder (LS)

6.3.1. Sugarcane bagasse ash

Bagasse refers to the residual fibrous material that remains after the extraction of sugarcane juice, and it constitutes a significant portion of the solid waste produced during the sugar producing process. The sugarcane bagasse ash is obtained from the region of Gujrat, India, with is composition mentioned on Table 6. The sugar industry often utilizes bagasse as a fuel source, and upon combustion at elevated temperatures, it generates sugarcane bagasse ash. Sugarcane bagasse ash is produced in significant quantities by several nations as a byproduct of waste material. The use of bagasse ash from sugar cane is very advantageous according to its fundamental pozzolanic characteristics. It has been used in the production of ceramics (Teixeira et al., 2008), biomass ash filters [129]–[131], and mortar as SCM. It is regarded as one of the sustainable building materials. Cordeiro et al. [73] found that subjecting SCBA to controlled circumstances at a temperature of 800°C may effectively inhibit the development of crystalline phases, hence enhancing its pozzolanic activity. Many industrial enterprises directly acquire this bagasse due to its high silica concentration for the purpose of generating sugarcane bagasse ash.

After extraction of sugarcane juice the collected bagasse goes through the drying process as it content moisture it can be dry under sun for 24hrs or in the drying chamber at 250 ^{o}C to 300 ^{o}C for 24hrs. These dried sample further goes to combustion chamber where it burned at temperature ranging from 6000 ^{o}C to 8000 ^{o}C for 8hrs. The unburnt carbon particles can contribute to low specific gravity and non-reactive thus by sieving fibrous particles can be removed. The grinding process is done in ball mill apparatus where finer particles are further reduced in proper size and shape which increase its pozzolanic nature. The grinding time is maintained for 8min to 240min. After completion of grinding the material is sieved in 300μm to get the finer materials.

Sugarcane bagasse ash is a naturally occurring pozzolanic substance characterised by its high content of silica, alumina, and iron oxide. According to the ASTM C618 standard (ASTM, 2001) [132], it is required for natural pozzolans to have a minimum composition of 70% silica, alumina, and iron oxide. According to James and Pandian [133](2017), did an in-depth investigation on the valuation of sugar cane bagasse ash. The results indicate that the majority of the research analyzed shows the compliance of sugarcane bagasse ash with the specified criteria. The silica compound (SiO_2) included in the ash derived from sugarcane bagasse has a chemical reaction with the free lime compound ($Ca\,(OH)_2$) that is generated during the process of cement hydration. The chemical equation representing the process of hydration of tricalcium silicate, which is a prominent constituent of cement, may be expressed as follows: It is

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO.4H_2O + 3Ca\,(OH)_2 + Heat \qquad (2)$$

Tricalcium silicate + Water = Calcium silicate hydrate + Calcium hydroxide + Heat

Various studies shows the benefits of addition SCBA as SCM to cement replacement in mechanical properties of composites according to Ali et al. (2016) [134][100] investigated the impact of sugarcane bagasse ash on the properties of cement-stabilised earth blocks, including the strength of compression, retention of water, density, and early absorption rate. It includes the incorporation of sugarcane bagasse ash into cement stabilised lateritic blocks at varying proportions: 0%, 20%, 25%, and 30% by weight of cement. The compressive strength of blocks having 20% ash from sugarcane bagasse was found to be greater compared to the control specimen. Still, it was observed that with a rise in the proportion of sugarcane bagasse ash, there was an associated decrease in compressive strength. The incorporation of sugarcane bagasse ash resulted in enhanced water absorption and initial rate absorption, whereas the blocks with sugarcane bagasse ash showed a slightly lower weight compared to the control specimen.The results suggested substituting a proportion of 10% to 20% of the total weight of cement with sugarcane bagasse. Sumesh and Sujatha (2018) [135] , Srinavasan and Sathiya (2010)[136], and [102]). Also it can be noted that the substitution of cement with sugarcane bagasse ash at an amount of 10% be considered. Basika et al. and Ali et al. (2015) [137], [138]) focused on investigating the potential use of sugarcane bagasse ash as a building material in the construction industry. Their findings suggest that it is feasible to substitute up to 20% of the weight of cement with sugarcane bagasse ash.

6.3.2. Rice husk ash

RHA generally refers to an agricultural byproduct of burning rice husks at a temperature of 700-800 ^{o}C. The process produces about 20% ash of complete mass containing 80-90% amorphous silica and some alumina phases, which makes it highly prozzolanic. RHA is produced either by open field burning, which causes high pollution or under incineration condition where temperature (600-800 ^{o} c) and duration (up to 6hrs) are controlled. The RHA with good amount of amorphous silica can be obtained through controlled process and its properties varies accordingly[139], [140] RHA produce from open filed contains high carbon content which affects its performance and results in low reactivity. According to researchers the controlled process with combustion temperature should be between 500-800 ^{o}C and duration up to 6hrs. The RHA is obtained from the region of Chhattisgarh, India, with is composition mentioned on Table 6.

On the other hand, Ling [141] reported that combustion temperature at 1000 ^{o}C is possible if the duration is less then 5min. Nowadays the production of RHA is done in controlled machine where temperature and heating rates is possibly maintain due to advance oven and furnace systems, which leads to high quality RHA with good reactivity. The grinding process determine the fineness of

RHA, for the process ball or hammer mills are used in industrial. Crystalline ash is harder and need more time to grind in order to achieve desired fineness. Researchers [69], [141]–[144] agree that finer pozzalanic ash has a higher rate of reaction and can increase strength of a mortar or concrete to a higher degree than a coarser one. This effect is connected to the easier access of water to the bigger specific surface of the ash, allowing for the faster reaction and higher reaction rate. It should be noted however, that with higher fineness of the ash, workability of the mortar or concrete mix can significantly decrease due to the physical effect of water adsorption on the fine grains of the material.

6.3.3. Jute fibers

Jute fiber is derived from the corchorus genus of the Tiliaceace family, obtained from the region of Gujrat, India. The process of obtaining jute fiber involves many steps, including cutting, roasting, shredding, drying, packaging, and sorting. The characterized by their elongated structure, soft texture, and lustrous appearance. These fibers exhibit a color range from cream to brown, as seen in Figure 9b. Jute fiber reinforced concrete is a concrete repair mix of aggregate, binder, and jute fiber. Jute is a bast fiber-long, soft, lustrous, and capable of spinning coarse, strong threads. Sacking, hessian and thread are used to back tufted carpets. After cotton, one of the cheapest natural fibers, it is the second most manufactured and useful. It has the greatest average tensile strength after bamboo, Maguey, and Lechuguila. After bamboo, jute fiber has the greatest modulus of elasticity. Jute fibers contain mostly cellulose, lignin, and pectin. Traditionally, jute was utilized in textile machines because it contains cellulose and lignin. In addition, the car, pulp and paper, furniture, and bedding sectors are employing jute and its associated fibers to make nonwovens, technical fabrics, and composites. The incorporation of jute fiber into concrete results in a rise in its compressive strength, with its small fiber length and low fiber content. The addition of a significant quantity and length of yarn poses challenges in achieving consistency within the concrete mixture. The addition of jute yarn in comparison to coarse aggregate has been the subject of many investigations. It shows that the inclusion of jute yarn leads to an increase in the percentages of coarse aggregate, resulting in fiber agglomeration. It, in addition, may create a higher porosity in the cement matrix [8], [145]. T. Sai and B. Manoj investigated the behavior of jute fibers involved in concrete as a reinforcing material. Resulting in improved mechanical characteristics of concrete. Also concrete with a jute content of 1%, cured for a period of 56 days, shows increase in compressive strength compared to normal concrete [146]. Basudamet. al. also exported a significant enhancement of 66% in the flexural strength of concrete when jute fiber reinforcement was absent. This increase was obtained at an optimal fiber length of 5mm and a volume proportion of 1% jute fiber loading by weight.

6.3.4. Sisal fibers

Sisal is a natural fiber extracted from the foliage of the Agave Sisalana plant (Fig 9a). The plant grows in huge amounts in Mexico; nevertheless, it is now being maintained and produced in East Africa, Brazil, Haiti, India, particularly in the region of Assam, and Indonesia. A normal sisal plant is characterized by possessing a range of 200 to 250 leaves, with each individual leaf containing a minimum of 1000 to 1200 fiber bundles. The composition of a sisal plant consists of 4% fiber, 0.75% cuticle, 8% dry matter, and 87.25% water in its whole. Sisal fibers used in this experiment are stiff fibers taken from agave plant [14] acquired from Gujarat state, India, with features in Table and cut to the desirable length (15 mm). Those filaments seen in Fig. 9b are straight, silky, and bright yellow. Kenya (Africa) and India are frequent locations for production. Researchers [4], [40]–[43have discovered that its usage as a construction material increases the longevity and strength of structural components. Sisal is a completely biodegradable and extremely long-lasting vitality asset. The term "responsibility" refers to the act of determining whether or not a person is responsible for his or her own actions. In sisal, there are three types of strands: curve filaments, directing filaments, and basic filaments. The basic strands are the most widely used because of their strength and the fact that they do not separate during the extraction process. Out of which auxiliary strands are for the most part received due to durability as they don't split during extraction process. They are very well safe against heat. Sisal filaments are used as house support in developing countries. Experimental suggests that the use of treated sisal fibers could reduce the negative effects related to natural fibers, such as their high water absorption capacity. In order to decrease the hydrophilic properties of the fiber, two distinct approaches were used, namely bulk and surface treatments. The primary difference between the two treatments lies in their impact on the fiber. The first treatment induces a significant alteration throughout the fiber, resulting in a notable modification of its morphology and semi-crystalline phase. Conversely, the second treatment mostly preserves these properties, with only a little modification seen in the outer layer.

6.4. Other implemented materials

6.4.1. Polypropylene fiber

The primary reason for incorporating fibers into a cement matrix is to increase the toughness and tensile strength of the resulting composite, as well as to improve its cracking resistance. The primary advantage of including fibers is in their ability to bridge fractures and undergo pullout processes, so impeding further deformation until more energy is supplied by the loading source. Under applied loads, reinforcing fibers exhibit greater elongation compared to concrete and mortar. As a result, until first crack strength, the composite system of fiber reinforced composites is assumed to function as if it were unreinforced. Fiber reinforcement takes over at this point and holds the concrete together. The maximum load carrying capacity of a reinforced composite is controlled by fibers pulling out of the composite.

Polypropylene (PP) is a flexible thermoplastic made by polymerizing propylene monomer units into long chains. This catalyst-aided reaction happens under controlled heat and pressure [147] . Low temperatures make polypropylene brittle, although it's rigid and stiff. As temperature rises, the material loses hardness and gains flexibility, beyond its practical limit. Polymer crystal structure changes significantly at melting temperature. Polypropylene's high melting point makes it resistant to harsh temperatures. Time, temperature, and stress affect polypropylene mechanical properties. Since the material is semi-crystalline, its mechanical properties depend on crystallinity and orientation. The substance might be homopolymer, block copolymer, or random copolymer. Additionally, fillers, reinforcements, and modifiers may dramatically modify it. Polypropylene fibers are crystalline and non-crystalline. Fiber spinning and drawing may orient crystalline and amorphous materials. Polypropylene fibers are resilient, heat-resistant, strong, and elongated.

Kakooei et al. [50] investigated The impact of polypropylene fibers on the characteristics of reinforced concrete structures was examined by Kakooei et al. in their study [44]. The researchers performed experiments to examine the impact of varying quantities of polypropylene fibers on the qualities of concrete. It evaluated the permeability, electrical resistivity, and compressive strength as indicators of these attributes. It was noticed the compressive strength of concrete exhibited a direct correlation with the volume ratio of PP fiber and concluded that the inclusion of polypropylene (PP) fibers in concrete has a retarding effect on the deterioration process. This is attributed to the reduction in permeability facilitated by the PP fibers, which in turn leads to a decrease in the extent of shrinkage and expansion experienced by the concrete. These factors result in the enhancement of the durability of the concrete structure. Additionally, the electrical resistivity of concrete containing fiber ratios of 1 and 1.5 kg m_3 exhibited greater values compared to the other samples.

Banthia and Gupta [54] (2006) examined how PP fiber shape affects concrete plastic shrinkage cracking. Separate concrete overlay mixes received three monofilament and one fibrillated PP fiber volume fractions. They found that PP fibers effectively limit concrete plastic shrinkage cracking. Fibers decreased crack area, breadth, and quantity. They also said fiber reinforcement effectiveness increased with fiber volume fraction.

Sukontasukkul et al. [148] (2010) evaluated the post-crack flexural response and toughness of FRC after exposure to high temperature. They looked at three different volume fractions of three different fibers: steel, polypropylene, and polyethylene. Temperatures of 400 ^{o}C, 500 ^{o}C, and 800 ^{o}C were applied to the specimens. The authors concluded that the response was entirely dominated by the response of the concrete matrix prior to the peak. The post-peak flexural response of FRC was influenced by two factors: temperature and FRC type. Large drops of load-deflection responses were observed for the PP and PE FRC due to fiber evaporation. SRFC was not one of them.

Zhang and Li [149](2003) Investigated the impact of polypropylene fiber on the long-term resilience of a concrete composite that included fly ash and silica fume. The lengths (10-15 mm and 15-20 mm) of single short PP fibers into a mixture with a fixed volume of fly ash and silica fume content is maintained. The volume fraction of the fibers ranged from 0.06% to 0.12%. The results have shown that the inclusion of PP fiber resulted in a decrease in the workability of the matrices. The slump and slump flow exhibited a gradual decrease with an increase in the fiber volume percentage. The use of PP fiber effectively reduced the dry shrinkage of concrete that had both fly ash and silica fume. Additionally, polypropylene (PP) fibers in the composite material significantly decreased the extent of carbonation penetration.

Polypropylene fibers are desirable because of their flexibility. It is cheaper than many materials, has excellent qualities, and can be made in numerous ways. The structure and composition of polypropylene provide it these benefits. Homopolymer polypropylene resin produces polypropylene fibers in various forms, sizes, and characteristics.

6.4.2. Limestone powder

Limestone powder is uses as non-reactive filler agent in cement instead of clinker which is been used in Europe from past 30 years and frequently as an substitute to OPC when sulphate resistance is present. Isn’t especially necessary. Limestone cements often have a lower water content. Demand, which leads to improved concrete workability [150]. To acquire physical strength. The limestone powder must undergo a more refined processing method, akin to the conventional Portland cement, despite its much better grind ability compared to clinker. In addition, limestone is a cost-effective and easily accessible substance that exhibits greater ease of crushing compared to clinker, hence leading to enhanced hydration. The main benefits of this technology are lower costs and less pollution from carbon dioxide. Researchers have found that using up to 20% limestone in cement production and following modern industry standards may lead to a 10% drop in energy use and carbon emissions compared to other types of Ordinary Portland Cement (OPC). No changes were made to the performance properties of the cement in order to get this good result [151].

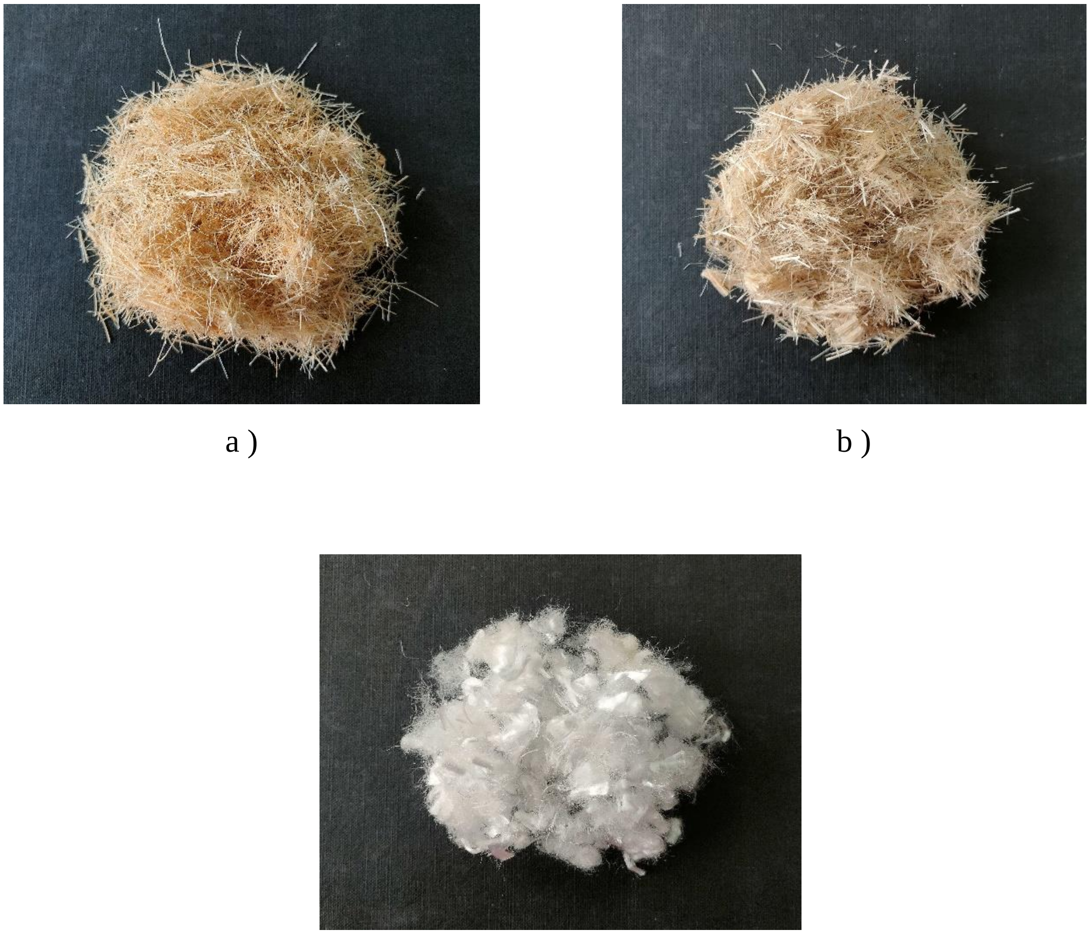
Limestone-based cements also have lower porosity, which is probably because the holes aren't connected as well rather than having less volume. They also have freeze-thaw resistance that is about the same as Portland cement as long as the air void system is controlled. [152]. The European standard EN 197-1[153] provides for three distinct dosage amounts of limestone in cements. CEM I may include up to 5% minor extra elements, one of which being limestone. CEM II/A-L and CEM II/B-L contain 6% to 20% and 21% to 35% ground limestone, respectively [152]. The utilization of limestone filler as a substitute for cement is now gaining popularity owing to its manifold advantages, encompassing enhanced cement efficiency, reduced manufacturing expenses, and environmental preservation via a substantial decrease in CO_2 and NO_2 emissions per metric tonne of cement manufactured. The use of limestone filler with Portland cement is a prevalent practice seen in many places around the globe, owing to its manifold advantages and positive impact on the physical characteristics of mortar and concrete. Consequently, Portland limestone cement emerges as a viable choice among the several forms of cement that may be manufactured inside cement plants. The necessary components for the production of this kind of cement are easily accessible, need a lower energy input during manufacturing, and result in reduced emissions of carbon dioxide (CO_2) and nitrogen dioxide (NO_2).

The limestone filler used in the experimental programme was procured from a Polish manufacturer. The inclusion of the European standard EN 197, which outlines the specifications for including limestone as additions or as the primary element filler in cement, was properly considered.

Limestone is frequently used as a constituent to enhance the flowability of mortar and concrete [154] . The material is generated as a byproduct of stone-crushing activities. In comparison with regular concrete, the incorporation of limestone results in a decrease in initial and final setting durations of the concrete, with a little increase seen in the overall shrinkage.[155]. The limestone filler also improves workability by increasing viscosity [156].

The incorporation of limestone powder into mortar is designed to enhance its workability and decrease the amount of water needed for a clean paste that contains limestone. The improved workability of paste and mortar may be attributed to the suitable texture fineness and particle size distribution of cement that incorporates limestone. [36]

Newman's research findings indicate that the addition of limestone powder to cement paste and mortar leads to an enhancement in early strength, while maintaining workability of the mortar. Additionally, it has been determined that the use of finely powdered limestone in the range of 10 to 40% enhances the initial strength of Portland cement. [157]. According to various studies, limestone, which primarily serves as a filler in cement-based materials, improves pore size distribution as well as fresh and hardened properties [158], [159]



a)

b)

c)

Figure 9. Fibers Additives a) Sisal Fiber, b) Jute Fiber, and c) Polypropylene fiber

Table 7. Physical properties of fibers

Property	Sisal fiber	Jute fiber	Polypropylene fiber
Density (g/cm^3)	1.58	1.3	0.91
Elongation (mm)	0.8 - 12	17	12
Young's modulus (GPa)	9 - 22	-	3.5
Tensile strength (MPa)	385 - 728	230	0.56 - 0.77

CHAPTER 7

PREPARATION OF SAMPLES

7.1. Mix compositions of mortars

The preceding chapter discusses the generality of the experiments required for this thesis, including material, specimens, equipment, and standards. More details will be provided in Chapter 7, and the lab work will be precisely explained step by step.

The experimental work procedure is simplified by categorizing it into three major steps:

1. Preparation of the paste with desire proportions
2. Examine the paste to find out the fresh mortar properties (consistency and air content)
3. Mortar casting and immediate tests
4. Hardened mortar properties (compressive, flexural and dry shrinkage)
5. Investigating the microstructural properties after 28days curing with hardened mortar samples

Three reference samples are considers in mix design one with OPC in proportion 1:6, cement - lime with 1:1:6 and APA cement with 1:6 binder ratio and 0.50% APA to weight of cement.

All of the mixed designs assist us in gaining the proper insight into comparing mortar characteristics such as consistency, air content during the wet process, and compressive and flexural strength, shrinkage after drying samples.

Table 8 and 9 display the mixed designs for all of the samples. The average value of three samples was considered, including the reference and additive samples. The three reference samples are cement mortar (CM), cement lime mortar (CL), and APA cement mortar (CA). There are three fiber samples with Jute, sisal, and polypropylene with the addition of 1% and 2% weight to cement as a reinforcement. For biomass ashes, rice husk ash, sugarcane bagasse ash, and limestone powder with replacement up to 5, 10, and 15% to the weight of cement. The weight of fine aggregate, cement, and water in the mortar with a w/c ratio was taken according to maintain consistency.

Table 8. Mix Proportions of all the mortar samples with and without SCM

Mixtures	Constituents (in gram)								
	CEM II/ 42.5R	Lime	Water	w/(c + L) ratio	Sand	APA	Biomass Ashes		
							RHA	SCBA	LS
CM	450		440	0.98	2308				
CL	350	253	410	0.68	1795				
CA	450		310	0.44	2308	2.25			
CM-RHA5	427.5		440	0.97	2308		22.5		
CM-RHA10	405		440	0.92	2308		45		
CM-RHA15	382.5		440	0.87	2308		67.5		
CM-SCBA5	427.5		440	0.97	2308			22.5	
CM-SCBA10	405		440	0.92	2308			45	
CM-SCBA15	382.5		440	0.87	2308			67.5	
CM-LS5	427.5		440	0.97	2308				22.5
CM-LS10	405		440	0.92	2308				45
CM-LS15	382.5		440	0.87	2308				67.5
CL-RHA5	332.5	253	410	0.7	1795		17.5		
CL-RHA10	315	253	410	0.72	1795		35		
CL-RHA15	297.5	253	410	0.8	1795		52.5		
CL-SCBA5	332.5	253	410	0.7	1795			17.5	
CL-SCBA10	315	253	410	0.72	1795			35	
CL-SCBA15	297.5	253	410	0.8	1795			52.5	
CA-RHA5	427.5		310	0.73	2308	2.25	22.5		
CA-RHA10	405		310	0.76	2308	2.25	45		
CA-RHA15	382.5		310	0.81	2308	2.25	67.5		
CA-SCBA5	427.5		310	0.73	2308	2.25		22.5	
CA-SCBA10	405		310	0.76	2308	2.25		45	
CA-SCBA15	382.5		310	0.81	2308	2.25		67.5	
CA-LS5	427.5		310	0.73	2308	2.25			22.5
CA-LS10	405		310	0.76	2308	2.25			45
CA-LS15	382.5		310	0.81	2308	2.25			67.5

Table 9. Mix proportion of mortar sample with and without fibers

Mixtures	Constituents (in gram)						Fibers		
	CEM II/ 42.5R	Lime	Water	w/(c+L) ratio	Sand	APA	Jute	Sisal	Polypropylene
CM	450		440	0.98	2308				
CL	350	253	410	0.68	1795				
CA	450		310	0.44	2308	2.25			
C-P1	450		440	0.98	2308				4.5
C-P2	450		440	0.98	2308				9
C-J1	450		440	0.98	2308		4.5		
C-J2	450		440	0.98	2308		9		
C-S1	450		440	0.98	2308			4.5	
C-S2	450		440	0.98	2308			9	
CL-J1	350	253	410	0.72	1795		4.5		
CL-J2	350	253	410	0.72	1795		9		
CL-S1	350	253	410	0.72	1795			4.5	
CL-S2	350	253	410	0.72	1795			9	
CA-J1	450		310	0.69	2308	2.25	4.5		
CA-J2	450		310	0.69	2308	2.25	9		
CA-S1	450		310	0.69	2308	2.25		4.5	
CA-S2	450		310	0.69	2308	2.25		9	

Figure 10. Apparatus for mixing materials to paste

CHAPTER 8

RESEARCH AND RESULTS FOR MORTARS WITH FIBERS

8.1. Consistency analysis of mortar with fibers additives

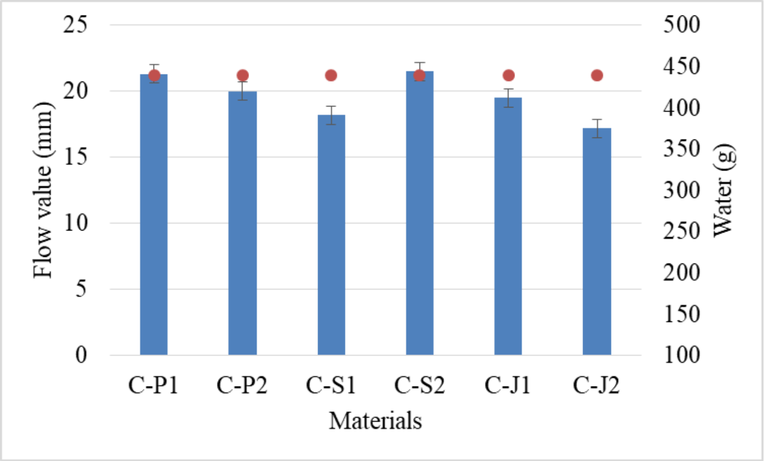
The analysis of the consistency of mortar is discussed in both methods for reference mortar and mortar with additives. The methods include flow table method and Novikov's cone. The difference in value of consistency in mortar can be noted in results with and without additive this might be because cone and plunger penetration are somewhat dependent on the viscosity of the new mortar, whereas flow diameter is related to its yield stress.

Generally, the consistency values for cement mortar, cement lime mortar, and APA cement mortar differ. Adding lime to cement raises the consistency with the same quantity of water as in cement mortar; thus, the water value is reduced to keep the value, and it is comparable in APA mortar because of its aerating function, which promotes water absorption.

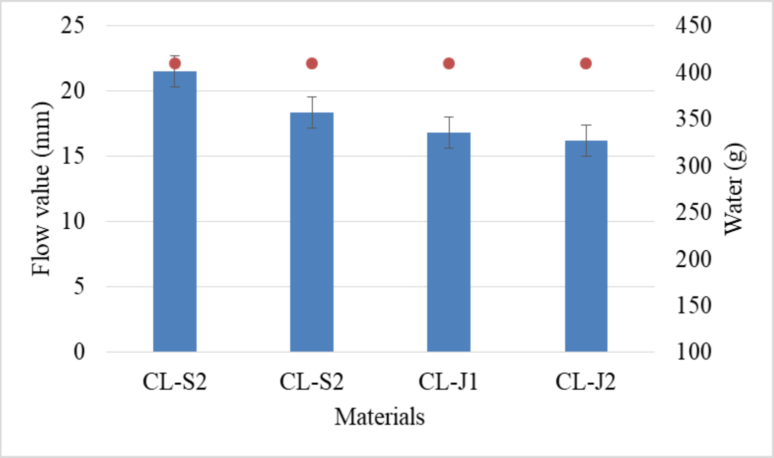
The values of reference cement mortar and cement mortar with fibers are shown in Figure11. According to the data presented in Figure, adding fibers to cement mortar reduces the flowability of the mortar, with the addition of jute and plastic fiber reducing the flowability to 5% with can be noted in figure below. The cement mortar sample with polypropylene 2% (C-P2) has a higher flow value than the other fiber samples; this might be due to the inclusion of the maximum amount and shorter fibers ratio.

The consistency also depends on water binder ratio as we can see in results of cement-lime mortar samples. As a result, cement mortar loses consistency more quickly than lime mortar. From the start, lime mortar had a plastic consistency. According to Bauer et al. [39], the flow table method has a high degree of variability, so mortars with spreading diameters ranging from 190 mm to 290 mm produced by this method would be suitable for use as coating mortar. For required consistency in lime mortar, the w/b ratio is not the same as in cement since lime's water absorption is more than cement's due to its fineness. Figure 11 b shows that the addition of fibers is expected to reduce flow ability because natural fibers are hand cut with a size of 1cm, which is longer than polypropylene fibers, and the interaction between longer fibers was more active and caused fiber balling, clumping, which could cause internal resistance against the flow. No specific changes were observed with polypropylene fibers. Including 2% sisal fibers enhances the flow due to the water absorption capabilities of natural fibers due to the presence of cellulose and lignin.

According to figure 11 c the APA addition improves the workability of mortar paste which can be seen from values compare to other two reference sample. The APA effect was connected to a drop in water surface tension; therefore, it acted stronger when more water was in the mortar. Adding APA solution with the same w/c ratio causes significant water absorption, so the amount of water used in the mixture must be reduced to maintain consistency. The difference in the amount of water differed from 6.8% for cement-lime to 29.5% for APA cement mortar compared to cement mortar. Including fibers, however, balances out the consistency without making it overly watery. For the plunger penetration method of consistency measurement the values differ for several samples compare to flow table. Cement mortar with sisal fibers has a higher consistency than the reference sample. The consistency of mortars prepared with APA and 2% sisal fibers shows a comparable outcome. The consistency of samples with sisal is higher compared to others and the reason as stated before is that the natural fibers consist of cellulose and lignin which are hydrophilic in nature. The similar results can be noted in cement -lime samples with the higher amount of sisal the consistency values is increase. The use of jute fiber to the mortar reduced its consistency. Similar effects of jute fibers were reported by Chakraborty [160] who pointed out that the fibers higher friction and spatial orientation have a detrimental influence on consistency . Naturally, the effect was more visible in the case of plasters, which contained more water due to their hydraulic nature, but in the case of APA samples, the increase in plasticity is due to its aqueous solution, which increases surface water tension. From the results it can be stated that addition of sisal increases the water absorption and with higher amount of 2% the consistency value is maximum both in flow table and plunger penetration values.



a)



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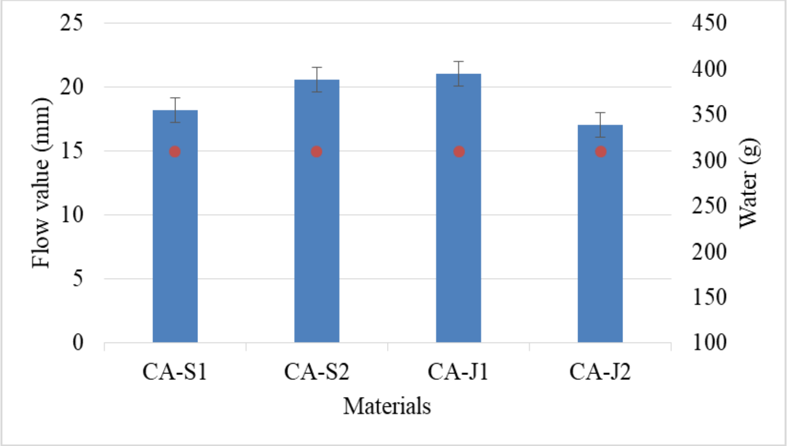
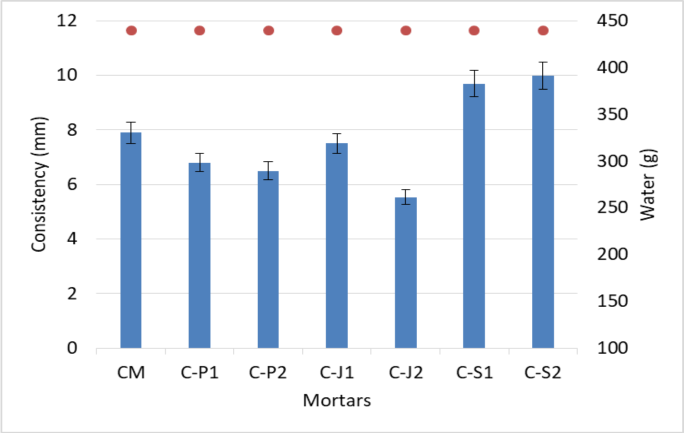
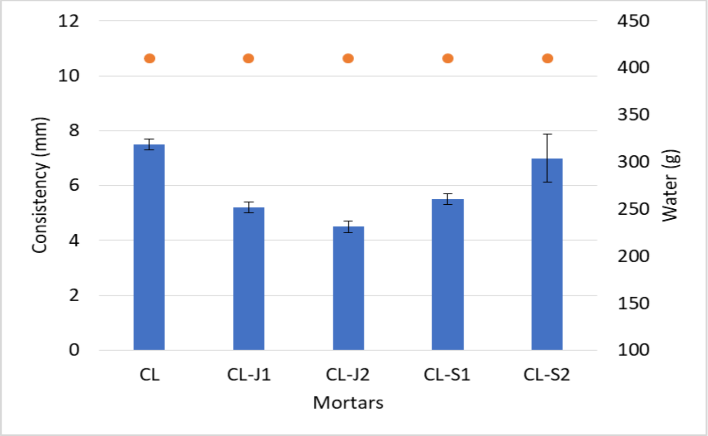


c)

Figure 11. Flow table values a) cement mortar, b) cement-lime mortar, and c) APA cement mortar with fibers



a)



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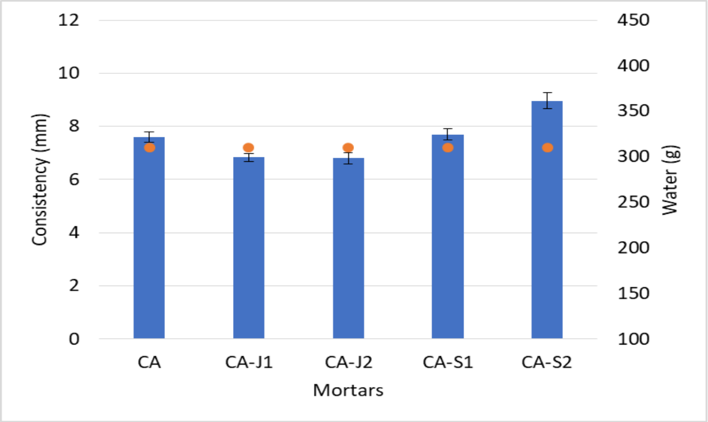


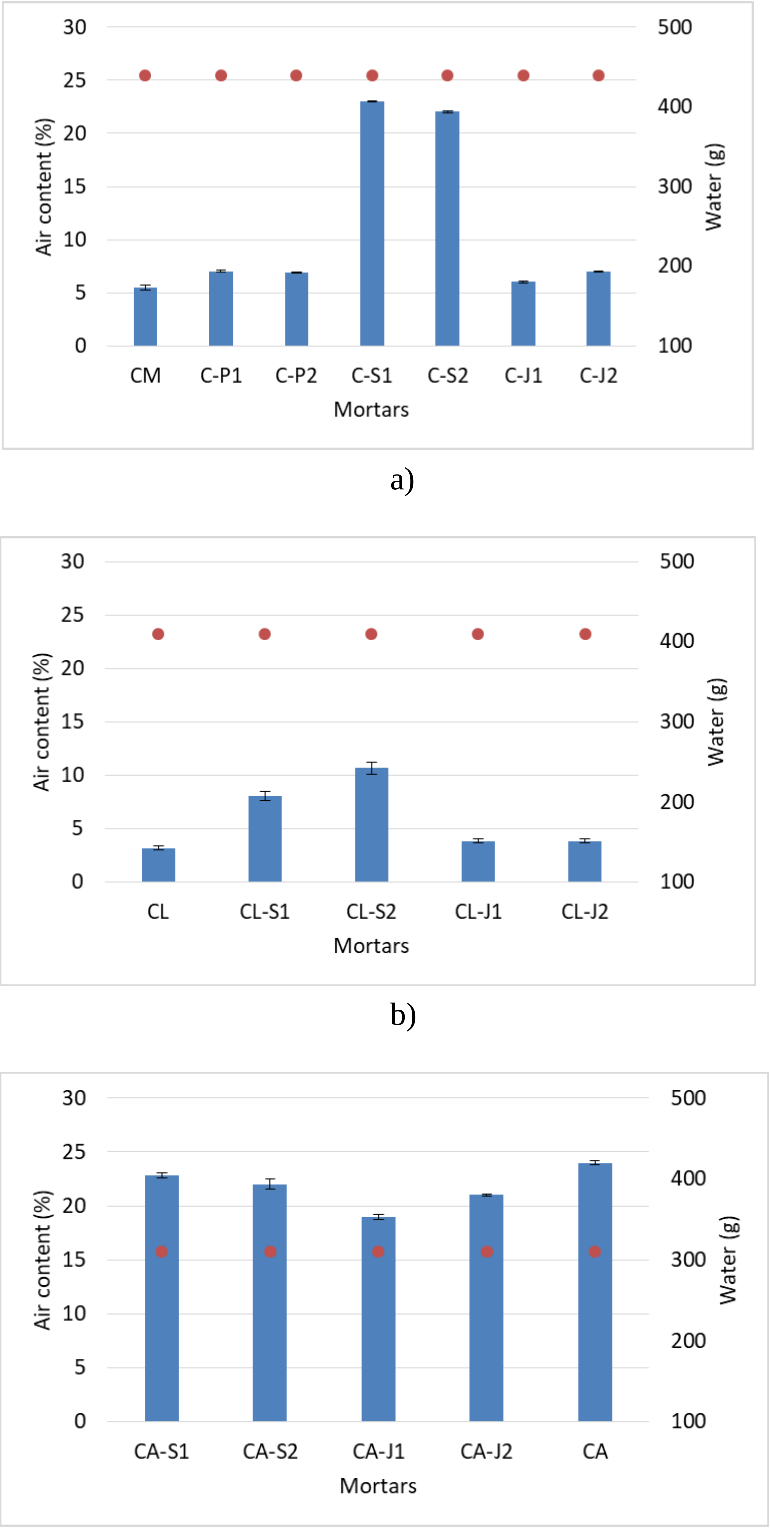
c)

Figure 12. Penetrometer values a) cement mortar, b) lime-cement mortar and c) APA cement mortar with fibers

8.2. Air content analysis in mixes with fibers

The figure 13 below illustrates the results of the air content tests. It is obvious that the air content in cement and cement-lime mortars has been significantly lower when compared to APA mortars, which is due to the influence of the admixture. It is important to note that cement-lime mortars exhibited lower air content compared to cement mortars. The observed phenomenon can be related to the reduced water content in cement-lime mortars, along with a potential filler effect resulting from the presence of fine lime particles. The addition of jute and polypropylene fibers did not result in any significant impact on the air content of the tested cement-lime and cement mortar. The absence of any apparent effect of polypropylene fibers on-air content aligns with the findings reported in prior investigations of cement mortar. [161], [162].

A slight reduction was seen when jute fiber was incorporated into the mortar using APA. However, the inclusion of sisal fibers had a notable impact on the air content of cement mortars and cement-lime mortars, resulting in a fourfold increase. On the other hand, sisal fibers did not provide any visible effect on APA mortars. This finding suggests that sisal fibers have the capacity to enhance the aeration of mortar. The possible reason for the observed effect may be attributed to the elevated cellulose content present in the composition. Cellulose possesses hydrophilic characteristics, enabling it to absorb water and subsequently augment the viscosity of fresh mortar [163]. Therefore, the mortar's ability to undergo natural deaeration throughout the mixing and handling procedures would be reduced, resulting in an increase in air content. The effect of fibers on air content in APA mortars is different from that in cement mortar and cement lime-mortar. Given this disparity, it's possible that the addition of fibers reduces the aerating properties of APA mortars. Fiber presence physically interferes with the air introduced by the presence of APA, and does not provide enough aeration to fully offset this effect.



a)

b)

c)

Figure 13. Air content values with fibers: a) cement mortars, b) cement-lime mortars, c) cement mortar with APA

8.3. Results on the compressive strength of mortars with fibers

The figure 15a shows the compressive strength of cement reference samples after addition of fibers with amount of 1% and 2%. The compressive strength is measured of all mixtures were obtained at 7, 28, 56 and 90 days after curing.

The compressive strengths of various reference samples are depicted in Figure 14. As indicated in Table 8, different water binder ratios were utilized for each sample. Specifically, the cement mortar utilized differs from the cement-lime and APA cement mortar samples. In contrast, the water intake requirements for lime mortar and APA mortar are reduced to 6.8% and 29%, respectively, to maintain constant mortar consistency. As a result of the increased water absorption and air content caused by the addition of APA, the compressive strength of the samples decreases. Cement mortar and lime mortar have comparable compressive strengths, with the exception of a small strength reduction in the lime sample related to the presence of minor voids. The use of APA reduces compressive strength drastically by generating a large number of air voids.

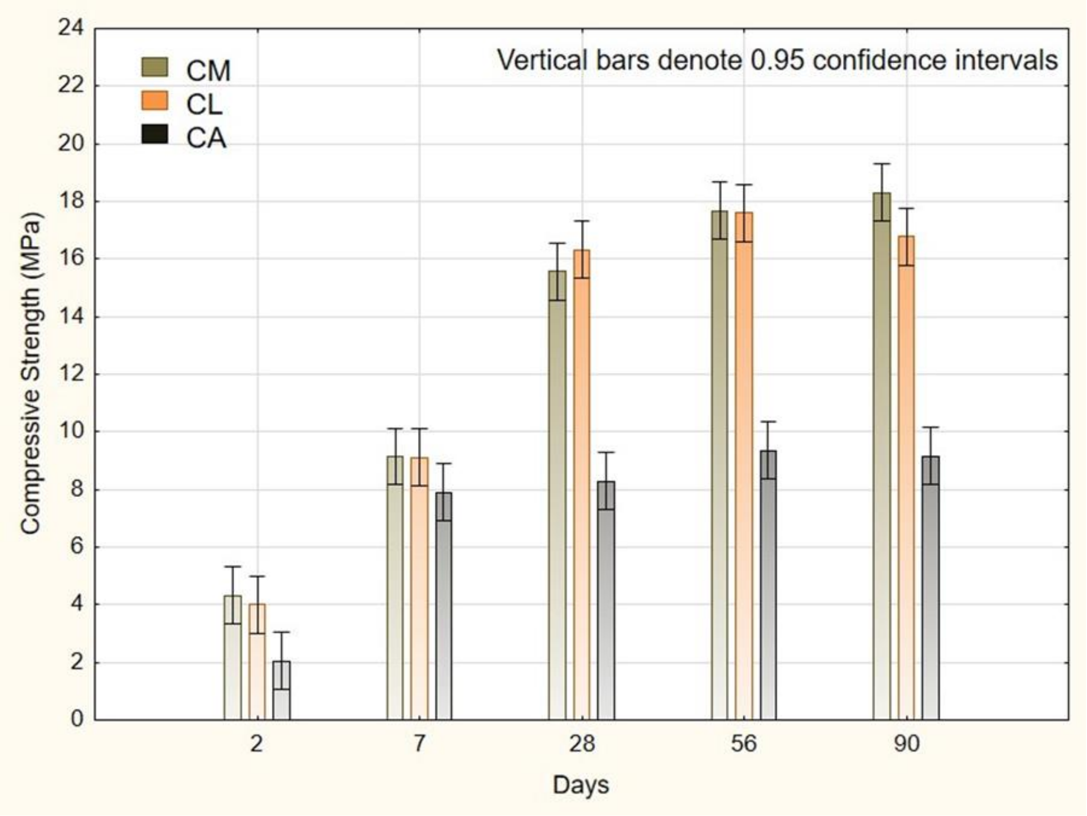


Figure 14. Compressive strength of reference sample

According to results obtained it can be seen that the addition of 1% amount sisal fiber to cement mortar decreases the strength up to 6% for each testing period. The decrease in compressive strength of mortar with sisal fiber can be attributed to the existence of components like as cellulose and lignin, which possess properties such as water absorption. However, increasing the quantity of sisal fiber to 2% results in the destruction of samples during the initial days of curing; the strength of samples with less than 1MPa appears to decrease by 40% in comparison to the sample of reference cement mortar. Sisal fiber possess an extensive amount of hydroxyl groups (OH), resulting in their hydrophilic characteristics what leads to insufficient adhesion between the fiber and matrix, as water present on the surface of the fiber interferes with the bonding between the paste and fiber. Consequently, this results in a reduction of compressive strength. However, it is possible that this issue could be resolved, given the proposition of chemical treatment methods.. Few of the method include Saline, alkali, and monomer graft copolymerization are these approaches. Alkali treatment is a popular way to clean and change natural fiber properties. Alkali treatment reduces surface tension and improves fiber-matrix adhesion. [63], [164].

On the other hand, the findings of the jute fiber sample exhibit different outcomes compared to the sisal fiber sample. Figure 15a illustrates that the inclusion of jute fibers, up to an amount of 1% (C-J1), leads to an increase in the compressive strength of the cement mortar specimen across all stages of the curing process. The addition of jute fiber in cement mortar results in a significant increase in compressive strength, indicating a rise of up to 11% when compared to the reference cement mortar. Furthermore, the incorporation of jute fibers in the cement matrix at a concentration of up to 2% (C-J2) results in a significant improvement in strength, with an increase of up to 15% observed after 28 days of curing. However, it should be noted further the strength decreases to 5% at 56 and 90 days of curing. The manufacturing process of jute differs from that of sisal, potentially resulting in variations in production methods. It has been observed that jute has a lower water absorption rate compared to sisal, which may contribute to enhancements in its mechanical qualities.

When adequate doses of polypropylene fiber were added to all mortar mixes, the findings showed an increase in compressive strength after up to 7 days. In the case of compressive strength, the findings demonstrate an improvement in compressive strength up to 0.5% of PP fiber as a volumetric fraction of the mix. Still, above this percentage, compressive strength decreases, up to

16% in comparison to reference sample which is connected to the fact that the compaction was made with less workable material and Similar results can be seen with mortar addition of more than 0.5% to matrix there is constant decrease in strength [47]. Polypropylene's hydrophobic surface hinders chemical contact with cement, preventing water absorption. Polypropylene fibers adhere and anchor in mortar matrix through interfacial adhesion. Disadvantages of polypropylene include low modulus of elasticity and weak matrix bonding.

The compressive strength of cement-lime mortar is comparatively low compare to plain cement mortar because lime mortar is more porous than cement mortar and lime in generally weaker binder then cement.

Jute increases the compressive strength of cement-lime. Sample CL-J1 reveals a strength increase of 50% after 2 and 7 days. However, the strength decreases, despite being greater than that of the reference cement-lime mortar. Sample CL-J1 appears to experience a 15% increase in compressive strength upon jute addition at 28, 56, and 90 days. An increase in the proportion of 2% jute to the material results in a 15% increase in strength for the first seven days and an 18% reduction by the end of the 28-day period as seen in Figure 15b. A lesser quantity of jute fibers bonds well to the matrix, resulting in an increase in strength. However, as the concentration exceeds 2.0%, compaction becomes more challenging due to reduced flowability, ultimately leading to a reduction in strength. Addition of sisal fiber in cement-lime mortar sample shows better strength compare to addition in cement mortar. As previously stated, the incorporation of sisal fibers significantly enhances water absorption. However, when added to lime mortar, the inclusion of a lower percentage of sisal fibers, as observed in sample CL-S1, has more favorable outcomes. Specifically, there is an increase in strength of up to 80% and 10% at 2 and 7 days, respectively. However, the strength of the sample gradually decreases by up to 10% over the remaining days. Additionally, when compared to sisal fibers addition in cement mortar, the findings are superior in cement lime mortar. This could be attributed to the rapid evaporation of water in the lime sample, which prevents the additional absorption of water by sisal from influencing the sample. The samples containing sisal are initially weaker, and upon compressive loading, they fracture immediately, resulting in a strength of less than 1 MPa; this provides evidence that the sample is of inferior quality. The compressive strength experiences a fall of 30% on subsequent days due to increased water absorption, resulting in a reduction in strength.

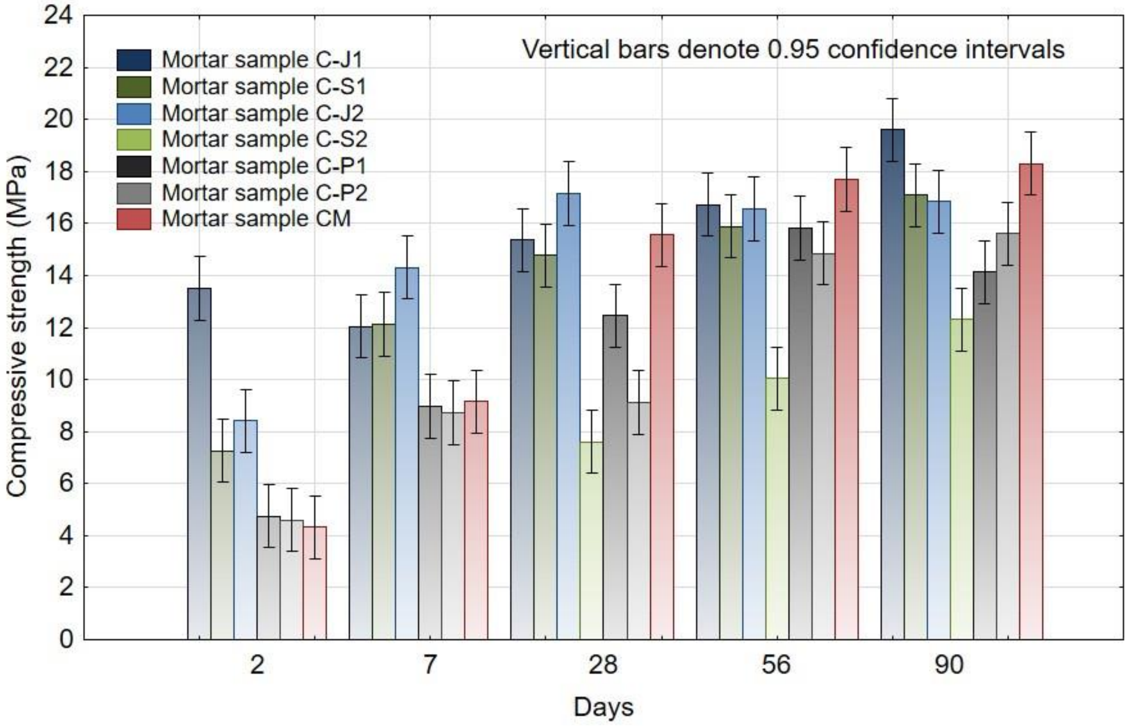


Figure 15a. Compressive strength of cement mortar with fibers

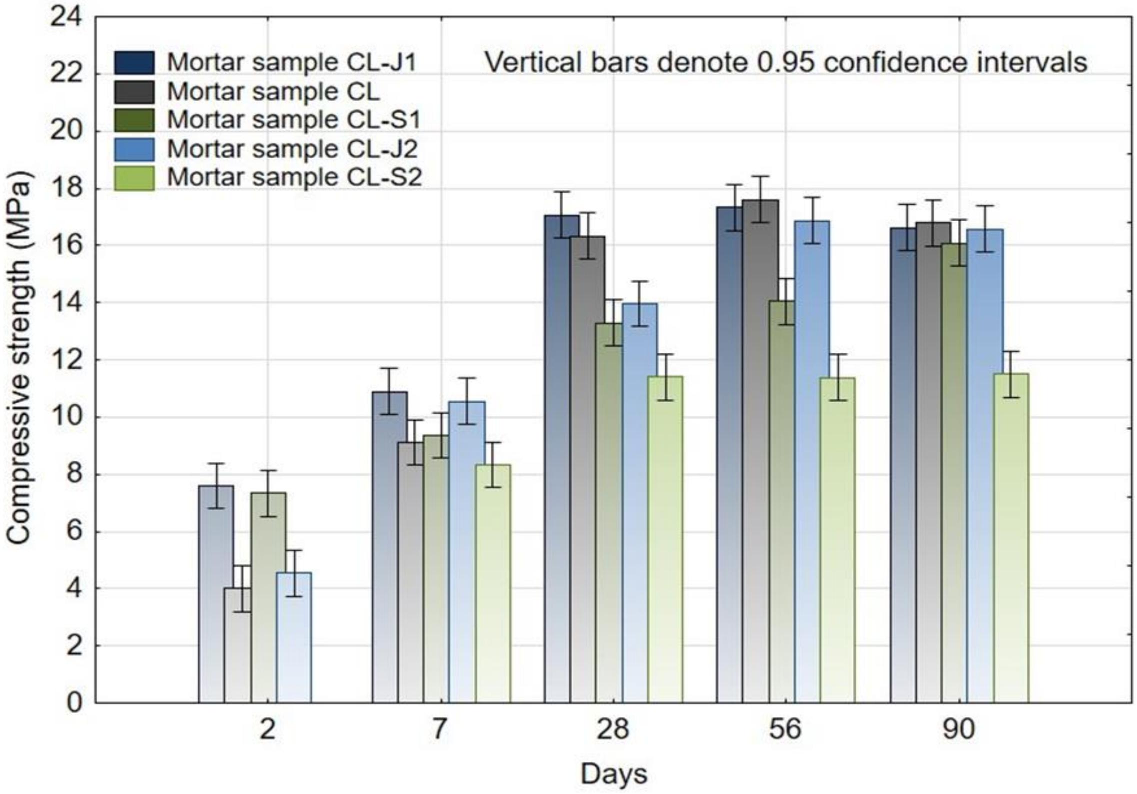


Figure 15b. Compressive strength of cement-lime mortar with fibers

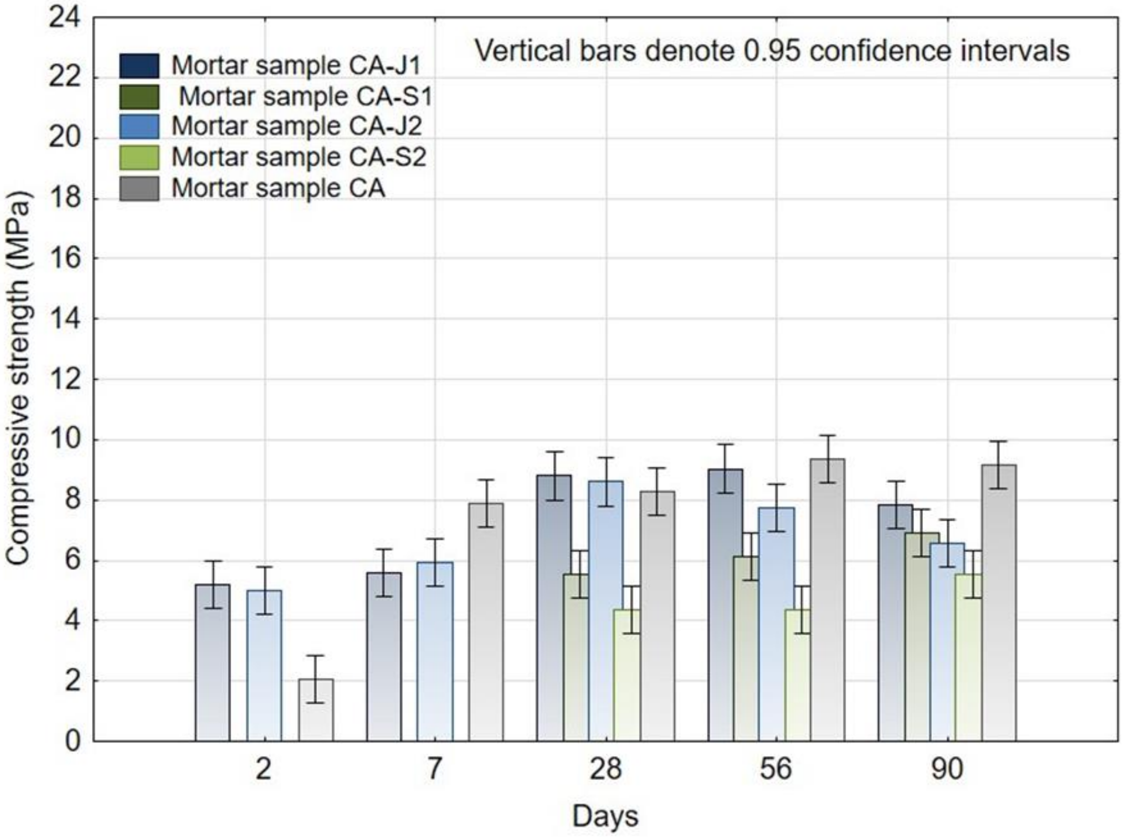


Figure 15c. Compressive strength of APA cement mortar with fibers

When APA cement mortar is compared to other cement mortar and cement-lime mortar samples figure 15c, there is a significant difference in compressive strength. The addition of fibers does not produce positive outcomes in terms of strength in APA mortar sample. Figure 8c demonstrates that jute fibers enhance strength by 15% for sample CA-J1 and 10% for sample CA-J2. However, the strength is decreased on other days due to natural fibers water absorption qualities and the addition of APA, which increases uniformity and aerating features. In general implementation of natural fibers improves the compressive strength compare to control samples in 28days and which shows that the fiber addition have positive results in strength.

In summarizing the effect of fiber addition on the compressive strength of mortar samples, it can be concluded that lower percentages of fiber addition result in higher compressive strength compared to larger amounts. The addition of jute in all reference samples results in improved compressive strength. The observed decrease in strength of the sample is attributed to the elevated water absorption resulting from the extended 90-day period.

8.4. Results on the flexural strength of mortars with fibers

The mechanical test results, including flexural strength, of mortars are presented in Figure 16. Cylinder samples with dimensions of 40x40x160mm were used for the flexural test. According to the figure 16a, it is noted that the addition of a lower percentage of sisal fiber, i.e. 1% by weight of cement, in sample C-S1 shows increases in resistance toward bending to 59% and 34% at 2 and 7 days, respectively. Further, the strength is reduced to 7.5%, 10%, and 18% for 28, 56, and 90 days, respectively. Also it can be noted that sisal fiber is acting better in respective to flexural strength compare to its properties in compressive strength. Higher amount of sisal (2%) decreases the flexural strength of mortar initially, the values are zero due to the breaking of sample outside of the machine testing range, and thus can be estimated to be less than 1MPa. It should be noted however that sample C-S2 shows increases in strength to 35% at 28 days, though the increase is lesser compared to the reference cement mortar sample. Sisal fibers show huge water absorption, as explained previously which is the reason for the weaker sample [165]. Moreover, increased amount of fibers in mortar leads to the creation of air space as we can see in results of air content which might contribute to the decrease in flexural strength at higher doses.

The addition of jute to cement mortar improves flexural strength significantly. The use of jute fibers in the study yielded excellent results in strength in all different reference samples. The sample C-J1 shows an increase in flexural strength of 31% and 10% at 7 and 28 days, respectively compare to control sample CM, but the strength decreases with the remaining days, with a difference of 6% at 56 days and 2% at 90 days when compared to the reference sample, which is not a significant difference. Jute fibers show better adhesion between cement matrix and the porosity is quite low in these samples, as will be shown in the SEM photography discussed later in this thesis. The results obtained from the examination of jute sample C-J2 indicate that the flexural strength exhibited a significant improvement of 80% and 38% at 2 and 28 days respectively, in comparison to cement mortar. Furthermore, the strength continued to gradually increase by 8% and 12% at 56 and 90 days respectively. Similar findings have been seen by several researchers, that the inclusion of jute fibers enhances the flexural strength of a material by enhancing the bonding between the fibers and the cement matrix, which allows the direct transfer of loads to the fibers [20], [145], [166]. It has also been suggested that fibers block the fracture mechanism and enhance flexural strength more than compressive strength.

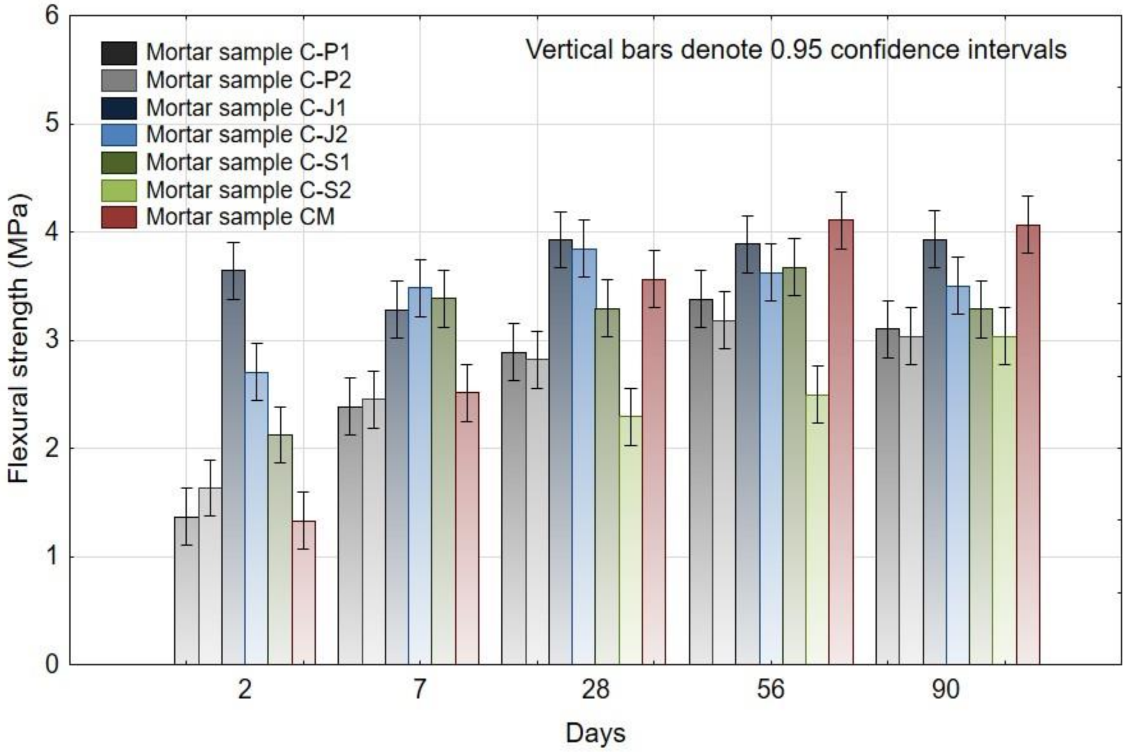


Figure 16a. Flexural strength of cement mortar with fibers

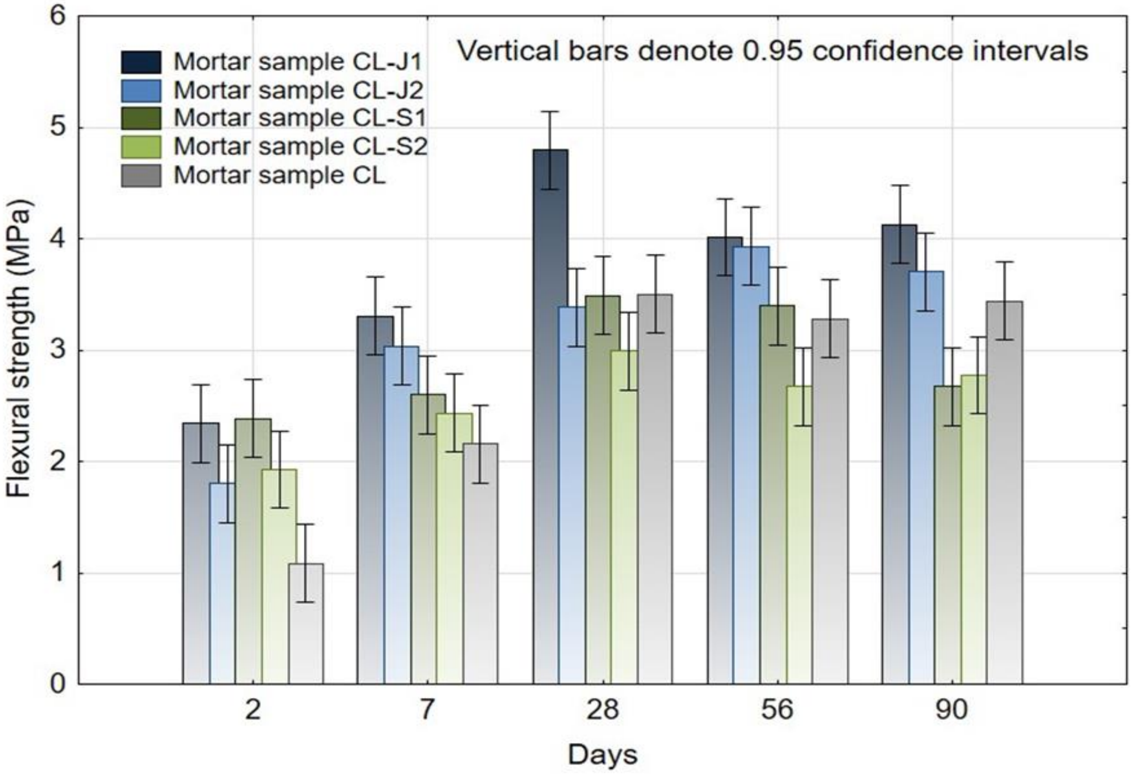


Figure 16b. Flexural strength of cement-lime mortar with fibers

The flexural strength of polypropylene fibers, on the other hand, remained unchanged regardless of the proportion of cement added. According to studies [38], [47], the compressive strength is increased when polypropylene is included. However with flexural strength the results in reduce to 28% at 28days and 18% at 90days as noted in sample C-P2. The flexural strength of mortar is affected when polypropylene fibers of varying lengths are introduced; shorter fibers have a weaker bonding surface with the matrix, leading to a lower pull-out load and less efficient fracture bridging. Figure 16b shows the flexural strength of cement-lime mortar and 5 groups of different fiber reinforced composites on the 2, 7, 28, 56 and 90days.

The total number of pores found within the lime matrix directly influences the strength and durability of the lime mortar. Increased porosity inside the lime matrix has an adverse impact on the strength and durability of the mortar. The incorporation of natural fibers into the matrix has been suggested by researchers to enhance the inadequate strength and durability of lime mortar. Also the researchers had investigated the impact of adding organic and inorganic types of fiber additives on the mechanical properties of lime matrices [167], [168]. The results suggests that the addition of additives serves as a form of secondary reinforcement, enhancing the binding between lime particles and fine aggregates within the matrix. The insertion of additives in lime matrix improves the resistance to crack by encouraging better adhesion among lime particles. Therefore, the inclusion of fiber additives in lime mortar leads to an improvement in flexural strength compared to cement-lime mortar without additives. According to results shown is figure 16 b addition of jute fibers to amount of 1 % (CL-J1) to weight of cement increases the flexural strength to 53% and 37% with 7 and 28days respectively. Further even after longer curing period of 90days there in improve in strength up to 20% for sample. The improvement in flexural strength of fiber-reinforced mortar may be owing to an increase in fiber quantity up to a particular limit (1%) that aids in more successfully controlling crack formation, widening, and propagation. The bridging effects of fibers across cracks has been found to enhance the durability of mortar prisms, hence improving the flexural strength of mortar. Similarly, after 1% jute fiber utilization, the flexural strength begins to decline due to the balling effect and improper fiber bonding with mortar, and it may decrease due to high porosity and irregular dispersal of reinforcing fibers in mortar, but the flexural strength is superior to control cement-limemortar. Addition of jute 2% shows increase in strength to 40% at 28days and 20% at 56days curing which is lower than addition with 1% although it’s higher than reference cement-lime sample.

The presence huge amount of water in sisal sample affects the strength of composites because of swelling of samples [169]. Despite the lower cost of natural fibers compared to synthetic fibers, enhancing their qualities through techniques like resin impregnation is frequently required in place of extensively utilized synthetic fibers. The main components of natural fibers that have an influence on their qualities include cellulose, hemicellulose, lignin, waxes, oils, and pectin. Cellulose is primarily formed of three elemental components, namely carbon, hydrogen, and oxygen. It serves as the fundamental structural constituent responsible for the formation of the cell wall's natural fiber. Typically, cellulose remains in the form of micro-fibrils within a plant's cell wall. The main factor influencing flexural strength is cellulose. The presence of hemicellulose influences sisal fibers high hygroscopicity. The structure of the sisal fiber demonstrates that it swells when wet. According to results addition of sisal in lower amount increase the flexural strength to 20% at 7days and 5% at 56days the strength remain same as control sample at 28days.

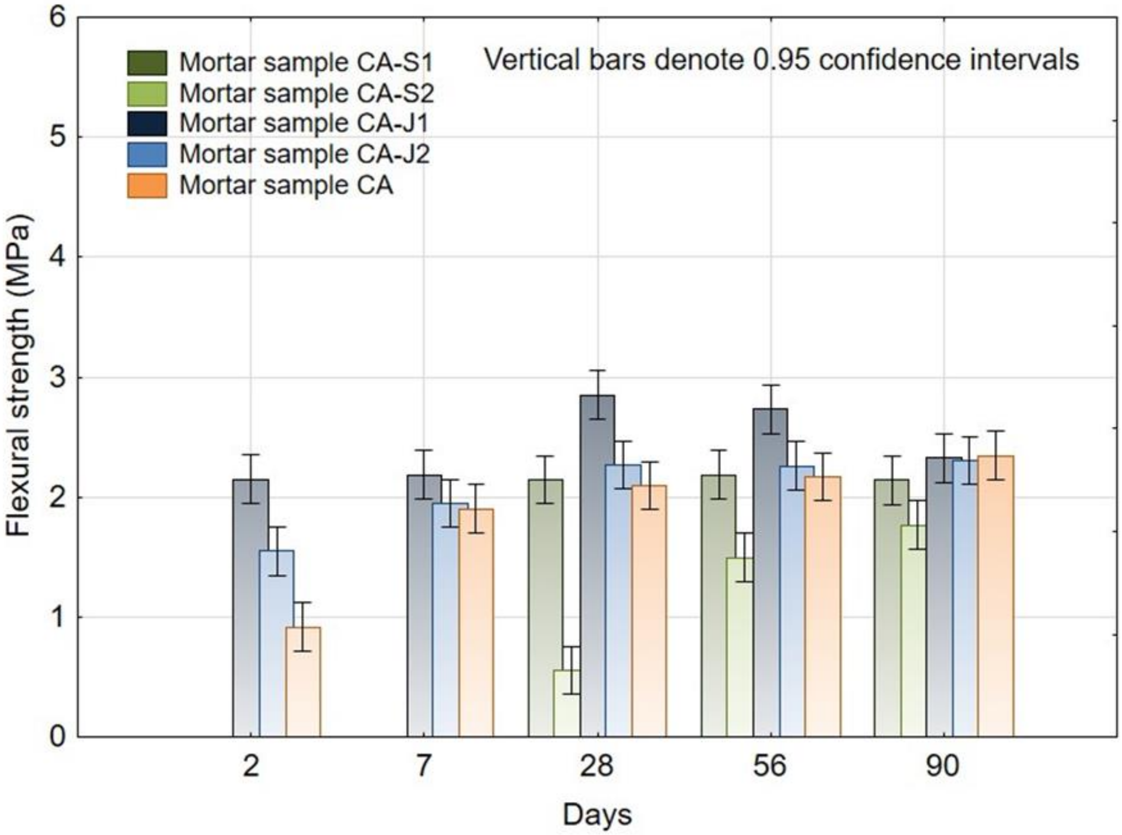


Figure 16c. Flexural strength with APA cement mortar with fibers

Incorporating 2% amount of sisal reduces the strength to 20% compare to reference cement-lime sample the reason is huge water absorption characteristics of sisal and porous properties of lime which leads to poor adhesion to the cement-lime matrix. Adhesion of the natural fiber to the matrix affects composite mechanical properties, especially compression and bending strength. Figure 16c shows the flexural strength of APA cement mortar with addition to fibers according to above values of strength of reference APA cement sample is seems to be low with fibers sample , the reason is the increase in water absorption and air content values in these samples which ultimately effects the strength of mortar. The use of sisal fiber in APA cement mortar results in a decrease in flexural strength as compared to the utilization of jute fiber. The incorporation of 1% sisal fiber (CA-S1) leads to the early breakdown of the sample during the early days, mainly due to its significant water absorption capacity. The flexural strength shows a lower strength in the remaining days when compared to the reference samples. Because natural fibers include a high concentration of hydroxyl groups (OH), they exhibit hydrophilic behavior. As natural fibers have a high content of hydroxyl groups (OH), which causes the hydrophilic behavior. When natural fiber is used to develop composite materials, its hydrophilic behavior results in poor adhesion between fiber and matrix [8], [170] and it can be easily visible in the results of sisal fiber samples. The flexural strength of sample CA-S2 falls to 50% compare to reference APA cement mortar.

With the results of flexural strength it can be noted that addition of jute fibers to cement mortar shows positive results compare to sisal and APA cement mortar sample. Incorporating the jute fibers with 1% (CA-J1) in APA cement increases the strength up to 14%, 35% and 25% at 7days, 28 and 56% respectively, the strength for 90days remain same as control sample. Addition of the higher amount 2% (CA-J2) decreases the flexural strength compare to sample CA-J1 however the strength in comparatively higher to control sample there is increase in strength to 8% at 28days and 4% at 56 and 90day.Below the results of strengths and air content of tested mortars are presented in table 9. The results show that the increase in air content in samples effects the strength directly. The compressive and flexural strength seems to be reduce with high amount of air voids.

Table 10. Comparison between air content and strength of samples with fibers

Sample	Aircontent (%)	Flexural Strength(MPa)					Compressive Strength(MPa)				
		Days					Days				
		2	7	28	56	90	2	7	28	56	90
CM	5.5	0.94	1.54	3.92	4.2	3.9	2.83	4.42	14.2	17.8	17.1
CL	3.2	1.1	2.2	3.5	3.28	3.4	4	9.1	15.78	17	16.7
CA	24	0.92	1.9	2.1	2.17	2.3	2.0	7.9	8.3	9.35	9.17
C-S1	23	2.12	3.4	3.3	3.7	3.3	7.3	12.1	14.76	15.6	17.0
C-S2	22	0	0	2.3	2.5	3.0	0	0	7.6	10.1	12.3
C-J1	6.1	3.64	3.28	3.93	3.88	3.9	13.	12.	15.35	16.7	19.6
C-J2	7	2.7	3.48	3.85	3.62	3.5	8.41	14.3	17.15	16.5	16.8
C-P1	7	1.36	2.35	2.89	3.38	3.1	4.75	8.98	12.45	15.8	14.1
C-P2	6.9	1.63	2.45	2.82	3.2	3.0	4.6	8.72	9.12	14.5	15.6
CL-S1	8	2.4	2.56	3.49	3.4	2.6	7.34	9.4	13.28	14.1	16.0
CL-S2	10.5	1.93	2.4	2.99	2.67	2.7	0	8.33	11.39	11.3	11.5
CL-J1	3.8	3.36	3.83	4.8	4.01	4.1	7.59	10.9	17.07	17.3	16.6
CL-J2	3.9	1.8	3.04	3.5	3.93	3.7	4.55	10.5	13.96	16.8	16.5
CA-S1	23	0	0	2.14	2.2	2.1	0	0	5.55	6.12	6.89
CA-S2	22	0	0	0.55	1.5	1.7	0	0	4.42	4.34	5.54
CA-J1	19	2.15	2.2	2.83	2.7	2.3	5.2	5.6	8.8	9.03	7.83
CA-J2	21	1.55	1.9	2.2	2.26	2.2	4.98	5.94	8.6	7.76	6.55

8.5. Results on shrinkage effects of fibers

Figure 17a illustrates the dry shrinkage of mortar specimens, both with and without fibers, over a 28-day period. To ensure precision, the mean values of two samples were used for verification purposes. It was observed that the cement-lime reference mortar has higher shrinkage rate compared to the other two reference samples. The development of dry shrinkage in mortar might be due to the permeable characteristics of lime at the microstructural level, which promotes the movement of moisture within the matrix. In aspect of shrinkage the APA cement mortar is showing decrease in shrinkage this might be due to presence of APA within the paste make homogenous distribution of materials leading to lesser cracks. The observed outcome can potentially be attributed to the reduced water-to-cement ratio (w/c) in these particular mortars in comparison to the reference mortars [171].

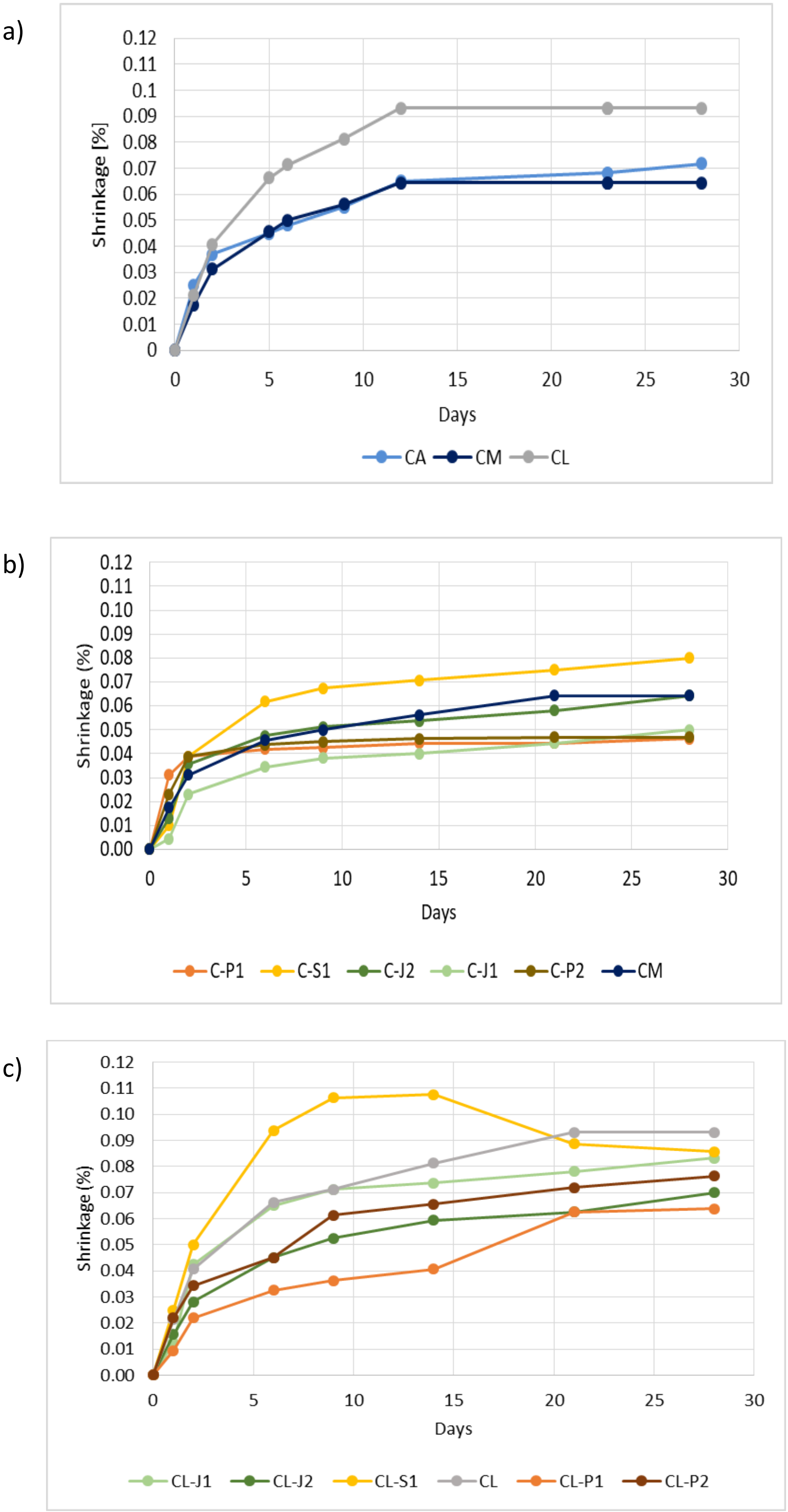


Figure 17. Shrinkage value of a) reference samples,) cement mortar with fibers and, c) cement-lime mortar with fibers

The moisture absorption of the CA mortars was not affected by the air content. However, the incorporation of fibres into cement-lime mortar results in a reduction in shrinkage compared to the control sample of cement-lime mortar. The bonding strength between the APA and fiber samples was found to be insufficient, leading to the fracture of the mould upon demoulding. Consequently, it was not feasible to obtain shrinkage measurements for CA mortars including fibers. The findings in Figure 17b indicate that cement-sand samples containing polypropylene and jute fibers exhibit reduced shrinkage and contract compared to the reference mortar samples. The addition of 2% sisal fiber results in a notable 15% increase in the dry shrinkage of the cement matrix. The addition of 1% sisal fibers results in a reduction in shrinkage of C-S1 mortars, which is comparable to that of the reference sample. Figure 17c demonstrates comparable levels of shrinkage in cement-lime mortars that are reinforced with both natural and polypropylene fibers. Silva et al. [63] established a correlation between the shrinkage of the cement matrix and many factors, including porosity, as well as the form, size, and continuity of the capillary system in the wet paste. When compared to reference, jute, and plastic fibers, the presence of sisal fibers increases the porosity in the matrix, increasing the number of voids and cracks. According to Fapohunda et al [172] found that sisal fiber reduces dry shrinkage by 28% compared to the reference blend, contradicting the current findings. The maximum expansion shows within 7 days of age, and the shrinkage value remains constant with small fluctuations up to 28 days. Dry shrinkage increases when fibro content is increased, reversing its benefits. Adding 2% sisal fibers to cement cracks samples. Due to their hydrophilic nature, bio fibers adhere poorly to cement matrix, however chemical treatment can improve [173]. The incorporation of 2% jute fiber and 1% polypropylene fiber into cement lime mortar results in a shrinkage decrease of up to 15%, as observed in Figure 17c. When comparing cement mortar to cement lime mortar, minor cracks are observed. The shrinkage examination did not occur when a higher amount of sisal was added, as it led to the destruction of the sample. Nevertheless, the inclusion of a lesser amount, specifically 1%, of sisal in the cement lime mortar resulted in an initial increase in shrinkage. However, after 28 days, there was a corresponding decrease in shrinkage to 11% when compared to the reference cement-lime mortar. The addition of APA to cement mortar weakens the sample with fibers, which is why shrinkage testing was not performed.

8.6. Results on pore structure analyzes of mortars with fibers

Porosimetry measurement results are presented in Figure 18. Based on an analysis of the porosimetry results, it can be determined that the pore structure of the reference mortars is indicative of their material composition. The results obtained from the MIP analysis reveal significant differences in the pore characteristics of all the mortars, irrespective of the presence or absence of fibers table 11 for without fiber and table 13 with fibers. The presence of pores with tiny diameters is prominent in cement mortar C and cement-lime mortar CL, constituting a significant percentage of 85.5% and 95.5%, respectively, within the range of 0.01 - 1μm in figure 18a. In a cementitious material known as mortar, which incorporates an APA admixture, it has been shown that a significant proportion of the overall porosity, specifically 56.9% (as seen in Figure 18c, is attributed to the presence of pores with relatively larger diameters ranging from 1 to 60 micrometers. This occurrence is primarily attributed to the air-entraining action of the APA admixture in contact with water resulting in the formation of foam. The impact on the structure of mortar varied based type of fiber incorporated. The addition of jute fibers did not significantly alter the pore structure of cement and cement-lime mortars. The fibers exhibited a tendency to preserve a greater proportion of small pores, which were comparable in volume to the pores present prior to the addition of the fibers as seen in figure 18a and b. The addition of jute fibers in cement mortars with APA admixture resulted in a 54% increase in the presence of pores with tiny diameters ranging from 0.01 to 1 μm in Figure.18c. Whereas sisal fibers exerted distinct effects on the porosity structure of mortars. Pore size modification was seen in cement mortar C, as depicted in Figure 18c. Particularly, there was a reduction in the small pores, while the number of pores with larger diameters ranging from 1 to 100 m exhibited an 80% rise. The incorporation of sisal fibers in CL mortars resulted in a significant 77.6% increase in the number of pores exhibiting a smaller in size range of 0.1 - 1 μm.

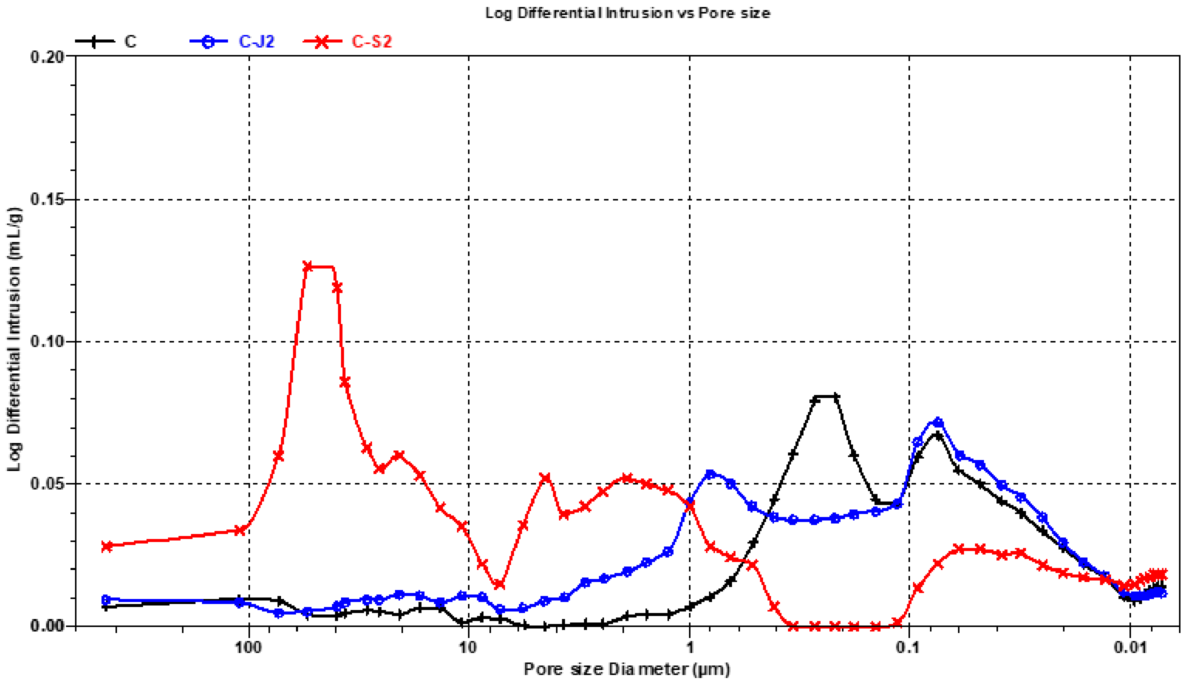


Figure 18a. MIP analyzes of cement mortar with fibers

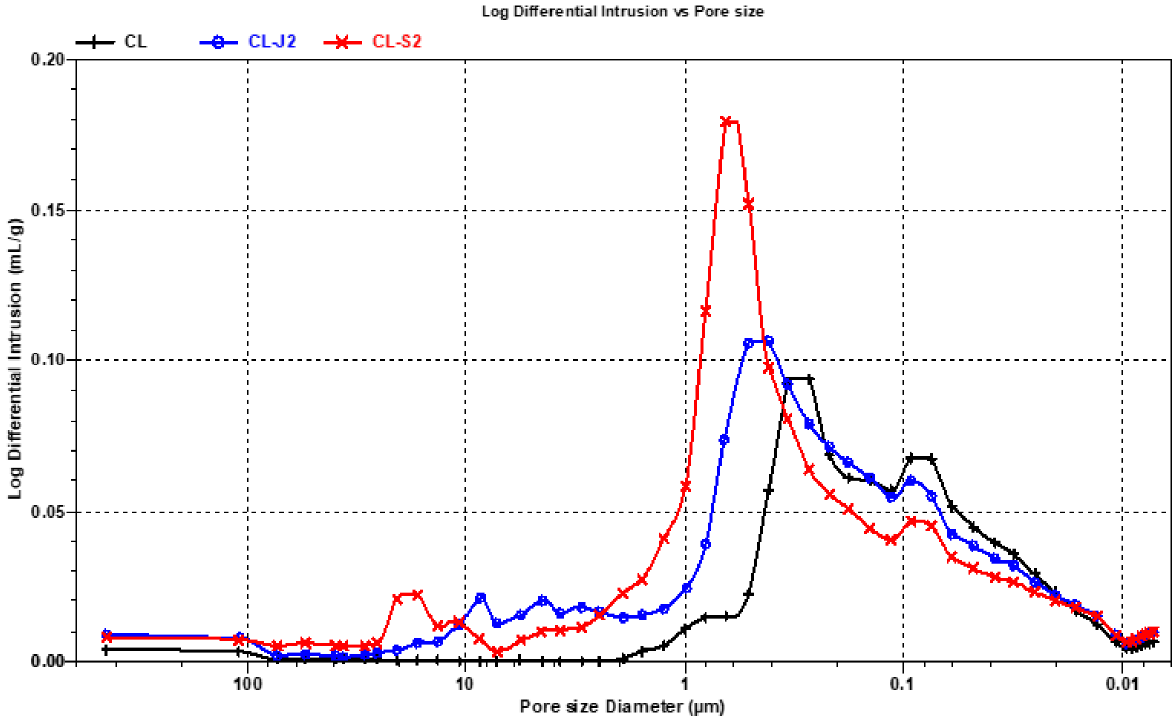


Figure 18b. MIP analyzes of cement-lime mortar with fibers

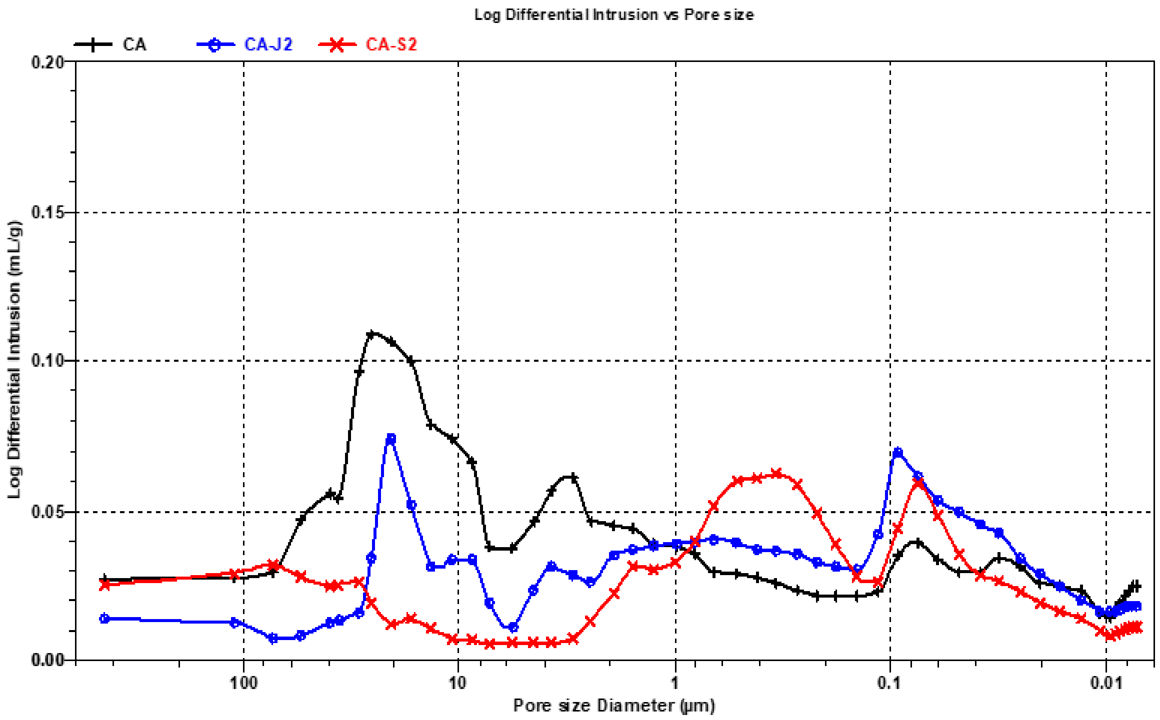


Figure 18c. MIP analyzes of APA cement mortar with fibers

Figure 18b is depicted in the given text. The same phenomenon was observed in mortars with an APA admixture, with larger pores, measuring between 0.05 and 5 µm, representing 52.8% of the overall composition seen in Figure 18c. The determination of binders and additives can be simplified by analyzing physical property parameters, such as density and porosity, together with microstructure parameters, such as surface area, median pore diameter, and tortuosity. The measured volumetric bulk densities vary between 1.3 and 2.0 g/cm^3, depending on the specific type of additives used. The incorporation of APA and fibers leads to the decrease in density. The open porosity, exhibits lower values in the case of C and CL mortars, while additives result in greater values ranging from 22.4% to 28.6%. The porosity values of the reference mortars were determined to be 19.7% (CM), 18.7% (CL), and 25.1% (CA) after a curing period of 28 days. The inclusion of 2% jute fibers resulted in a respective increase in pore volume of 22.4% (C-J2), 24.7% (CL-J2), and 25.7% (CA-J2). The inclusion of 2% sisal fibers resulted in a significant increase in porosity, with values of 28.6% (C-S2), 26.8% (CL-S2), and 24.5% (CA-S2), respectively. The determination of average pore radii in mortars is influenced by the presence of additives, which corresponds to the ranges of dominating pore diameters. The incorporation of APA and sisal fibers yields a higher value of pore, specifically 6.56 m and 16.55 m, respectively. However, the remaining cases have measurements ranging from 0.15 to 0.62 m. Sisal fibers, has greater effects on the surfaces of pores within the range of 4.3 - 6.6 m^2 /g. This influence appears as a decrease in surface area, mainly due to the development of pores with larger diameters. The presence of additives has an influence on the tortuosity of pores. Specifically, when APA or fibers are utilized, the effect is minimal below figure 18 c. However, the impact becomes significantly greater when considering the total surface values of the pores. Notably, the pore total surface value remains similar regardless of the specific additive utilized.

Table 11. Results on Mercury Intrusion Porosimetry of the reference mortars

No	Tested parameter	Unit	C mortar	CL mortar	CA mortar
1	Volume of mercury intrusion	ml/g	0.0982	0.0933	0.1936
2	Total surface area	m^2/g	6.040	5.094	5.913
3	Volumetric mediane of pore diameter	µm	0.16	0.15	6.56
4	Surface mediane of pore diameter	µm	0.03	0.04	0.02
5	Average diameter according to the cylindrical model	µm	0.07	0.07	0.13
6	Bulk density	g/ml	2.00	1.90	1.30
7	Real density	g/ml	2.49	2.46	1.73
8	Open porosity	%	19.67	18.69	25.11
9	Permeability	mdarcy	0.011	0.010	139.6
10	Tortuosity	-	563.5	385.7	9.5

Table 12. Pore size distribution of reference samples

Tested parameter	Unit	C mortar	CL mortar	CA mortar
> 90 µm	%	1.59	0.20	2.68
60-90 µm	%	1.38	0.29	9.09
30-60 µm	%	0.95	0.13	9.47
20-30 µm	%	1.41	0.08	13.41
10-20 µm	%	2.19	1.52	24.91
1-10 µm	%	4.57	4.63	5.03
0.5-1 µm	%	16.92	24.67	4.10
0.25-0.5 µm	%	23.45	25.94	4.37
0.1-0.25 µm	%	18.85	20.00	5.79
0.05-0.1 µm	%	12.90	12.06	4.83
0.025-0.05 µm	%	8.78	7.22	5.02
0.01-0.025 µm	%	1.47	0.59	1.36
< 0.01 µm	%	100	100.00	100.00
Total sum	%	100	100.00	100.00

Table 13. Results on MIP measurements of the mortars with sisal fibers

No	Tested parameter	Unit	C-S2 mortar	CL-S2 mortar	CA-S2 mortar
1	Volume of mercury intrusion	ml/g	0.1649	0.1472	0.1312
2	Total surface area	m^2/g	4.312	4.803	4.729
3	Volumetric mediane of pore diameter	µm	16.55	0.51	0.53
4	Surface mediane of pore diameter	µm	0.02	0.03	0.03
5	Average diameter according to the cylindrical model	µm	0.15	0.12	0.11
6	Bulk density	g/ml	1.74	1.82	1.87
7	Real density	g/ml	2.44	2.49	2.47
8	Open porosity	%	28.65	26.86	24.49
9	Permeability	mdarcy	538.8	20.1	41.1
10	Tortuosity	-	5.6	12.8	17.2

Table 14. Pore size of sisal samples with fibers additives

Tested parameter	Unit	C-S2	CL-S2	CA-S2
> 90 µm	%	13.02	3.64	14.16
60-90 µm	%	6.46	0.63	4.21
30-60 µm	%	21.32	1.14	6.14
20-30 µm	%	5.84	0.76	2.41
10-20 µm	%	8.71	3.77	2.33
1-10 µm	%	24.53	11.84	11.05
0.5-1 µm	%	4.89	28.93	10.92
0.25-0.5 µm	%	0.81	17.32	13.99
0.1-0.25 µm	%	0.00	12.67	10.66
0.05-0.1 µm	%	4.23	8.54	11.70
0.025-0.05 µm	%	4.54	5.53	6.48
0.01-0.025 µm	%	4.19	4.61	4.96
< 0,01 µm	%	1.46	0.63	0.99
Total sum	%	100.00	100.00	100.00

Table 15. Results on MIP measurements of the mortars with jute fibers

No	Tested parameter	Unit	C-J2 mortar	CL-J2 mortar	CA-J2 mortar
1	Volume of mercury intrusion	ml/g	0.1163	0.1324	0.1439
2	Total surface area	m^2/g	6.328	5.270	6.653
3	Volumetric mediane of pore diameter	μm	0.21	0.31	0.62
4	Surface mediane of pore diameter	μm	0.03	0.03	0.02
5	Average diameter	μm	0.07	0.10	0.09
6	Bulk density	g/ml	1.93	1.87	1.79
7	Real density	g/ml	2.48	2.48	2.41
8	Open porosity	%	22.40	24.73	25.74
9	Permeability	mdarcy	43.2	4.1	48.4
10	Tortuosity	-	9.6	28.9	11.2

Table 16. Pore size distribution of jute fibers in mortar

Tested parameter	Unit	C-J2	CL-J2	CA-J2
> 90 μm	%	2.28	1.79	1.07
60-90 μm	%	0.74	0.40	0.16
30-60 μm	%	2.56	0.78	0.22
20-30 μm	%	2.01	0.54	0.10
10-20 μm	%	2.18	1.98	0.29
1-10 μm	%	8.88	7.60	10.96
0.5-1 μm	%	12.43	8.88	33.15
0.25-0.5 μm	%	13.99	11.86	14.50
0.1-0.25 μm	%	13.46	16.37	14.68
0.05-0.1 μm	%	23.17	28.26	14.88
0.025-0.05 μm	%	11.51	13.85	7.43
0.01-0.025 μm	%	5.82	6.63	2.28
< 0,01 μm	%	0.97	1.06	0.29
Total sum	%	100.00	100.00	100.00

8.7. Relationship between flexural strength vs compressive strength of samples with all the fiber additives

Main attention was focused on the relationships of mechanical properties the current study attempted to determine the relationship between the flexural strength and compressive strength of fiber-reinforced mortar composite after 90 days of age. The flexural strength of mortar composite was found to be closely associated with its compressive strength. Figure 19 depicts a power relationship in the line of best fit. The correlation coefficient (r) is greater than 0.9, indicating an outstanding association. Because both qualities were improved with a reduced fiber volume content, a strong link between flexural strength and compressive strength of fiber-reinforced mortar composite was established. It's interesting to observe that while individual strength properties in samples containing APA (air-entraining plasticizer) may appear to have lower values, there seems to be a stronger correlation between the various material properties. This suggests that the influence of APA on the overall performance of the materials may not be solely reflected in individual strength measurements. This phenomenon is not uncommon in materials science. Sometimes, additives or components can have complex interactions that lead to improved overall performance, even if individual properties appear to be less favorable. In the case of APA, it might be enhancing the materials in ways that contribute to their overall durability, resilience, or other important characteristics. This underscores the importance of considering a holistic approach to evaluating material performance, taking into account not only individual properties but also how they interact and complement each other in practical applications. Correlation analysis can provide valuable insights into these complex relationships and help guide material design and selection.

With the regression value it can be clearly see that the higher amount of fiber effects both compressive and flexural strength in both independently and vice-versa.

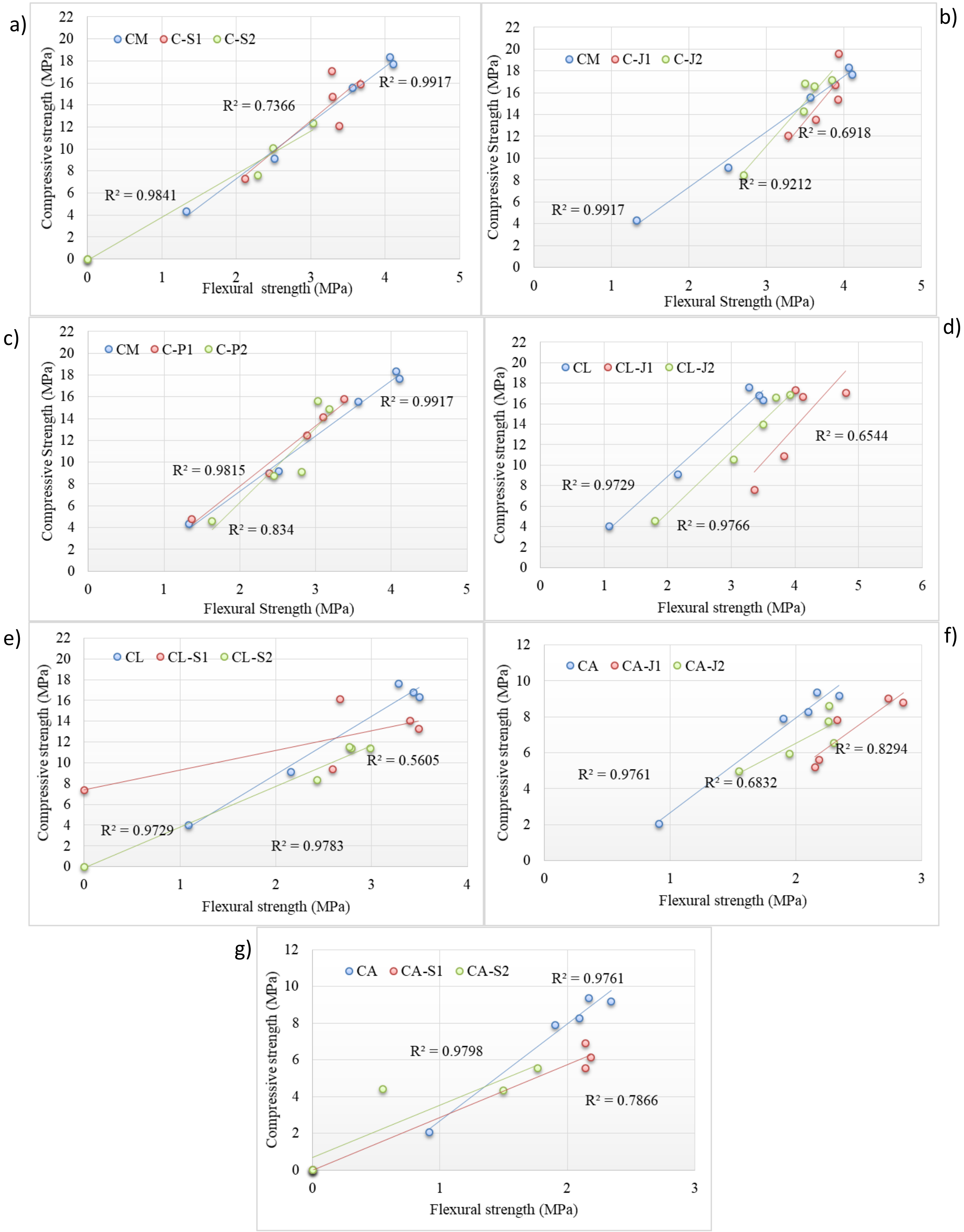
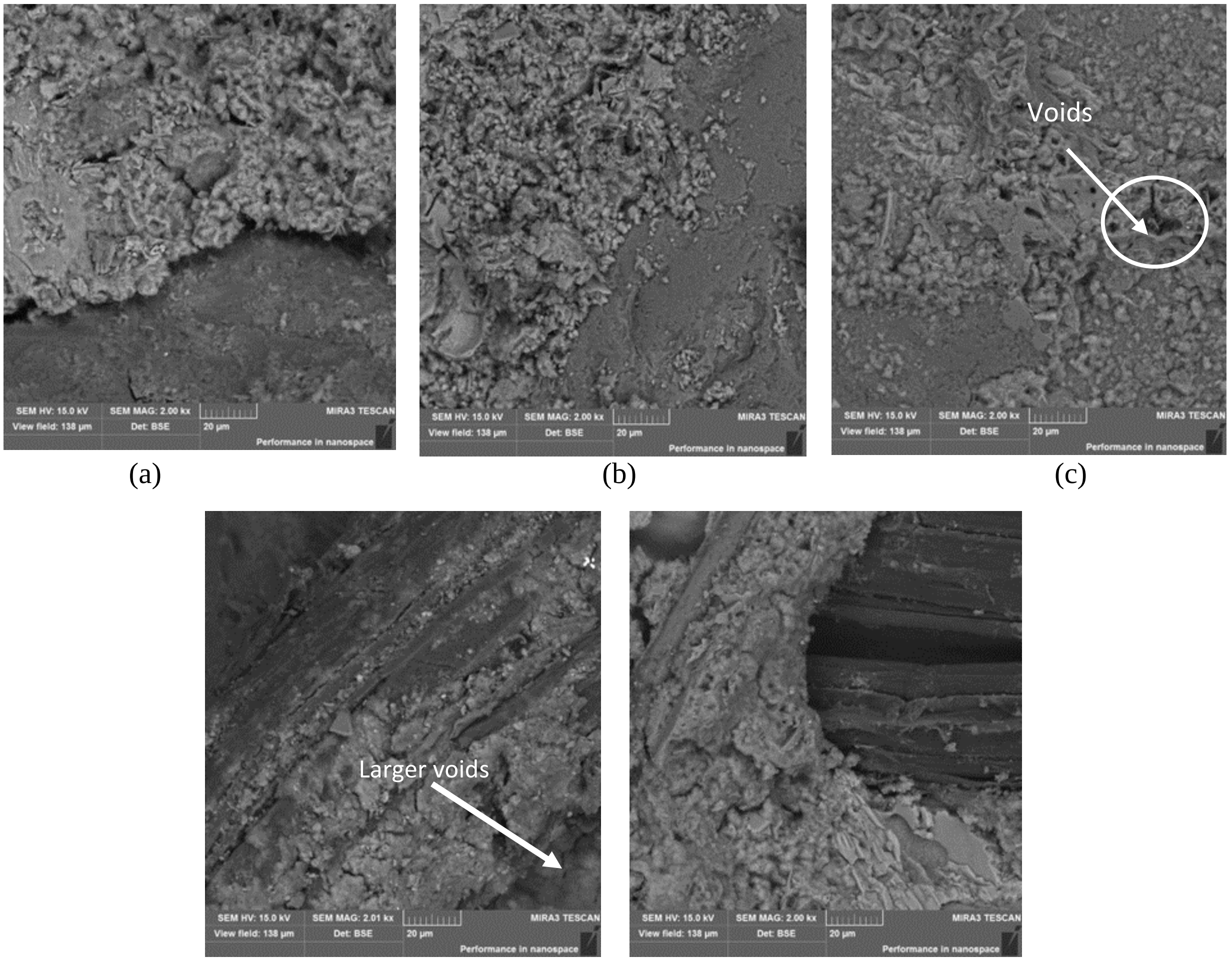


Figure 19. Relationship between strength a) CM with sisal, b) CM with jute and c) CM with polypropylene d) CL with jute e) CL with sisal, f) CA with jute and, g) CA with sisal

8.8. Results on surface morphology analyzes with fibers

Optical microscopy is used to examine the morphologies of the mortars. Mortars are cured for 28 days before being used. Following the mixing and extrusion processes, samples were observed.The microstructure after the mixer and curing for 2% cement fibre concentration is depicted in Figure 20. The matrix fibre distribution appears random. The figure 20 shows the microstructure of all the reference samples CM, CL and CA mortars. It is noted that even after 28days of hydration period the number of voids is higher in cement mortar sample compare to lime-cement mortar. The amount of cracks and larger voids are present in APA cement samples which somewhere leads to poorer mechanical properties.



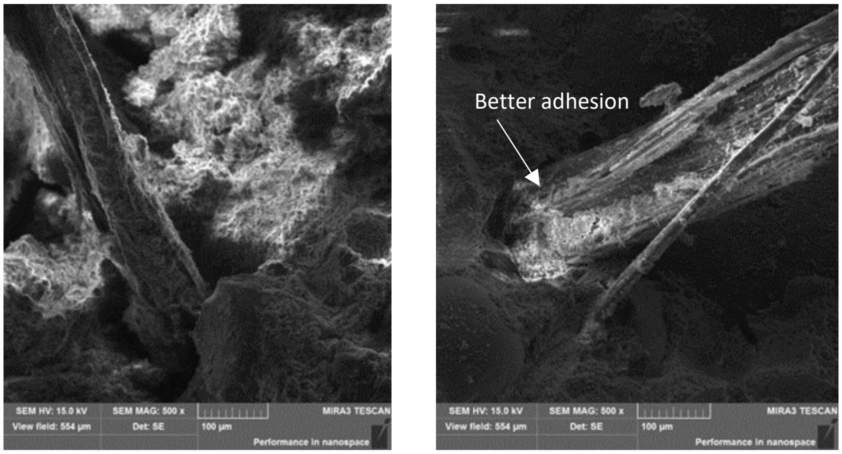
(a) (b) (c)

(d) (e)

Figure 20. SEM micrographs of the fracture surface of after 28 days hydration: (a) cement-sand mortar, (b) cement-lime mortar, (c) cement -sand mortar with APA, (d) cement-sand mortar with 2% sisal fiber, and (e) cement-sand mortar with 2% jute fiber

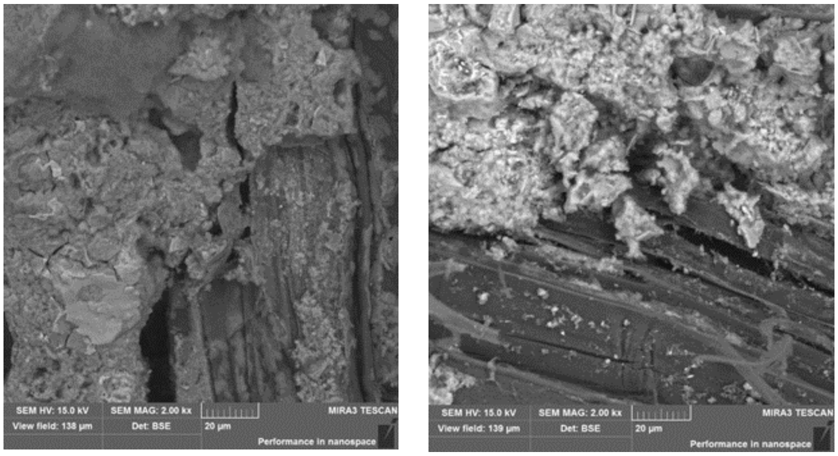
The matrix with the fiber concentration of 2% by weight of cement is also shown in Figure 20d and e. Another case of fiber concentration of 2% by weight of Lime-cement can be also seen in Figure. 20f and g and with APA cement sample in Figure h and i

When comparing the cement-sand mortar sample to the cement-lime sample Figure f and g, it has lesser presence of cracks and voids, along with a smoother and more uniform surface which contributes to enhanced bonding and material properties. The results obtained from the APA cement-mortar were found to be comparable, as shown in Figure 20c. However, the results regarding shrinkage indicate that cement-lime mortar samples exhibit an increased number of micro fractures, as confirmed by an observed increase in shrinkage magnitude. The APA reference sample, as depicted in Figure 20c, displays significant voids, with the size of cracks and air spaces in the mixture increasing as APA is introduced to enhance the flexibility of the mixture. The incorporation of jute fibres into cement-sand mortar Figure 20e and cement-lime mortar Figure 20g does not lead to any notable alteration in the microstructure surrounding the fibres. The adhesion between the fibres and the cement matrix exhibits a high level of strength, resulting in a reduced presence of cracks and voids within the samples. This characteristic leads to an efficient improvement in overall strength. The inclusion of fibre constituents, such as cellulose, hemicellulose, and lignin, plays a crucial role in enhancing interfacial adhesion due to their ability to facilitate water absorption and hinder adhesion with the cement matrix. It is advisable to eliminate non-cellulosic constituents from the surface of the fibre in order to enhance interfacial adhesion. The utilization of alkaline treatment is prevalent in the treatment of plant fibre composites primarily because of its cost-effectiveness [81]-[83]. In order to enhance the interfacial adhesion between fibres and matrix the utilization of coupling agents and compatibilizers is suggested. Researchers improve composite mechanical properties by modifying the materials with surface treatment which is important to avoid huge absorption of water with ultimately decreases the mechanical strength of composites [16].



(f) (g)

Figure 20 (f and g). SEM micrographs of the f) cement- lime mortar with 2% sisal fiber, (g) cement-lime mortar with 2% jute fiber,



(h) (i)

Figure 20 (h and i). SEM micrographs of the (h) APA cement mortar with 2% sisal fiber, (i) and APA cement mortar with 2% jute fiber

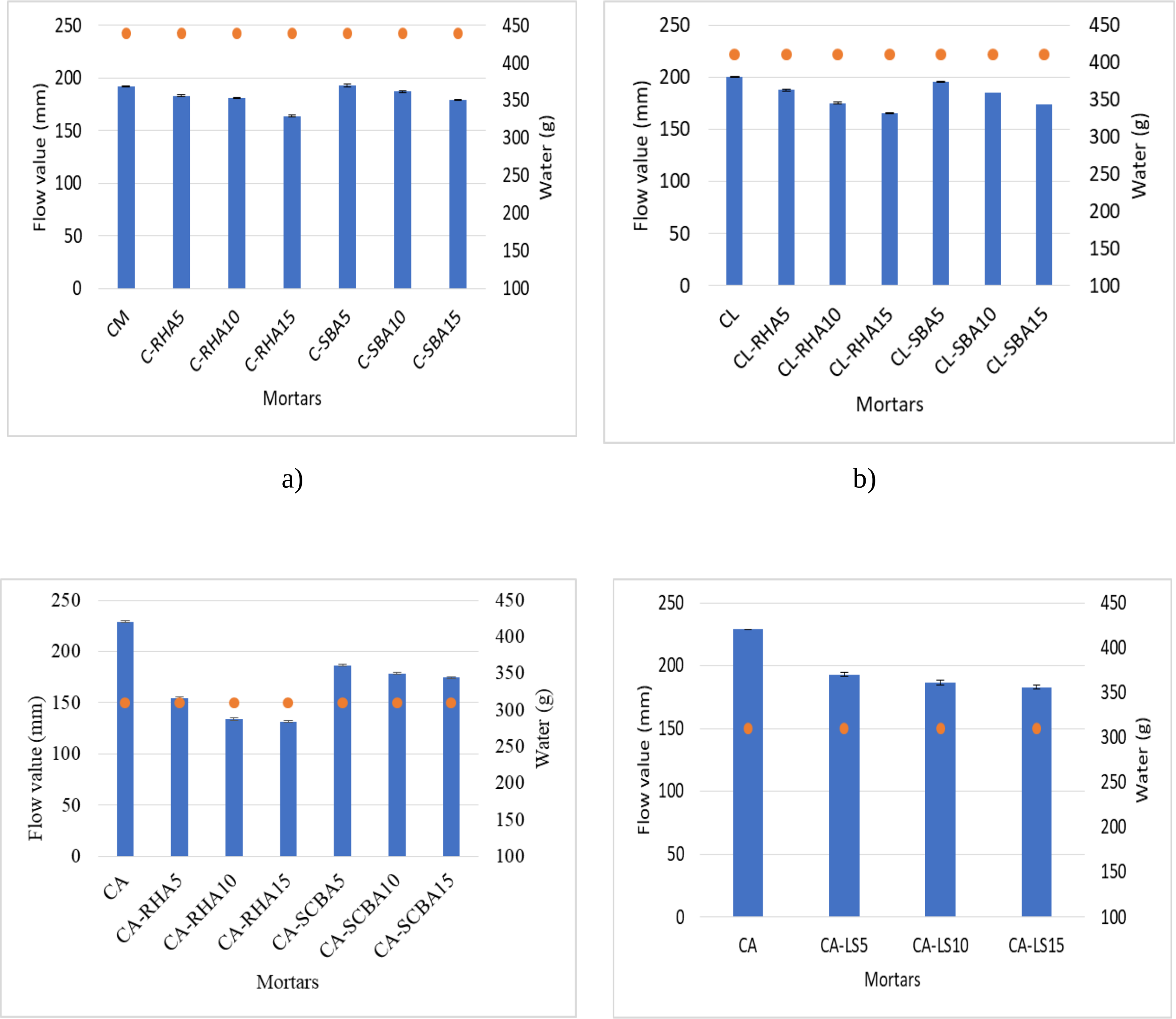
The jute sample treated with APA exhibits varying outcomes, as the fibers seem to be displaced from the surface due to an augmentation in gaseous pores induced by the presence of APA (see Figure 20i. The inclusion of sisal fibers in mortars results in the fibers acting as plasticizers, hence enhancing the porosity and water absorption characteristics of the mixtures. This effect is observed in both cement-sand mortar Figure 20d and cement-lime mortar Figure 20f, with the latter exhibiting a more pronounced influence. As a result, it can be shown that both the APA and sisal fiber samples show a reduced adhesive connection between the fibers and the cement matrix, leading to a reduction in overall strength as explained in the reasons listed above in Figure 20h

CHAPTER 9

RESULTS OF RESEARCH INTO SCM EFFECT ON MORTAR PROPERTIES

9.1. Consistency analysis of mortar with SCM

The consistency of mortar with all the ashes as a replacement of cement of conducted similar to the above mentioned methods. The result of standard consistency tests for the additive binders with sugarcane bagasse ash, rice husk and limestone powder at variable percentage replacement levels is shown in below Figures 21. According to the results of flow table the consistency is decreasing with addition of biomass ashes. Figure 21a illustrates the impact of biomass addition on cement mortar, with emphasis on the percentage amounts. The data shows that the flow ability of mortar decreases when rice husk ash is added. This can be attributed to the higher specific gravity of rice husk ash compared to plain cement. Additionally, as the percentage replacement level increases, the water requirement also increases. With the increase in percentage of replacement the water demand increase to 10% for replacement of rice husk ash (RHA) 15% to cement. However if we look to the consistency values of sugarcane bagasse ash (SCBA) there is no changes in consistency compare to reference sample with 5% and 10% addition, with 15% addition there is slight decrease in consistency and the amount of water demand increase to 8%. The sugarcane bagasse ash fineness is greater than rice husk ash as we can see in specific gravity values of ashes which is the reason of less water demand in mixture. The similar results can be seen with the lime sample there is no specific changes in the values of flow in cement-lime samples with all additives. There is constant decrease in consistency with percentage increase in lime sample with rice husk ash and its sample with bagasse ash. The sample with APA solution the consistency of flow is higher which shows the huge water absorption in reference CA samples, however addition of biomass ash to the APA cement mortar sample decrease the flow rate and make the sample to control the higher liquidity. Addition of rice husk ash to mix decreases the water demand up to 40% due to higher specific gravity were in case of bagasse ash the water demand decreases to 23% with higher percentage. The addition of limestone powder as a replacement of cement with the same percentage as other natural ash was done only with cement and APA cement mortar. The consistency is done both with flow table and plunger methods the results with both reference sample are shown in below, with the figure it is clear that the addition of limestone to cement mortar.



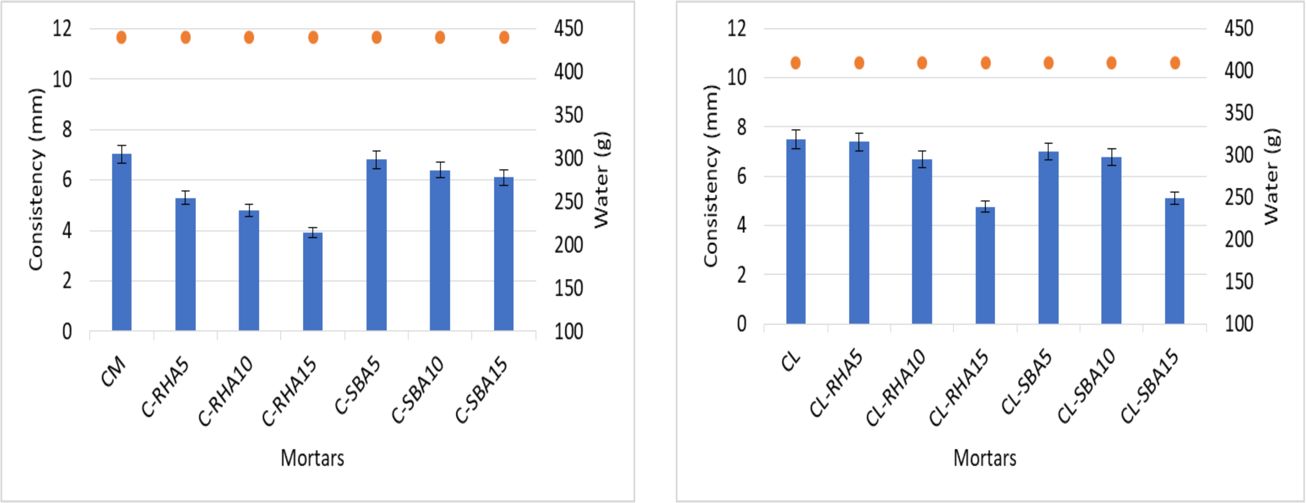
a) b)

c) d)

Figure 21. Flow table analysis of a) cement mortar with RHA and SCBA, b) cement-lime mortar with RHA and SCBA, c) APA cement mortar with RHA and SCBA and d) APA cement mortar with LS

The consistency value with penetration plunger is shown in figure 22, according to it can be clear that addition of ashes increases the water demand of mortar samples as the amount of ashes is maximum the consistency values decreases, similar result can be seen with all ashes in consistency researched in both method there is no specific changes in values with ashes addition which is different from the results of consistency in fibers samples. The samples with RHA shows lower consistency compare to all reference and other additive samples the reason is due to higher specific area of RHA compare to bagasse and limestone powder with increase the water requirement. The consistency values for samples C-RHA5, C-RHA10, and C-RHA15 are 28%, 35%, and 44% lower, respectively, when compared to the reference cement mortar. This indicates a reduction in consistency with the addition of RHA. Furthermore, the incorporation of SCBA leads to a decrease in consistency, with a more substantial drop observed in sample C-SCBA15, where the consistency decreases by 15% with a maximum addition of up to 15%. This information highlights the impact of these ash additives on the consistency of the cement mortar.

In the case of cement-lime mortar, the addition of the maximum amount of biomass ashes results in a significant decrease in consistency values. Both CL-RHA15 and CL-SCBA15 experience a considerable reduction in consistency, with values dropping to 36%and 34% respectively. This decrease indicates that the inclusion of the maximum allowable amount of these biomass ashes leads to a substantial change in the consistency of the cement-lime mortar.



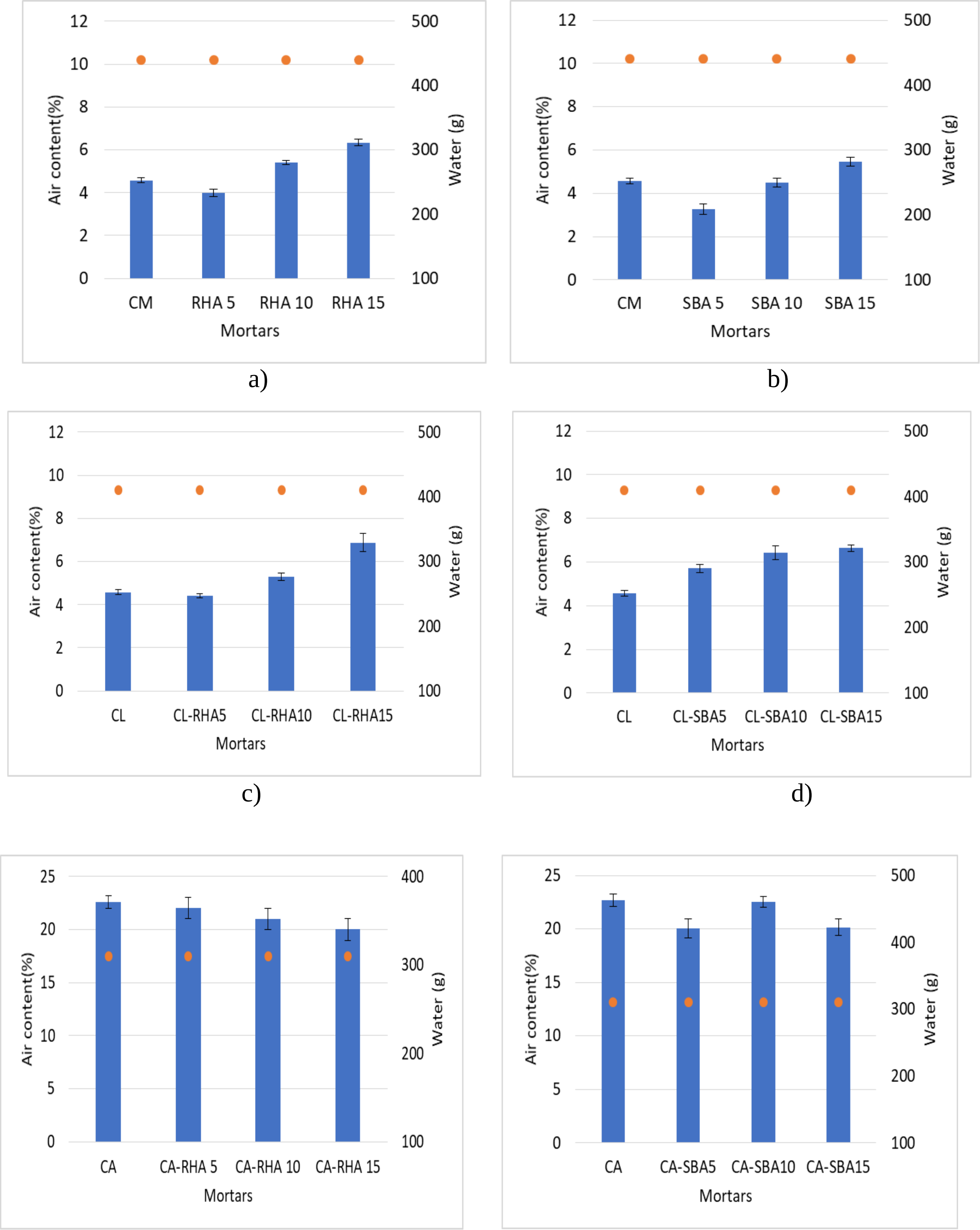
a) b)

Figure 22. Penetrometer values of a) cement mortar and b) cement-lime mortar with SCBA and RHA

9.2. Air content analysis in mixes with ashes

Increasing the amount of ashes in the mixture decreases air content, while increasing the amount of middle-size fractions of aggregates increases the air content. Sand grain size also affects air content by preventing air bubbles from escaping or aggregating into larger, more likely-to-break bubbles. The best void size for retaining bubbles is sand with the right amount of middle-size. Therefore increases in air content depends on many factors one of them are longer handling process can also infuse the air in mixture [75].

As presented in figure 23b, the SCBA reduces the air contents of in plain cement mixtures by 22 % and 5 % for the mix C-SBA5 and C-SBA10 respectively however increasing the amount of SBA up to 15% leads to increases in air content to 22% compared to reference sample. The decrease in the air content percentage resulted in improved workability, strength, and durability of the mortar what was discussed in above chapter. The air content in cement-lime mortar is similar to plain cement mortar with addition of SCBA the air content increases in all stages with 22%, 36% and 40% for the mixes CL-SCBA5, CL-SCBA10, and CL-SCBA15 respectively the increase in air content might be due to carbonization of SCBA [174]. As mentioned above, aggregate size and fineness also influence the amount of air in mixture which can be seen in samples with RHA. The addition of rice husk in cement mortar increases the air to 22% and 37% for mixes C-RHA10 and C-RHA15 respectively and it is noted that the specific area of RHA is higher than any other binder which leads to infuse of air in mortar. The amount of air content in mix C-RHA5 is 11% compare to reference cement sample it might be due to good bond between mixture and lower percentage of addition do not shows great affects in sample. Similar results can be seen in cement-lime mortar the addition of higher percentage of RHA in mixes CL-RHA10 and CL-RHA15 increases the air content to 13% and 44% respectively compare to reference cement-lime mortar



a) b) c) d) e) f)

Figure 23. Air content values of a) cement mortar with RHA, b) cement mortar with SCBA, c) cement-lime with RHA, d) cement-lime with SCBA e) APA cement mortar with RHA and f) APA cement with SCBA.

Mortars containing mixed cements CA-RHA and CA-SBA and an air plasticizing admixture have a higher air content than other mortars containing additives; however, when natural biomass ashes are added, the amount of air content decreases to 10% and 13%, respectively, when compared to reference APA cement samples. The workability of fresh mortar is significantly improved due to the production of a large number of micro-air bubbles as a result of the addition of high-quality APA admixture; however, its bleeding and segregating capacity are reduced, and the cohesiveness and homogeneity of mortar are reduced.

9.3. Compressive strength of mortar samples with ashes

Several studies have been carried out related to the utilization of by-products as supplementary cementitious materials (SCMs), with an emphasis on assessing their mechanical qualities for their suitability as SCMs. The impact of rice husk ash (RHA) on the compressive strength of mortar exhibited a consistent pattern across all observed cases. The data is depicted in Figure 24. As the rate of replacement increased there was an associated decrease in strength. The strength development observed in the control between 7, 28 and 56 days was relatively similar to the strength development observed in each of the trial mix designs, regardless of their RHA replacement percentages. However, a review of the above data shows that including a higher amount of RHA in place of OPC results in decreased strength development. There is slightly decrease in strength after 90days can be seen in control sample, however addition of low percentage of RHA increases the compressive strength to 20% then reference sample. The sample C-RHA5 shows decreases in strength at 28days although the strength increases afterward up to 3% and 20% at 56 days and 90day respectively. The sample C-RHA10 with addition of ash 10% shows greater in strength then reference sample the strength increases to 16% at 28days and 2% at 56days there in decrease in strength to 3% at 90days and the reason might be water absorption. The incorporation of a higher percentage of Rice Husk Ash (C-RHA15) in cement results in a reduction in strength, with decreases of 31%, 30%, and 27% seen at 28 days, 56 days, and 90 days, respectively. The main factor contributing to the overall reduction in strength is likely the decrease in the amount of $Ca(OH)_2$, which serves as the reactive component in cement. When adding a pozzolanic substance such as RHA into a mixture composition, it reacts with the surplus $Ca(OH)_2$ that remains after the hydration process of the cement. This phenomenon results in the formation of a greater quantity of calcium-silicate-hydrate (C-S-H) gel, which plays a substantial role in enhancing the mechanical properties of concrete. When the cement content is decreased and the amount of pozzolan rises, there is a decrease in the availability of Ca $(OH)_2$ as a reactive component. Therefore, the residual amorphous silica mainly functions as an inert substance inside the mixture, thus having no role in the enhancement of strength. The compressive strength findings of the mortar using SCBA are illustrated in Figure 24b. The phenomenon of strength enhancement has been noted to exhibit a positive correlation with advancing age.. Although the strength of the SCBA-modified mortar was found to be lower than that of the control mix after 7 days, as seen with all C-SBA15 samples, the mortar with 10% SCBA showed increased strength at all stages. At 28, 56, and 90 days, the strength increased to 22, 21, and 10%, respectively. However, adding more SCBA results in a slight decrease in strength after 7 days to 3, 6, and 5% at 28, 56, and 90 days. It is also noted that when sugarcane bagasse ash is added to cement, the compressive strength is higher than when rice husk ash is added. With SCBA addition, the difference in strength is up to 10% higher. The replacement of limestone powder in cement has led to a notable increase in strength, with a significant improvement of 30% observed after 28 days. This indicates that the incorporation of limestone powder has a positive impact on the compressive strength of the cement mortar, which is an important finding for material development and construction applications [175].

The compressive strength of cement-lime mortar, in comparison to plain cement mortar, is diminished due to its higher porosity and increased water and air content. These factors contribute to a reduction in strength. Similar results can be seen with strength in lime mortar sample the strength decrease with 90days.with cement-lime mortar the proportion maintained is 1:1:6 and the addition of ashes is done with the cement replacement. Therefore reduce in compressive strength can be seen in cement-lime mortar compare to addition with plain cement mortar.

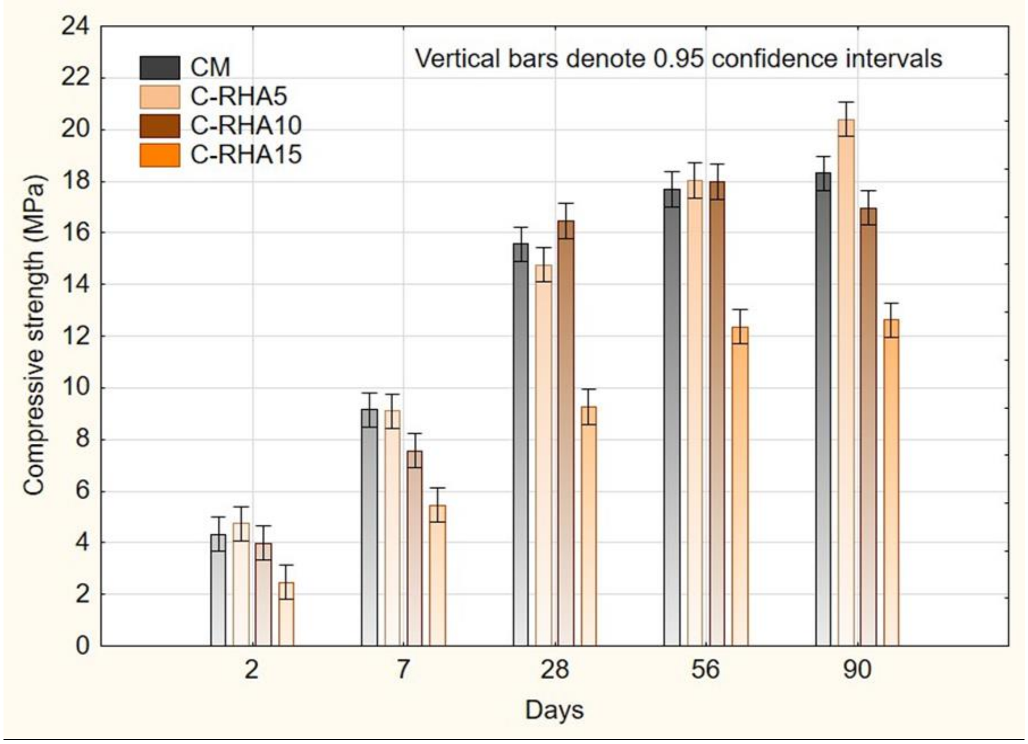


Figure 24a. Compressive strength of Cement mortar with RHA

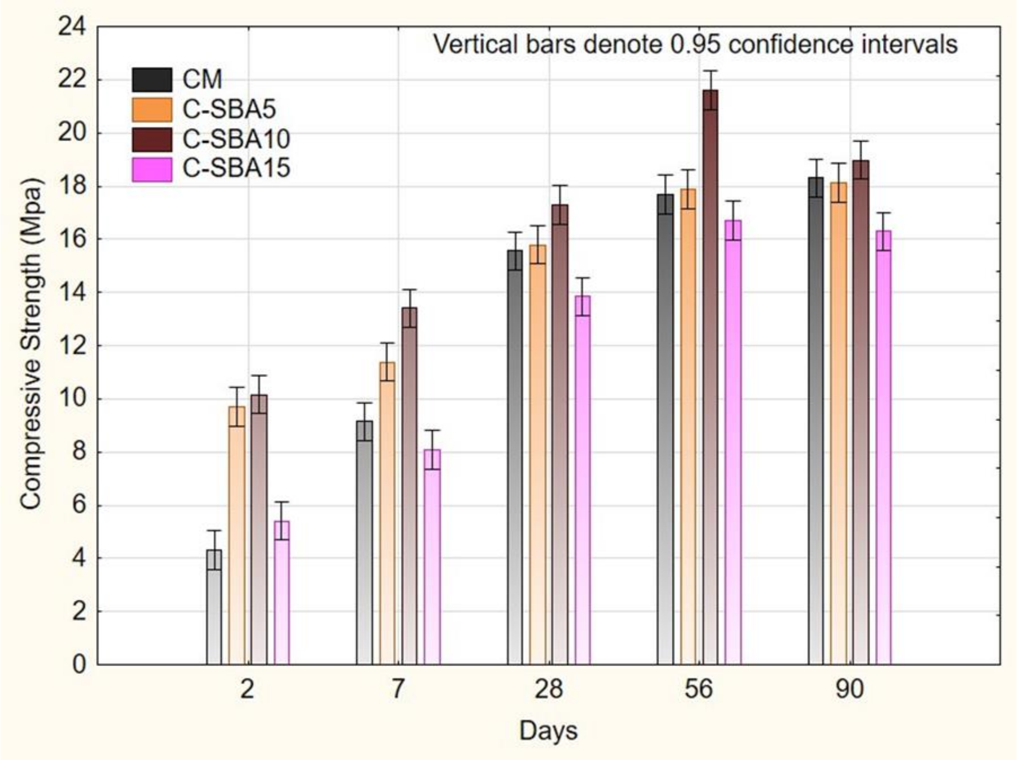


Figure 24b. Compressive strength of cement mortar with SCBA

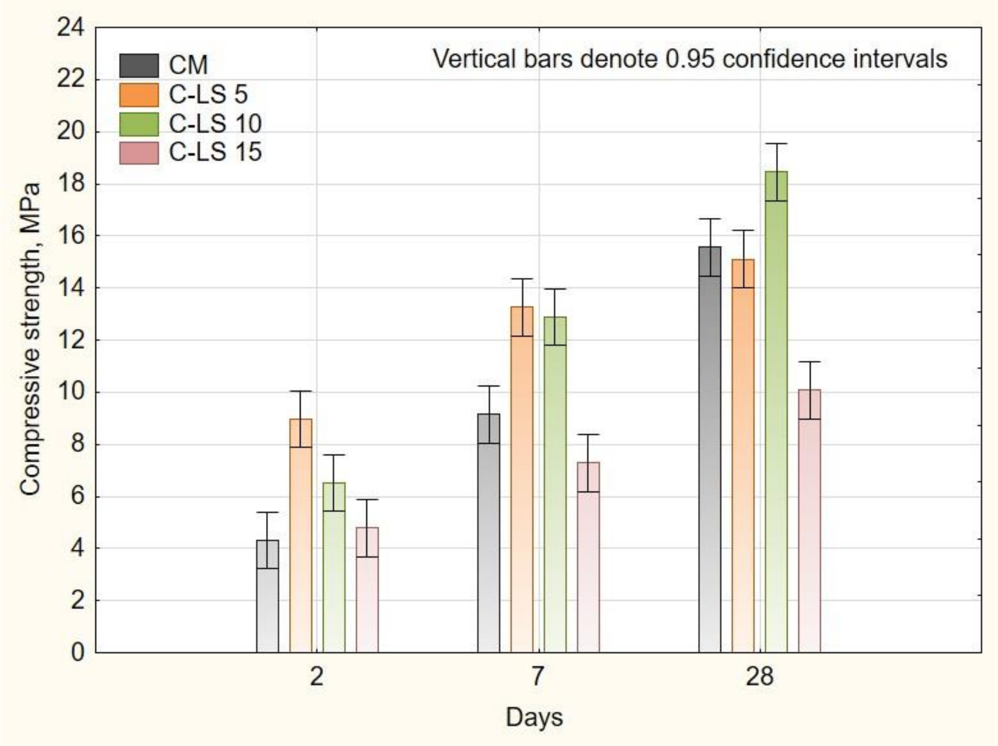


Figure 24c. Compressive strength of Cement mortar with LS

Addition of RHA in cement-lime mortar shows poorer in strength. With the lower amount 5 %(CL-RHA5) of RHA to cement-lime shows increase in strength to 2% and 10% at 56days and 90days. The sample CL-RHA10 shows gain in strength after 7day up to 12% and 5% for 28day and 56days respectively further the strength reduce to 9% at 90days. A comprehensive examination of the mentioned results reveals adverse effects on both the percentage of RHA substitution and the compressive strength. The results obtained in this investigation align with the conclusions drawn by additional researchers[81]and [176]. The previous investigators found in a prior investigation that the samples supplemented with different percentages of rice husk ash (RHA) demonstrated reduced initial strength when compared to the control sample. Nevertheless, after 56 days, additional compressive strength testing revealed that these specimens demonstrated improved strength development and, in some cases, surpassed the performance of a mixture comprising ordinary Portland cement (OPC). However addition of sugarcane bagasse ash shows better results in cement-lime mortar, addition with 5% and 10% shows increase in compressive strength with each days. In the case of cement-lime mortar, the compressive strength at 56 and 90 days exhibits variations for different samples. Sample CL-RHA5, with 2% replacement, records higher compressive strength, while sample CL-RHA10, with 10% replacement, exhibits lower strength. Notably, for sample CL-SBA5, which incorporates a 5% replacement, there is a significant increase in compressive strength, amounting to a 28% gain at 90 days. However, when the replacement level escalates to 15% in sample CL-SBA15, there's an initial increase in strength by 34% at 2 days, followed by a subsequent decline to 11%, 12%, and 2% at 7, 28, and 56 days, respectively, and so forth. These decreases in strength can be attributed to two primary factors. Firstly, the presence of high levels of unburned carbon in the ash may have a weakening effect. Secondly, the dilution of Portland cement due to the increased replacement ratio could also contribute to the observed reductions in compressive strength.

The compressive strength of APA samples are comparatively lower than any other samples with fibers as well as with ashes addition. The addition of APA in cement increase the air bubble formation in wet paste which leaves a huge number of voids in its hardened state. The incorporation of APA (Air-entraining Plasticizer Admixture) in mortar enhances its water absorption capacity. The principal objective of employing APA is to enhance the mortar's workability. However, it is crucial to acknowledge that the incorporation of APA into the mortar results in a substantial reduction in its strength properties.

Notably, the inclusion of APA and ashes additives in the samples yields noteworthy outcomes in terms of compressive strength. Specifically, the addition of 10% and 5% RHA (Rice Husk Ash) exhibits superior strength at 28 days, as observed in the CA-RHA10 sample. Furthermore, the strength of these samples remains consistent with that of the reference APA samples in subsequent days. The strength of sample CA-RHA5 exhibits a 10% rise, while sample CA-RHA10 demonstrates a 40% increase. The strength with higher addition is quite low at initial days the sample broke because of poor adhesion between matrixes. Moreover, the analysis of mean particle size distribution reveals an interesting trend. Mortar compositions with finer-grained SCBA (sugarcane bagasse ash) tend to display greater compressive strength compared to those containing coarser-grained RHA. For instance, at 28 days, there's a notable 12%, 5%, and 28% increase in compressive strength for samples CA-SBA5, CA-SBA10, and CA-SBA15, respectively. Remarkably, the sample incorporating a 10% replacement level stands out with an impressive 80% strength increase over the remaining test duration. This boost could be attributed to enhanced adhesion in the mix due to the utilization of sugarcane bagasse ash.

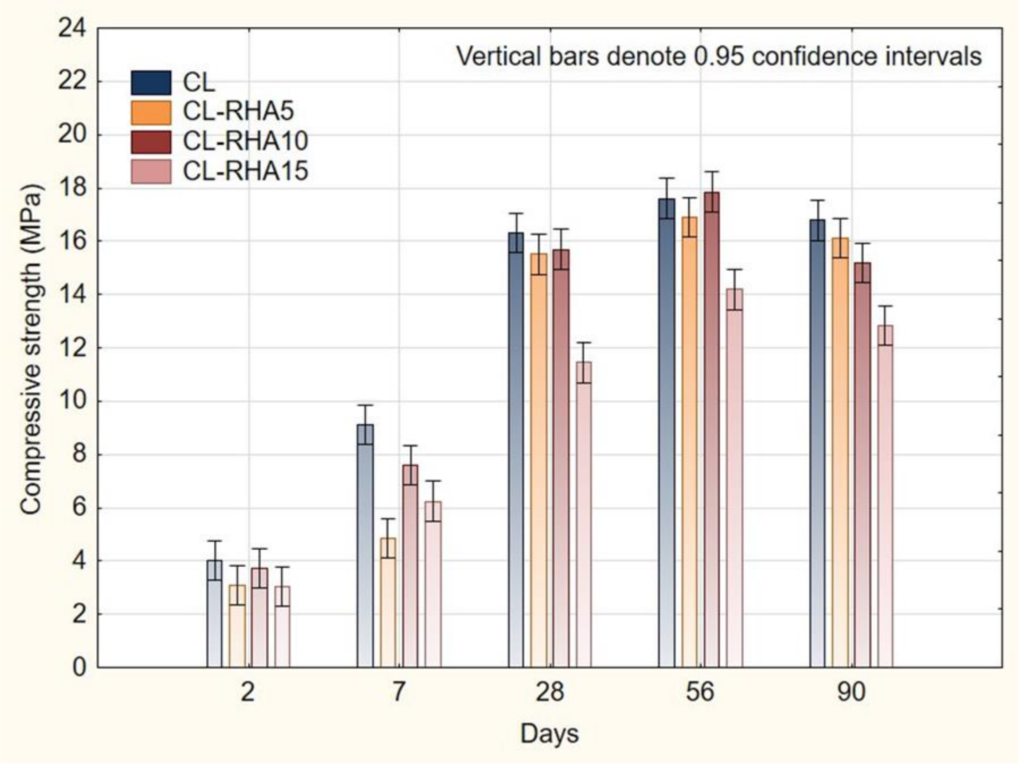


Figure 24 d. Compressive strength of cement-lime mortar with RHA

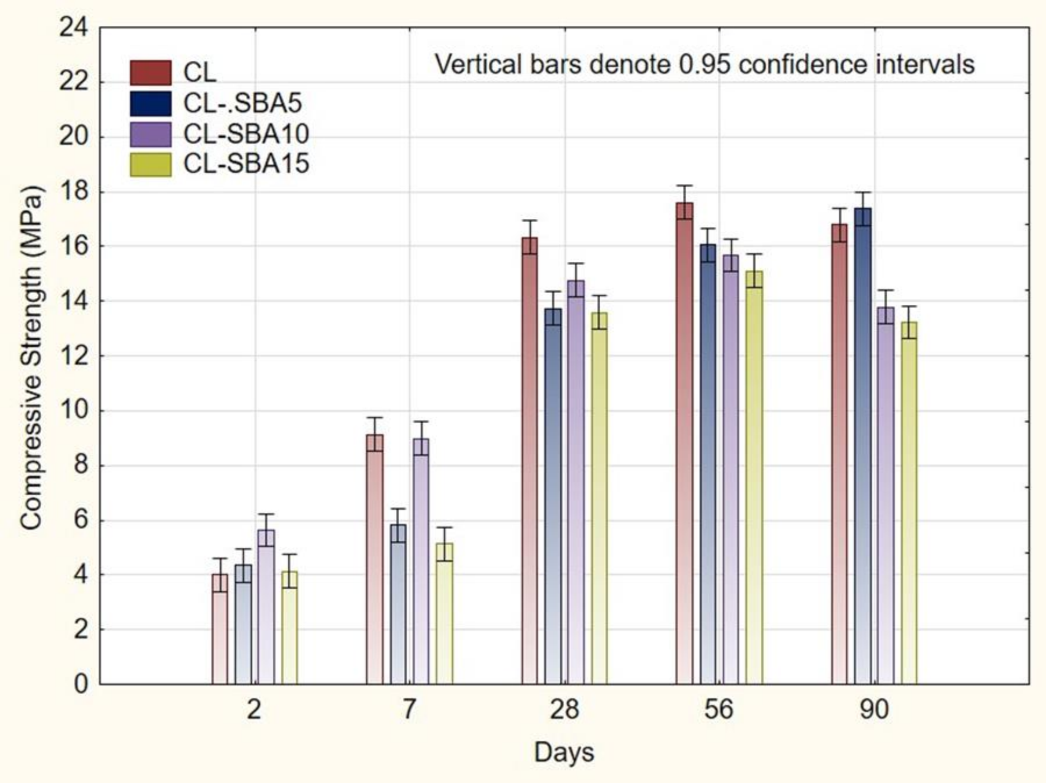


Figure 24e. Compressive strength of cement-lime mortar with SCBA

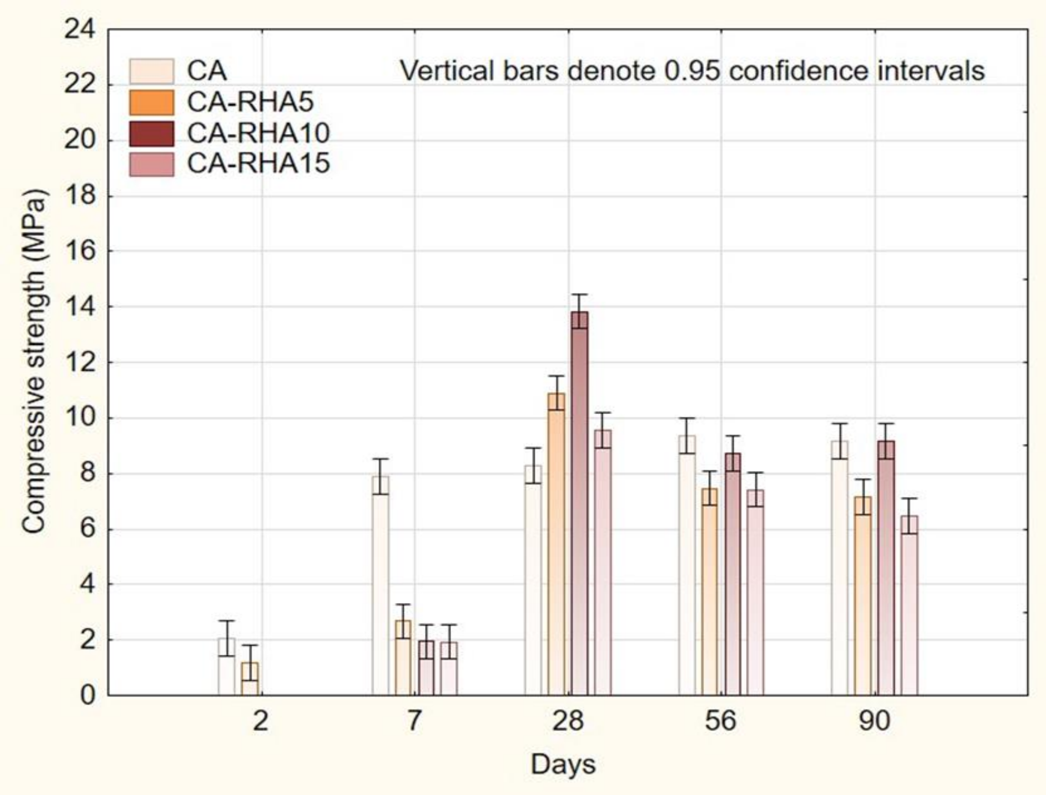


Figure 24f. Compressive strength of APA cement mortar with RHA

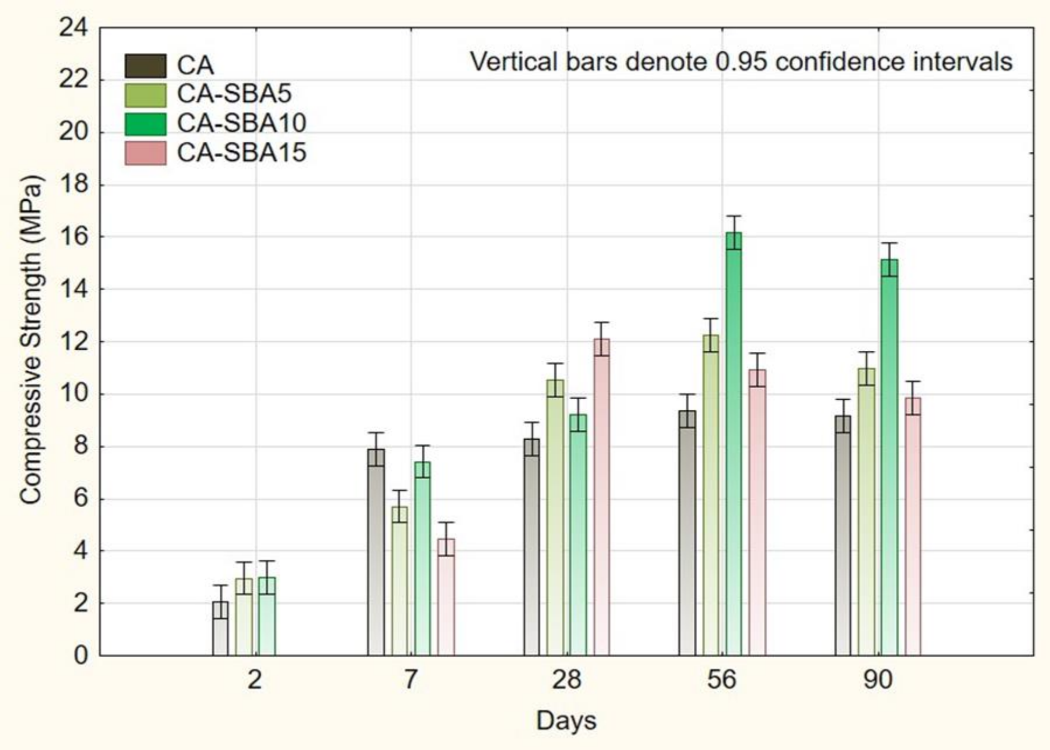


Figure 24g. Compressive strength of APA cement mortar with SCBA

9.4. Flexural strength of mortar samples with ashes

Figure 25 illustrates the flexural strength and pace of development of OPC mortar prepared using different quantities of RHA. The flexural strength of mortar containing fine RHA (RHA-5 and 10) at 56 days and 90days was higher than that of the sample containing (RHA-15) regardless of age. As a result, the RHA has a greater effect on flexural strength at younger ages than at older ages, such as 91 days. In general, RHA mortar flexural strength depends on time-dependent pozzolanic reactivity, cement hydration, and microstructure development. [177].Addition of RHA 10% shows increases in flexural strength up to 56days to 5% compare to control sample. Similar results can be seen According to [178], he analysis of tensile strength indicates that the acceptable threshold for replacing rice husk ash (RHA) is 10%. The composition of the RHA used in the study includes 85.49% silica, 3.02% loss on ignition, and 3.68% CaO, which is considered quite high for RHA. The sample with 10% RHA shows increase in flexural strength with sudden fall in 5% strength at 56days to increase in 5% at 90days compare to reference sample. Higher the amount of replacement effects the flexural strength with decrease in strength. The higher amount of amorphous silica content can be attributed to the better performance of RHA however with results 10% addition shows better results in strength compared to up to 15% replacement ratio. [82] Indicate a notable decrease in the strength of RHA mortar at replacement ratios of 10% and 15% in comparison to the OPC control. The observed variations in strength outcomes may generally be related to the particle size of RHA, which has a significant impact on its pore characteristics.

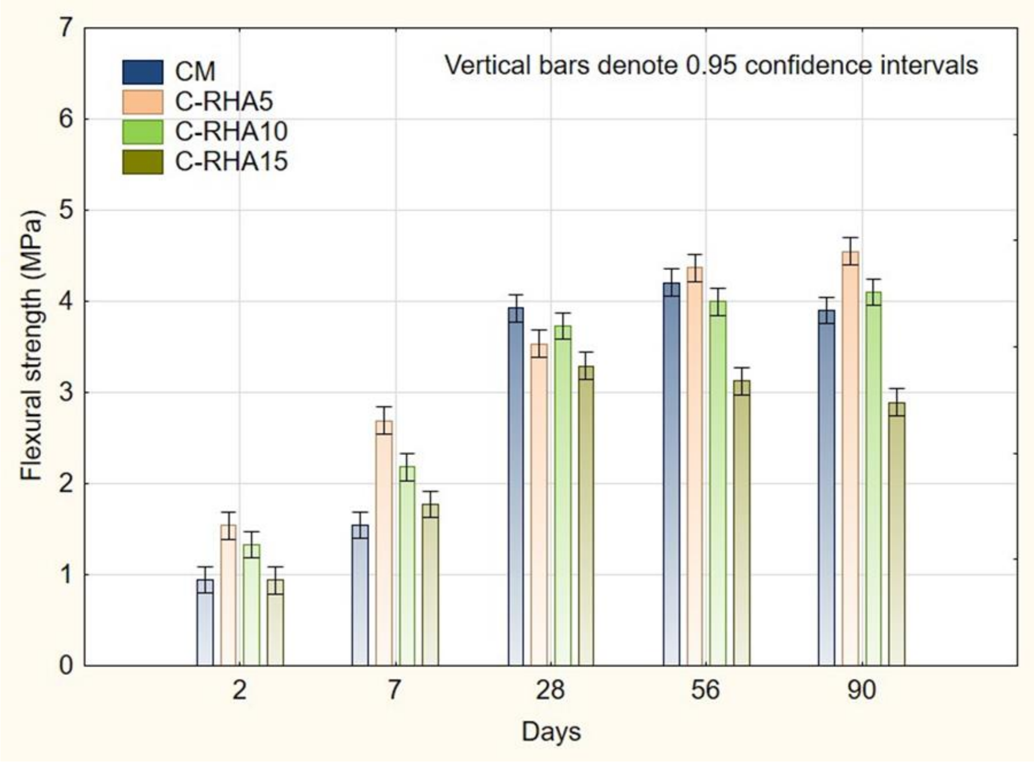


Figure 25a. Flexural strength of cement mortar with RHA

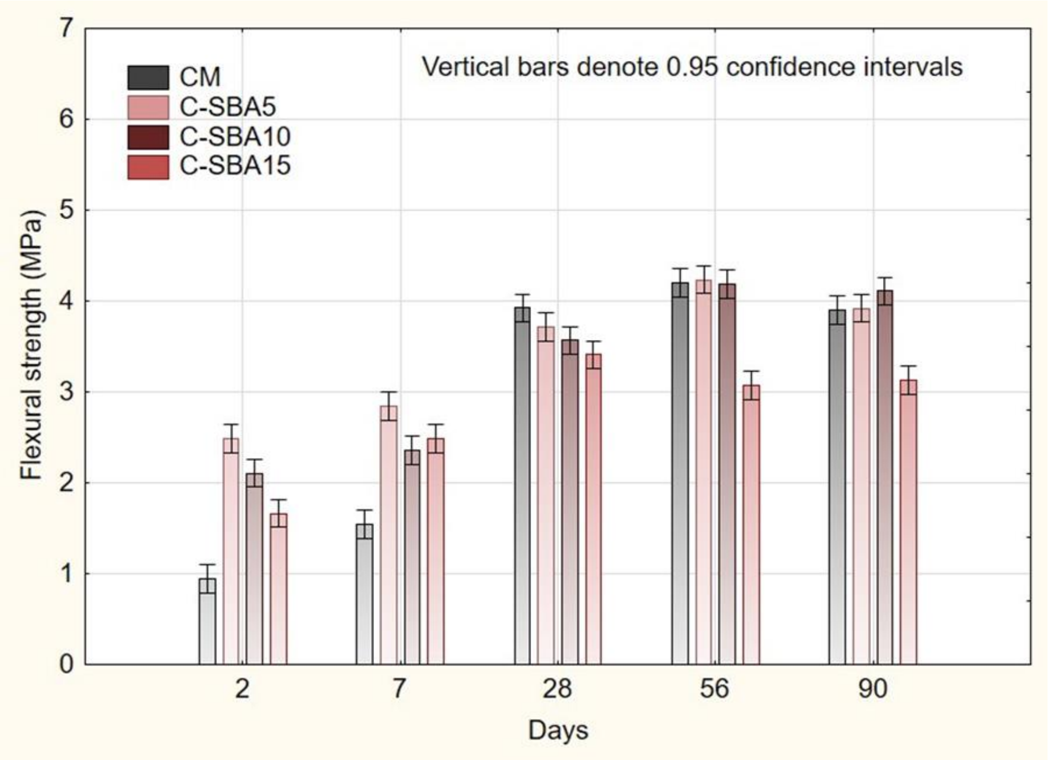


Figure 25b. Flexural strength of cement mortar with SCBA

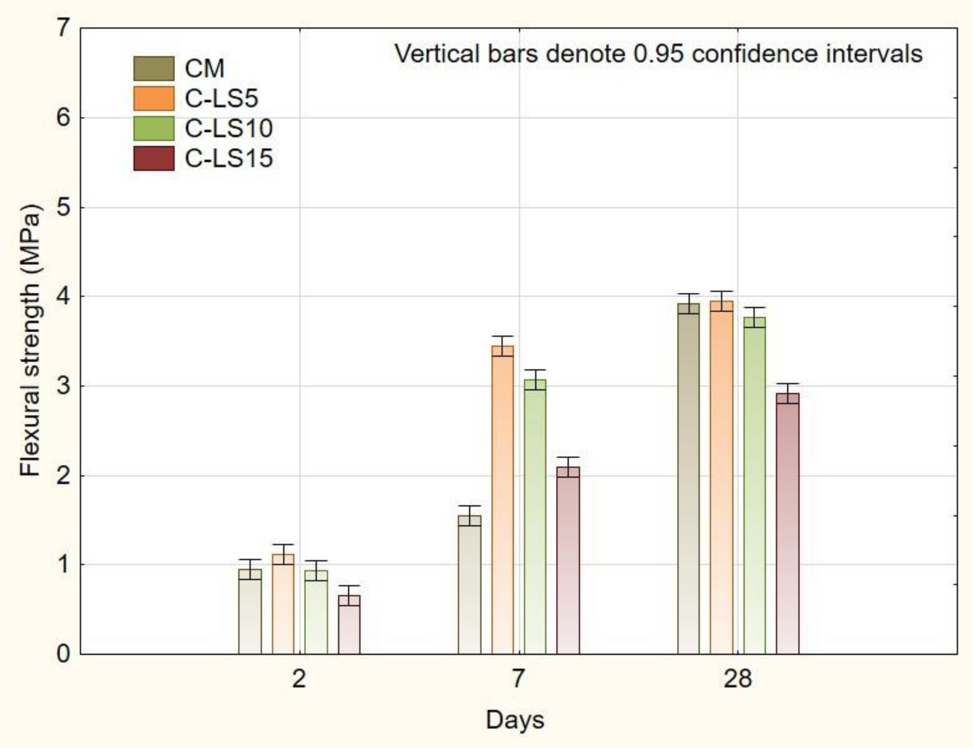


Figure 25c. Flexural strength of cement mortar with LS

An analysis of the data corresponding to 2, 7, 28, 56, and 90 days indicates that flexural strength exhibits an increase when utilizing SCBA as a replacement material, up to a level of 5%. However, upon reaching a 10% SCBA replacement level, the flexural strength of the mortar gets a value equivalent to that found for OPC without further increase in strength. With replacement of 15% SBA the strength in higher up to 50% at initial days of 2 and 7days due to hydration process. However the strength decreases when the cement replacement exceeds 15%, as observed. OPC free lime reacts with bagasse ash silica. Silicates increase binding agents, boosting strength. Bagasse ash production above optimal levels leaves extra silica in the mortar matrix, which has little binding property and decreases strength. The addition of limestone powder to the mix resulted in distinct changes in flexural strength. Notably, there is a clear decline in strength as the replacement amount increases, particularly when the replacement reaches a maximum of 15%. This decrease in flexural strength could be due to a variety of variables related to the interaction between limestone powder and the other components in the mixture, such as a potential dilution effect or changes in the composite's microstructure.

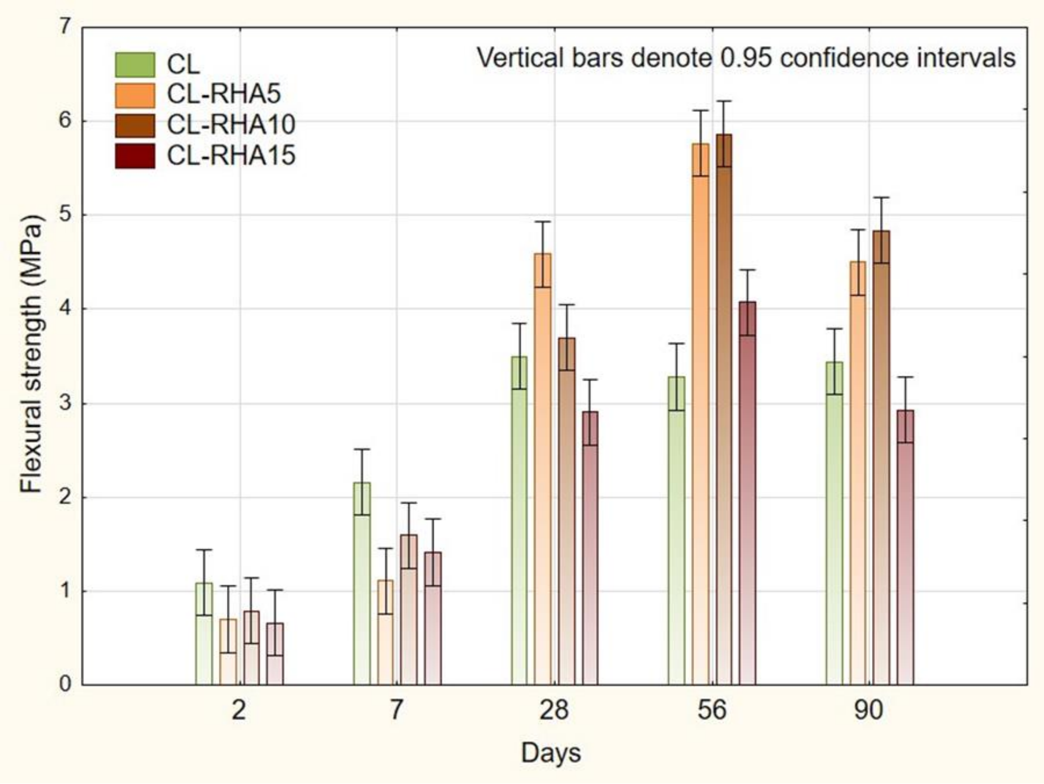


Figure 25d. Flexural strength of cement-lime mortar with RHA

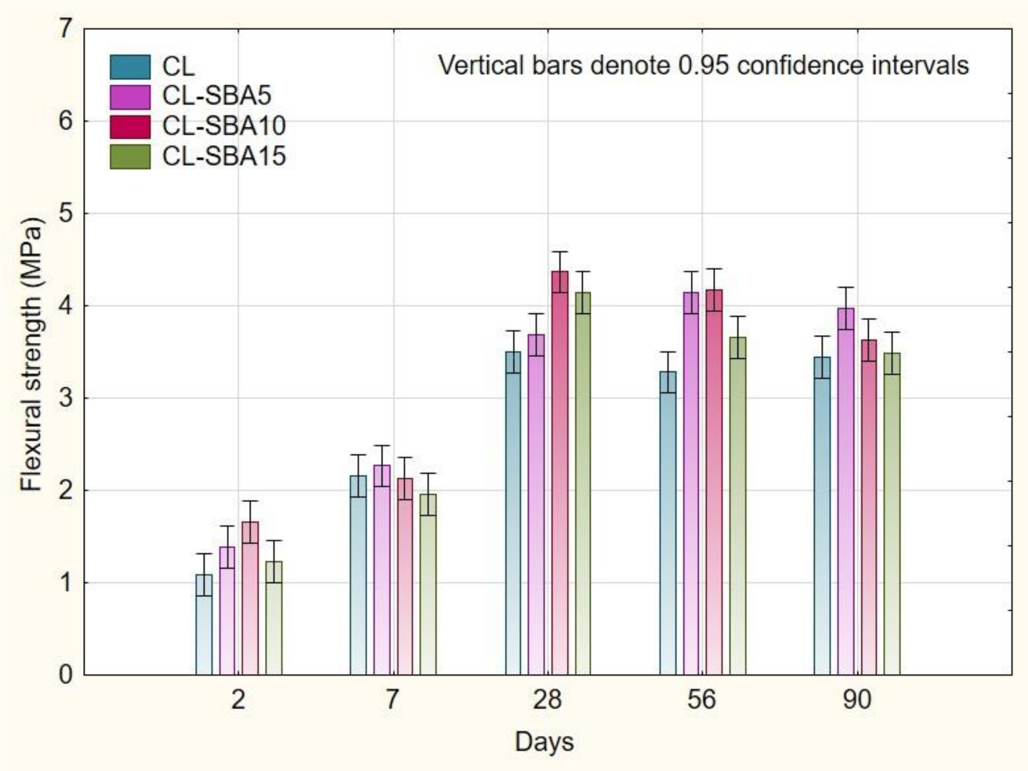


Figure 25e. Flexural strength of cement-lime mortar with SCBA

The flexural strength in cement-lime mortar is better compare to cement mortar with biomass addition. With the strength both RHA and SBA are acting completely different with its replacement in cement-lime mortar. The improvement in flexural strength of CL-RHA5 and CL-RHA10 blended lime mortar comparison to control mortar ranged in between 31% to 78%, which is showing a significant strength gain, despite the lower flexural strength at an early age (7days).with all addition later when the samples shift to humidity camber for curing purpose the strength gradually increases, sample CL-RHA5 and CL-RHA10 shows significant results with increases in flexural strength there might be the reason of lime with air curing. The flexural strength of CL-RHA5 increase by 31%, 75% and 31% at 28, 56 and 90days similarly CL-RHA10 its seems to be increased by 6%, 78% and 40% at 28, 56 and 90days with compare to reference cement-lime mortar. Higher addition leads to decrease in strength by 17% and 23% at 28 and 90days of curing. The decrease in flexural strength of RHA15 at higher replacement ratios is due to the presence of RHA particles functioning as porous micro-fine aggregates. Therefore, the results indicate that the pozzolanic reaction and the creation of crystallization nuclei may exhibit more significance compared to the filler effect, as it is not expected for fillers to contribute to strength enhancement. The factors might lead to a decrease in the overall stability of the matrix, which starts with micro-cracks resulting reduction in flexural strength of RHA mortar. However when we see the results of flexural strength with SBA addition its opposite of RHA, the strength of SBA with every amount addition shows increase in strength at all days. Similarly the effects of biomass addition is different in compressive strength then flexural strength. When cement is replaced with SCBA in mortar at 5% and 10%, the average amount of flexural strength increases by about 26% and 27%, respectively, when compared to the normal strength cement-lime mortar.

Furthermore, by increasing the curing period for both samples (CL-SBA5 and CL-SBA10) of mortar containing SCBA, the flexural strength was increased by 15% and 6% for 90 days. This phenomenon of increasing curing time strength is comparable to previous findings when using cement replacement materials. Addition of SBA 15% do increase the flexural strength but with lower percentage to 18%, 11% and 2% at 28, 56 and 90days. The samples with APA shows significant results with biomass additive. The flexural strength seems to be increases with RHA at 28, 56 and 90days with addition of 10% and 15% whereas the strength was lower with other reference sample with higher addition.

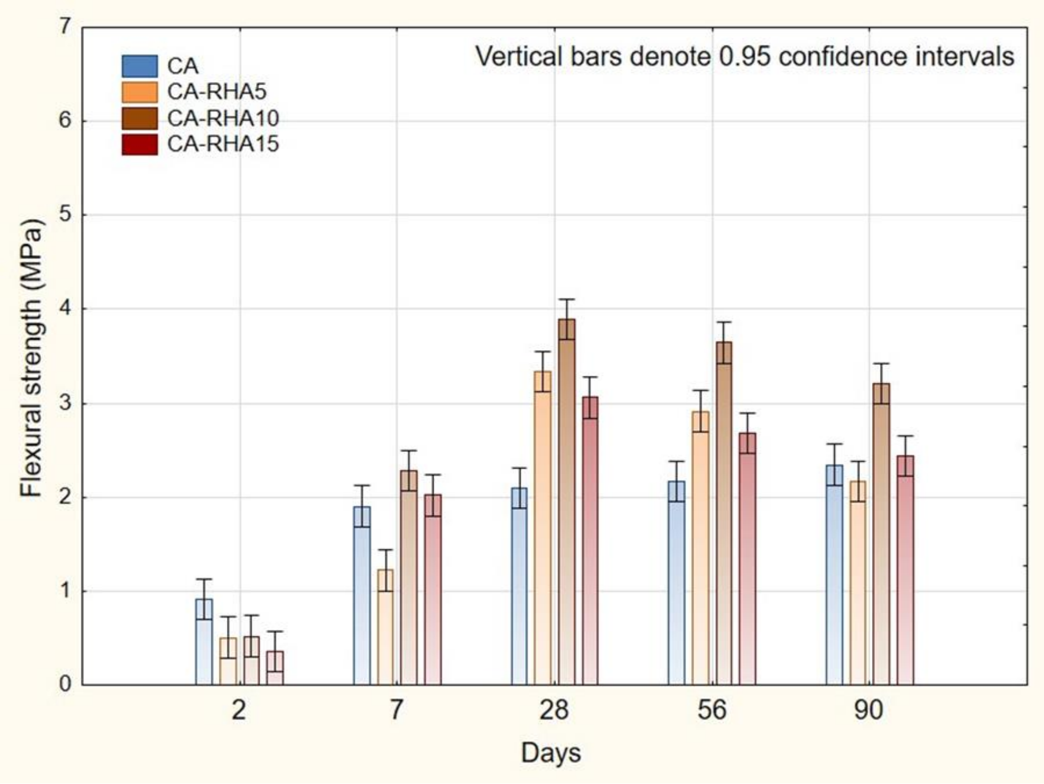


Figure 25f. Flexural strength of APA cement mortar with RHA

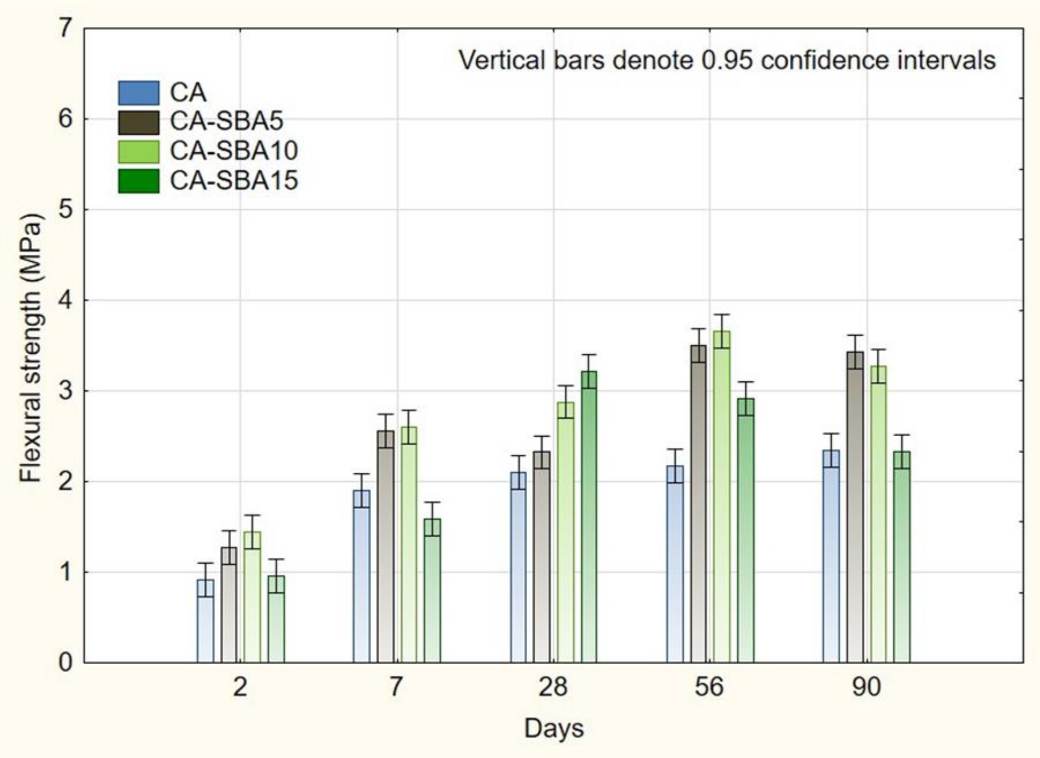


Figure 25g. Flexural strength of APA cement mortar with SCBA

Addition of APA was to enhance the homogeneity and workability of mixes which somewhere leads to huge water absorption and air content and this effects the strength properties of materials will all admixtures. However with ashes addition the flexural strength seems to be improved as the biomass contain carbon and huge silica particles which leads to water requirement with APA addition the properties get fulfilled hence the strength are better compare to reference APA samples.

Table 17. Comparison between air content and strength of samples with Ashes

Sample	Air content (%)	Flexural Strength (MPa)					Compressive Strength (MPa)				
		Days					Days				
		2	7	28	56	90	2	7	28	56	90
CM-RHA5	4	1.54	2.69	3.53	4.37	4.55	4.75	9.09	14.76	18.02	20.4
CM-RHA10	5.4	1.33	2.18	3.73	3.9	4.1	3.98	7.56	16.46	17.98	16.9
CM-RHA15	6.33	0.94	1.77	3.29	3.13	2.89	2.46	5.46	9.26	12.37	12.6
C-SBA5	3.3	2.49	2.84	3.71	4.23	3.92	9.69	11.4	15.8	17.9	18.1
CM-SBA10	4.5	2.11	2.36	3.57	4.18	4.11	10.2	13.4	17.3	21.6	18.9
CM-SBA15	5.5	1.66	2.49	3.41	3.07	3.13	5.41	8.09	13.85	16.71	16.3
CM-LS5	6.7	1.12	3.45	3.95	-	-	8.93	13.3	15.11	-	-
CM-LS10	6.9	0.935	3.07	3.76	-	-	6.51	12.9	18.4	-	-
CM-LS15	7.2	0.66	2.09	2.92	-	-	4.78	7.29	10.0	-	-
CL-RHA5	4.4	0.7	1.11	4.59	5.77	4.50	3.1	4.84	15.5	16.9	16.1
CL-RHA10	5.3	0.79	1.60	3.7	5.87	4.84	3.73	7.60	15.7	17.8	15.2
CL-RHA15	6.8	0.66	1.41	2.91	4.07	2.93	3.04	6.24	11.4	14.1	12.8
CL-SBA5	5.7	1.38	2.27	3.69	4.15	3.97	9.70	11.3	15.8	17.8	18.1
CL-SBA10	6.4	1.66	2.13	4.37	4.17	3.63	10.1	13.4	17.3	21.6	18.9
CL-SBA15	6.6	1.23	1.95	4.14	3.66	3.48	5.40	8.09	13.8	16.71	16.2
CA-RHA5	22	0.51	1.22	3.33	2.91	2.16	1.19	2.68	10.9	7.47	7.15
CA-RHA10	22	0.52	2.28	3.89	3.65	3.21	0	1.98	13.8	8.71	9.15
CA-RHA15	23	0.36	2.02	3.06	2.68	2.44	0	1.94	9.55	7.43	6.47
CA-SBA5	21	1.27	2.55	2.32	3.51	3.43	2.96	5.70	10.5	12.2	10.9
CA-SBA10	22	1.44	2.59	2.87	3.66	3.27	2.99	7.42	9.21	16.18	15.1
CA-SBA15	23	0.95	1.58	3.21	2.92	2.33	0	4.47	12.09	10.94	9.85
CA-LS5	28	1.46	2.02	3.3	-	-	3.21	5.9	6.39	-	-
CA-LS10	29	1.37	1.73	2.85	-	-	3.23	4.04	6.33	-	-
CA-LS15	30	1.47	1.63	2.29	-	-	3.41	3.72	6.7	-	-

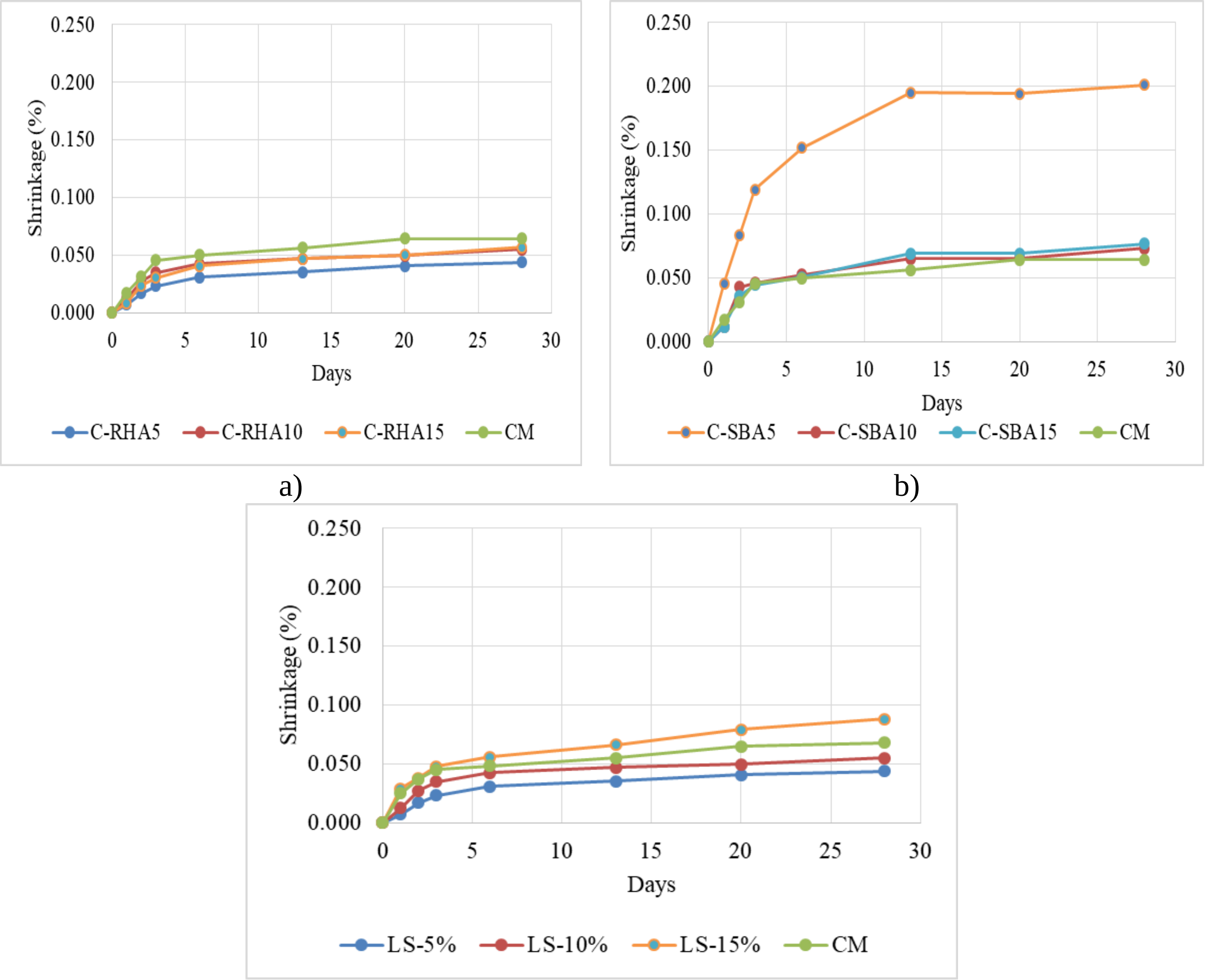
Air content values also effects the mechanical properties of mortar as seen in table 17. The higher the value of air voids in sample the flexural strength and compressive strength decreases. The air content in APA sample is four times higher in comparison to reference sample. With the addition of additive in APA sample there is no major changes in air content values so it can be said that use of APA decrease the strength in all samples.

9.5. Effects of ashes addition on shrinkage

The below figure 26 represent the shrinkage values of mortar with replacement of OPC to SCM materials. With RHA replacement the amount of dry shrinkage seems to be reduced compared to reference cement mortar, also the RHA5 shows improvement in crack resistance to 6%. The shrinkage value is quite variable in SCBA sample the replacement of 5% shows increase in shrinkage up to 70% however, the increase the amount slowed down over the 15% substitution ratio. Moreover the water-to-cement ratio increased as the SCBA substitution ratio increased, resulting in a reduction in the quantity of cement in the paste. Following this, both the micropore size of the paste and the overall pozzolanic reaction between SCBA and cement exhibited a reduction, helpful to decrease the dry shrinkage of mortar.

The limestone powder with replacement of 5% and 10% shows better results in cement mortar. Limestone powder also act as filler components in paste which might be the reason of reduction of dry shrinkage in LS-5 and LS-10 with 5% and 7% reduction respectively.

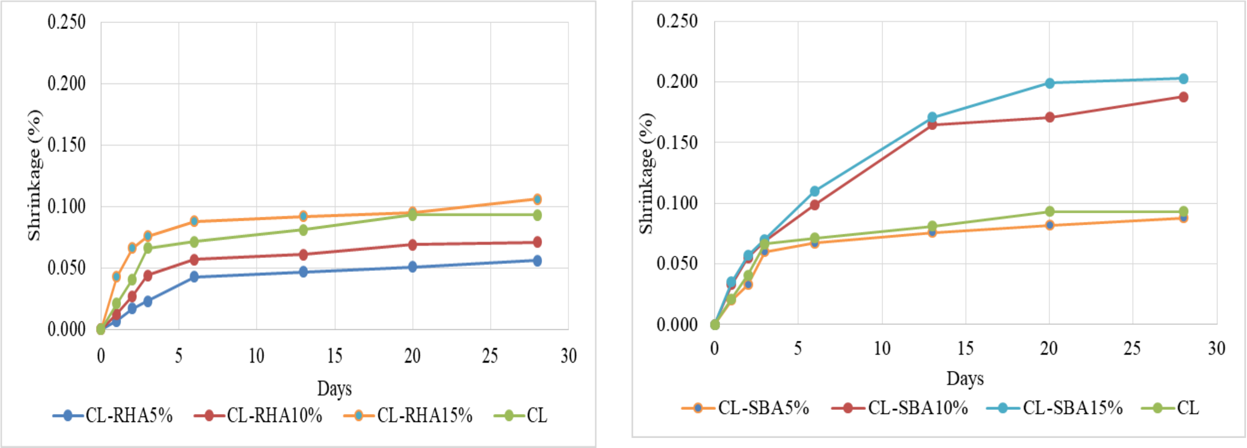
The dry shrinkage in cement lime mortar shows that substitution of RHA5 and RHA10 shows decrease in shrinkage value with 35% and 30% respectively in figure 27. However with increasing amount in RHA the shrinkage increases. The results is quite interesting with SCBA replacement in cement lime mortar with lower percentage the shrinkage value is quite similar to reference sample, although when the amount is increase to 10 and 15% the dry shrinkage increase this phenomenon could potentially be attributed to the ash's influence on the internal pore structure, as mineral admixtures have a tendency to decrease pore diameter concomitant with an increase in pore count. Small pore size is associated with an increase in contraction values a similar results can be seen with concrete with RHA substitution by researcher [179].



a) b)

c)

Figure 26. Shrinkage values of mortar with SCM a) cement mortar with RHA, b) cement mortar with SCBA and c) cement mortar with limestone powder



a) b)

Figure 27. Shrinkage values of mortar with SCM a) cement lime mortar with RHA and b) cement mortar with SCBA

9.6. Results on pore structure analyzes of mortars with ashes

The results of MIP parameters and pore structure distributions for all tested mortar samples are presented in Tables 18. Based on the investigation of the porosimetry data, it can be concluded that the pore characteristics of the reference mortars are reflective of their respective material compositions. The presence of pores with tiny diameters is common in cement mortar C and cement-lime mortar CL, accounting for a significant percentage of 80.2% and 89.8%, respectively. The presence of large-diameter holes ranging from 1 to 60 m in a mortar containing APA admixture represents about 56.9% of the overall pore volume. This observation can be attributed to the air-entraining properties of the admixture. This phenomenon could occur in freshly prepared mortar when the admixture is exposed to water, resulting in the initiation of a foaming process.

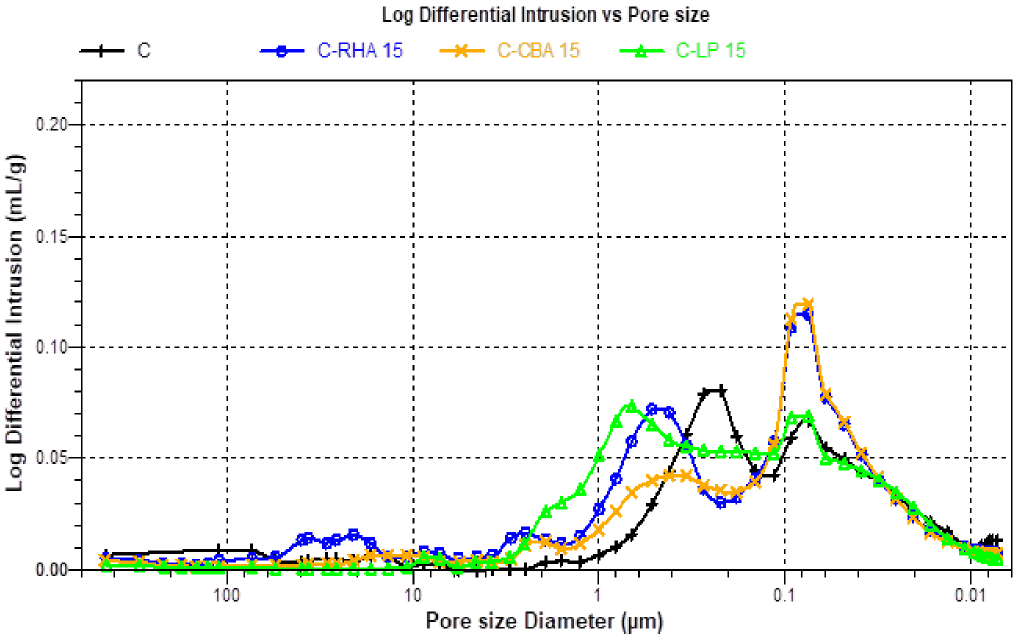


Figure 28a. MIP analyzes of cement mortars with ashes: a) C mortar b) Cement-sand Mortar C-RHA15 c) C-SBA15, d) C-LP15

The additions of the RHA and SCBA influenced the mortar structure differently, depending on the used additive. It was observed that the RHA ash affected the increase in the share of pores with larger diameters 0.5 – 1.0 µm in all mortars. Wherein slightly in cement mortar, more in cement-lime mortar and in mortar with APA admixture. Similar effect as for RHA in cement mortar was noted for the addition of lime stone powder. In turn, the addition of SBA caused an increase in the proportion of pores with smaller diameters, compared to the reference mortars this may be due to the fineness of sugarcane bagasse ash compare to rice husk ash. At the same time, in cement and cement-lime mortar, it is slightly and more clearly in the mortar with an admixture of APA in the range of 0.5 - 10 µm. A similar effect in the CA mortar occurred with the addition of LP powder.

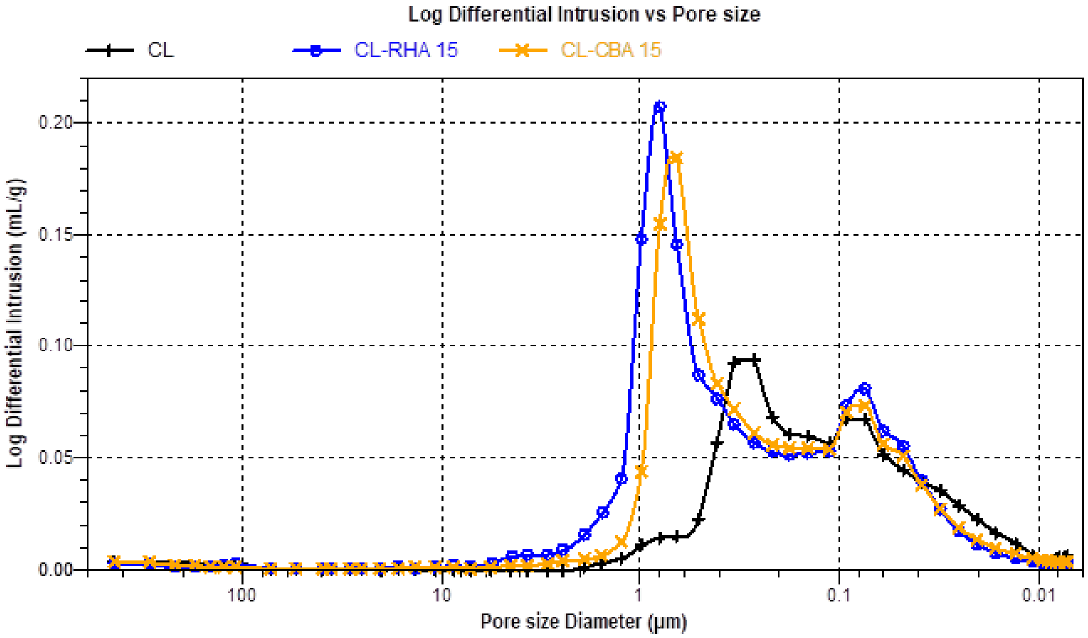


Figure 28b. MIP analyzes of cement-lime mortars with ashes: CL mortar, lime - cement mortar CL-RHA15, lime - cement CL-SBA15 mortar

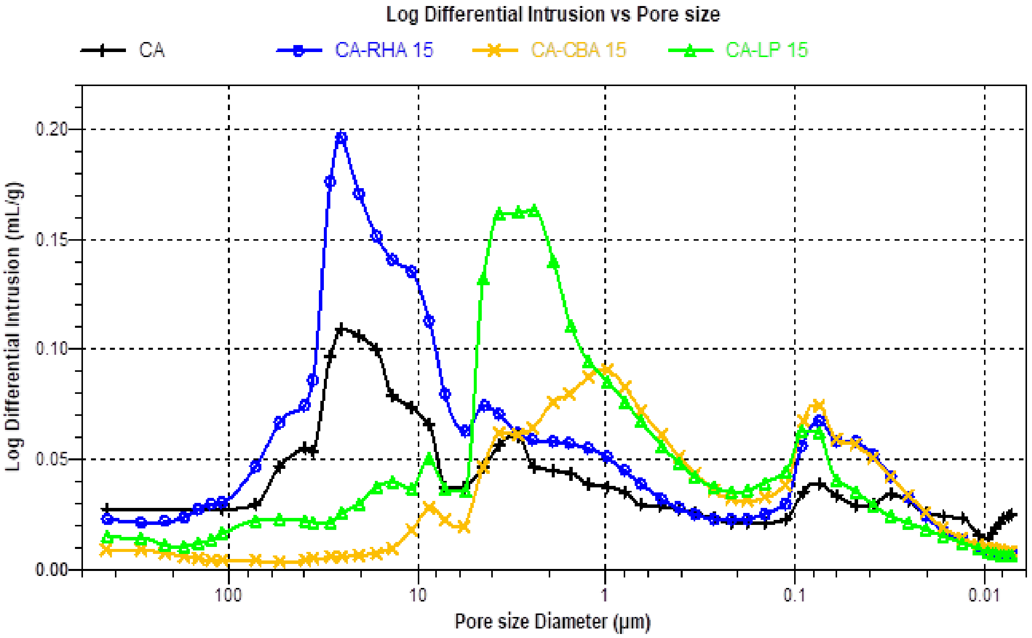


Figure 28c. MIP analyzes of APA cement m mortars with ashes: a) CA mortar, b) CA-RHA15, c) CA-SBA15 d) CA-LP15 mortar

By conducting an analysis of different physical qualities, including density, porosity, and microstructure parameters such as surface area, average radius (pore diameter median), and pore tortuosity as presented in Table 18, it can be determined that these parameters are indicative of the specific binder and additives used. The average pore radii values are descriptive of the pore distribution within each individual sample, as illustrated in above table 19. For the reference mortars C, CL and CA are respectively 0.16, 0.15 and 6.56 µm. In mortars with additives, these values are different. Only in cement-lime mortars RHA and SCBA ash additives increase the average pore radius, respectively 0.43 and 0.33 µm. In cement mortars, the addition of SCBA ash reduces the radius to 0.10 µm, while the addition of LP lime powder increases the radius to 0.22 µm. On the other hand, in the CA mortar with the admixture of APA, the addition of RHA ash increased the average pore radius to 8.80 µm, while the addition of SCBA ash resulted in a significant reduction to 0.71 µm, similarly to the addition of lime powder, to 1.93 µm. The measured bulk densities for reference mortars C, CL and CA are 2.0, 1.9 and 1.3 g/cm^3, respectively. Ash and lime powder additives cause a slight decrease in the density of mortars C and CL in the range of 1.84 - 1.98 g/cm^3. However, in the case of light CA mortar with APA admixture, these additives cause an increase in density in the range of 1.49 - 1.77 g/cm^3. However, rice husk ash RHA has a stronger effect, sugar cane ash SCBA has a weaker effect, and limestone flour LP has the weakest effect Figure 28 a.

Values of densities translate into porosity values .For reference mortars C, CL and CA it amounts to 19.7, 18.7, and 25.1 % respectively. Ash additions cause an increase in porosity, and a stronger effect is visible for RHA ash than for SCBA. For cement mortar, the porosity increases to 23.6% and 20.8%, respectively. For cement-lime mortar, the porosity increases to 26.4% and 24.5%, respectively. In turn, for cement mortars with an admixture of APA, the porosity increases to 39.9% and 28.6%, respectively. In the case of the addition of lime powder, a similar effect is observed, similar to the action of RHA ash. The porosities are 22.6% for the cement mortar and 35.7% for the APA-admixed mortar, respectively.

Table18. Results on MIP of the mortars with ash additives

No	Tested parameter	Unit	C-RHA 15	C-SBA 15	CL-RHA 15	CL-SBA 15	CA-RHA 15	CA-SBA 15
1	Volume of mercury intrusion	ml/g	0.13	0.11	0.14	0.13	0.27	0.16
2	Total surface area	m^2/g	6.23	6.13	4.37	4.53	5.52	5.93
3	Volumetric mediane of pore diameter	µm	0.16	0.10	0.43	0.33	8.88	0.71
4	Surface mediane of pore diameter	µm	0.04	0.04	0.05	0.05	0.03	0.03
5	Average diameter	µm	0.08	0.07	0.13	0.11	0.20	0.11
6	Bulk density	g/ml	1.90	1.98	1.84	1.90	1.49	1.77
7	Real density	g/ml	2.48	2.49	2.50	2.51	2.48	2.48
8	Open porosity	%	23.63	20.80	26.37	24.45	39.85	28.58
9	Permeability	mdarcy	0.08	0.041	0.092	0.13	250.4	2.0
10	Tortuosity	-	361.9	440.2	235.6	229.0	12.8	91.4

Table 19. Pore size distribution of RHA and SCBA in mortar

Tested parameter	C-RHA 15	C-SBA 15	CL-RHA 15	CL-SBA 15	CA-RHA 15	CA-SBA 15
> 90 µm	2.28	1.79	1.07	1.36	6.79	3.12
60-90 µm	0.74	0.40	0.16	0.14	3.03	0.45
30-60 µm	2.56	0.78	0.22	0.17	9.07	0.82
20-30 µm	2.01	0.54	0.10	0.11	12.21	0.70
10-20 µm	2.18	1.98	0.29	0.31	16.47	2.15
1-10 µm	8.88	7.60	10.96	3.78	25,56	34,86
0.5-1 µm	12.43	8.88	33.15	32.65	4.64	14.27
0.25-0.5 µm	13.99	11.86	14.50	17.63	2.96	8.50
0.1-0.25 µm	13.46	16.37	14.68	17.04	3.88	8.49
0.05-0.1 µm	23.17	28.26	14.88	15.23	6.81	12.28
0.025-0.05 µm	11.51	13.85	7.43	7.99	5.33	8.71
0.01-0.025 µm	5.82	6.63	2.28	3.14	2.79	4.84
< 0.01 µm	0.97	1.06	0.29	0.45	0.44	0.81
Total sum	100.00	100.00	100.00	100.00	100.00	100.00

Table 20. Results on MIP of the mortars with limestone powder additive

No	Tested parameter	Unit	C-LP 15	CA-LP 15
1	Volume of mercury intrusion	ml/g	0.1161	0.2232
2	Total surface area	m^2/g	5.726	4.652
3	Volumetric mediane of pore diameter	µm	0.22	1.93
4	Surface mediane of pore diameter	µm	0.03	0.03
5	Average diameter	µm	0.08	0.19
6	Bulk density	g/ml	1.95	1.60
7	Real density	g/ml	252	2.49
8	Open porosity	%	22.61	35.73
9	Permeability	mdarcy	0.13	6.84
10	Tortuosity	-	187.7	61.0

Table 21. Pore size distribution of LS in mortar

Tested parameter	Unit	C-LP 15	CA-LP 15
> 90 µm	%	1.08	4.48
60-90 µm	%	0.22	1.69
30-60 µm	%	0.25	2.99
20-30 µm	%	0.14	2.15
10-20 µm	%	0.29	4.99
1-10 µm	%	12.94	47.20
0,5-1 µm	%	17.45	9.49
0,25-0,5 µm	%	14.79	5.98
0,1-0,25 µm	%	18.09	7.02
0,05-0,1 µm	%	15.83	7.12
0,025-0,05 µm	%	11.06	3.73
0,01-0,025 µm	%	7.05	2.72
< 0,01 µm	%	0.80	0.47
Sum	%	100.00	100.00

The additives affected also the surface of the pores Figure 28a. For reference mortars C, CL and CA, they are respectively 6.0, 5.4, 5.9 m^2/g. Ash additives RHA and SCBA had a different effect, depending on the mortar. When added to cement mortar, they caused a slight increase in the pore surface, respectively 6.3 and 6.1 m^2/g. In the cement-lime mortar, they reduced the pore surface to 4.4 and 4.5 m2/g, respectively. In the CA mortar, only the RHA ash changed the pore surface causing its reduction to the value of 5.5 m^2/g. The SCBA ash did not change the surface of the pores. In the case of the addition of lime powder LP, the pore surface area in the cement mortar C and CA was reduced to 5.7 and 4.6 m_2/g, respectively. Comparing the pore tortuosity results for the reference mortars C, CL, CA with the values of 563, 386, 9.5, respectively, it can be seen that the plasticizing additive reduce the tortuosity, in particular the APA admixture. Ash additives RHA and CBA cause a decrease in tortuosity in the cement mortar to the value of 362, 440, respectively, and the addition of lime powder more to the value of 188. In the cement-lime mortar, the ash additives cause an even greater and equal reduction in the tortuosity to the value of 230. In turn, in the mortar with the addition of APA, the ash additives RHA and SBA and LP powder increase the tortuosity of the pores to the values of 13, 91, and 61, respectively.

9.7. Relationship between flexural strength vs compressive strength of samples with all the biomass ash additives

In many scenarios, there exists a requirement for conversion of compressive strength to flexural strength. This phenomenon is particularly frequent in the area of concrete and mortar design and specification. The establishment of a reliable conversion factor between compressive strength and flexural strength is essential in the context of quality control, as it makes sure that concrete and mortar materials correspond to the specified standards. The elements influencing mortar flexural strength are largely comparable to those influencing compressive strength. Flexural strength, on the other hand, is significantly more dependent on the type and shape of aggregates utilized. Figure 29 shows the findings of the scatter diagram and the ensuing statistical relationship between flexural strength and compressive strength for the mortar with varied additives and associated w/c ratios. The link between Flexural and compressive strength of mortar is good for the mix proportions for the three samples with SCM ash, with a very high coefficient of correlation, R^2 in the range 0.949-0.993.from From the regression analysis it can be noted that the sample with higher amount of additive up to 15% shows lower R^2 value which ultimately affect the use of this product. The flexural and compressive strength simultaneously increase with increasing in both strength the stronger the adhesion between matrix and additives, however the regression value lesser than 0.8 shows the change happening in is not efficient enough to predict the mechanical properties.

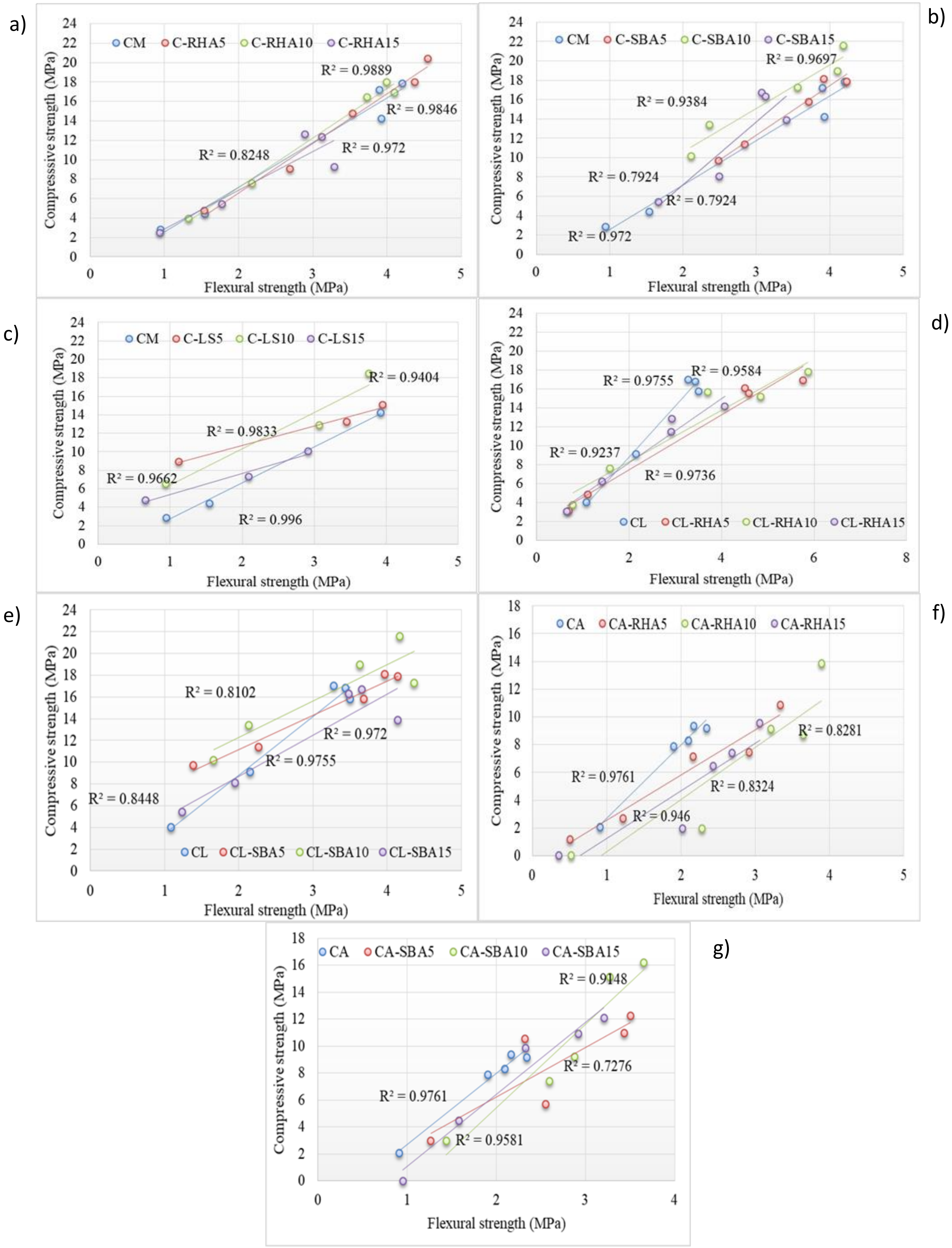
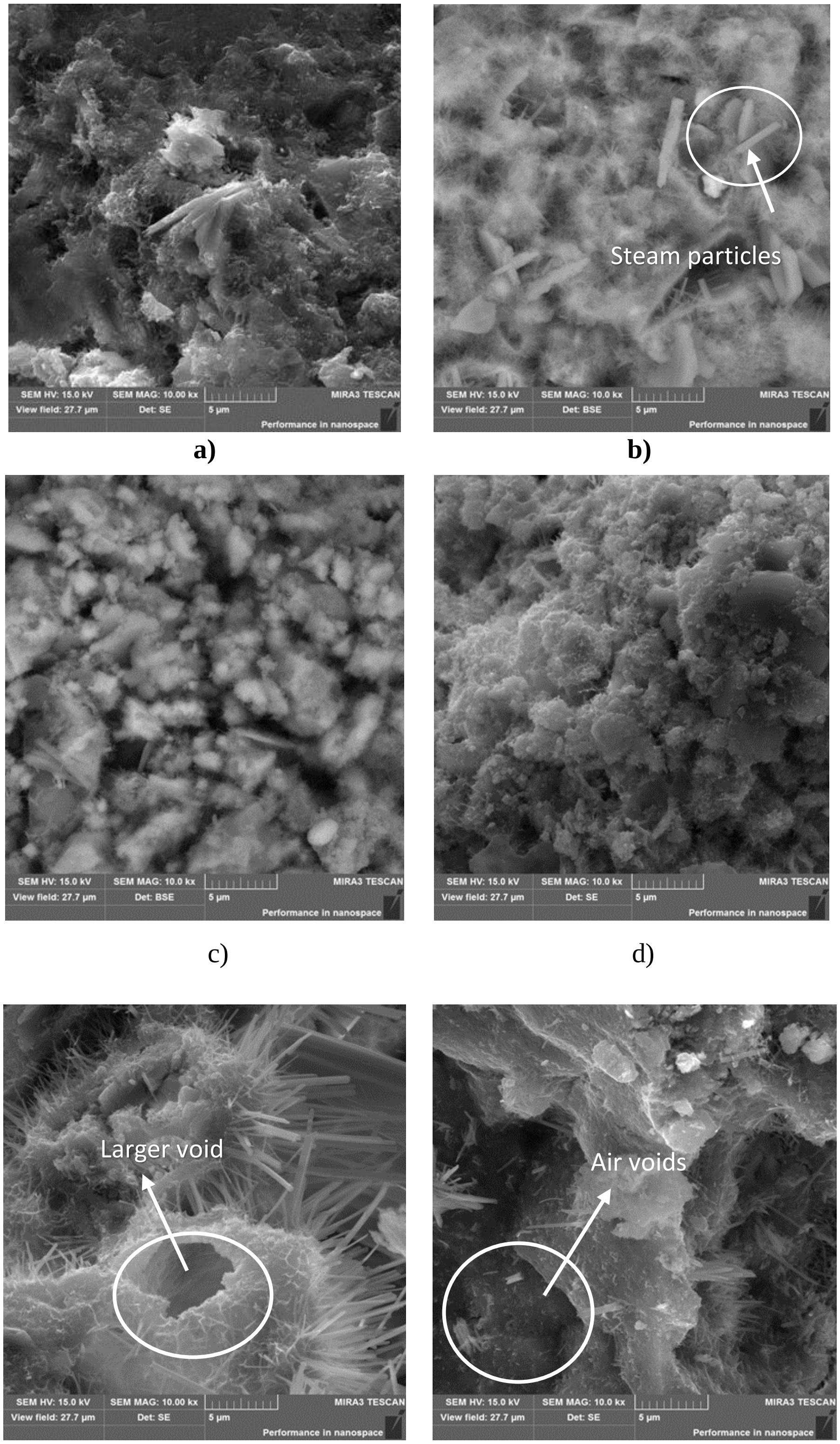


Figure 29. Relationship between strength a) CM with RHA ,b) CM with SCBA, c) CM with LS, (d) CL with RHA, e) CL with SCBA f) CA with RHA, and g) CA with SCBA

9.8. Results on surface morphology analyzes with ashes

The results of the SEM analyses of reference sample are mentioned above. Differences in microstructure can be observed between the reference samples, particularly between the cement mortar and the cement-lime mortar. It can be observed that the cement-lime grout is more fine-grained relative to the cement mortar. In mortar with aerating admixture, more developed "needles" in the microstructure were observed, which is related to the more porous structure of the grout. It can also be observed a lower porosity of samples with bagasse ash relative to rice husk ash. No clear differences were observed in the visible hydration products of pastes with rice husk ash versus bagasse ash. Large amounts of portlandite were observed in each case. Also the most important factor in which microstructure is depend is the grinding time[180] (Chindaprasirt, 2008). Consequently, the presence of smaller ash particles leads to the formation of larger pores and an increased number of nucleation sites, facilitating the precipitation of hydration products in cement paste.

One of the major factors influencing the rate of pozzolanic reaction is the fineness of pozzolanic materials. As demonstrated in this study, SCBA has finer particles react faster than RHA materials thus enhance the properties of mortar. Furthermore, the fineness of the material influences water requirements and the strength activity index. Similarly it can be clear with the figure 30 of all the matrix with addition of SCBA as the fineness is better than RHA which enhance the strength of materials. The surface of samples with lime and SCBA addition shows smother surface the RHA samples therefore the strength of samples with natural ashes and lime shows better in strength the with cement mortar



a) **b)**

c) d)

e) f)

Figure 30. SEM micrographs of a) cement- sand mortar with RHA 15%, (b) cement-Sand mortar with SBA 15%, c) cement-lime mortar with RHA 15%, (d) lime-cement mortar with SBA 15% (e) APA cement mortar with RHA 15%, (f) and APA cement mortar with SBA 15%

With addition of APA in the matrix of cement and ashes shows the surface with needles crystal shapes in microstructure diagram in figure 30. Natural ashes fill the pores of the surface. When the cement hydrate area is magnified, two distinct phases can be seen: the C-S-H gel and the needle-like crystals. According to Xu et al. (2018) [181], observed that the flake-shaped calcium hydroxide crystalline period is absent on the surface of the glassy phase in the matrix. This finding suggests that the presence of reactive silica in ashes can facilitate and expedite the secondary hydration reaction of $Ca(OH)_2$ in the cement matrix.. Also addition of APA increase the water absorption which on drying leaves huge larger voids which can be seem with the figure 30 (e and f).

CHAPTER 10

CONCLUSIONS

This chapter presents a comprehensive summary of the conclusions, findings, and contributions derived from the test results. These outcomes are in line with the aims and objectives outlined in the initial chapter of the thesis. Additionally, some recommendations for future research are provided. Based on the results obtained, it can be concluded that the objectives of the dissertation work were achieved and the thesis of the work was confirmed.

The research work was divided into two parts. The first part looked into adding fibers like jute, sisal, and polypropylene to mortar. The second part looked into using rice husk ash (RHA), sugarcane bagasse ash (SCBA), and limestone powder as extra cementitious material in place of cement. The properties of all of these additives were explained. It's possible to draw the following conclusions:

- The air content results imply that APA mortar admixtures increase air content. The air content of cement-lime mortars is lower than cement mortars due to decreased water content and possible filler effects from fine lime particles. APA-admixed mortars have six times more air than plain and lime-added mortars. Increasing void diameter by 25% increases porosity.
- Jute and polypropylene fibers appeared to have little impact on air content in mortar. Sisal fibers increased cement and cement-lime mortar air content by fourfold. This is presumably due to sisal fiber hydrophilic cellulose, which absorbs water.
- Fibers affect mortar flowability. Included jute and plastic fibers reduce flowability by 5%. C-P2 and CA-S2 cement mortar samples shoes higher flowability better than others. The increasing presence of shorter fibers may have affected C-P2 interaction dynamics. The presence of APA in CA-S2 and sisal fiber characteristics may have contributed to this result.

- The Novikov's cone test shoes similar results to consistency in accordance with the flow table test for both jute and polypropylene fibers. However, the addition of sisal fibers increases the consistency value because to their high water absorption capacity
- After 28 days, including 1% and 2% jute fibers results in significant increases in compressive strength, with increases of 11% and 15%, respectively, as compared to the reference sample. Similarly, with the addition of 1%, the strength of polypropylene and sisal fibers improves by 10% each after 28 days. Adding APA to fiber mixtures lowers compression strength. Because APA absorbs a lot of water, it seems to wipe out the strengthening effects of other fiber-reinforced mortar mixes.
- The flexural strength results demonstrate that fiber additions improve mortar flexural strength. 1% and 2% jute fiber mortars have significantly increased flexural strength. After 28 days curing. The flexural strength of cement-sand mortar increases by 10% and 38% over the reference sample. At 28 days, 1% and 2% jute fibers increase cement-lime mortar flexural strength by 37% and 40%, respectively. Sisal fibers improve cement-lime mortar flexural strength. After 56 days of curing, 1% and 2% polypropylene fibers increase flexural strength by 7.5% and 10%, respectively.
- The MIP and SEM results reveal that sisal fiber in cement-sand mortar has poorer adherence to the cement matrix than other fibers. This results in an 80% increase in pores with greater sizes (1-100 μm). However, the finer lime particles in a cement-lime matrix promote adhesion and bonding between sisal fibers and the matrix.
- The consistency value with the flowtable shows that replacing RHA 15% and SCBA 15% reduces flow to 10% and 8% as water demand rises. With all additions at higher percentages, cement-lime samples flow values do not change much. Due to higher specific gravity, combining APA rice husk ash reduces water usage by 40%, whereas bagasse ash reduces water demand by 23% with larger proportion..
- The consistency values compared to the reference cement mortar, novikov found that mortar C-RHA5, C-RHA10, and C-RHA15 have 28%, 35%, and 44% lower consistency values. Thus, Rice Husk Ash (RHA) affects consistency. Adding Sugarcane Bagasse Ash (SCBA) reduces consistency by 15%, with a maximum replacement of 15%. The reference sample and other SCBA samples had the same values. Cement-lime mortar's consistency

lowers to 36% and 34% for CL-RHA15 and CL-SCBA15, respectively, increasing water usage.

- The samples with APA and ash additions performed much better in terms of compressive strength. At 28 days, the incorporation of 10% and 5% RHA (rice husk ash) results in higher strength performance. These enhancements result in a significant 10% and 40% increase in strength in samples CA-RHA5 and CA-RHA10, respectively. At 28 days, the compressive strength of the samples CA-SBA5, CA-SBA10, and CA-SBA15 increased to 12%, 5%, and 28%, respectively. Surprisingly, the sample with a 10% replacement level outperforms the others with an amazing 80% strength gain for the remaining test length. This increase could be attributable to improved adhesion in the mix as a result of the use of sugarcane bagasse ash.
- All air content tests show that SCM increases air content. In cement mortar, replacing SCBA with 15% biomass ash increases air content to 22%. Similarly, Samples C-RHA5 and CL-RHA15 had considerably higher air content values, 37% and 44%, respectively. This rise in air content shows that the ash replacement affected the mortar's air entrainment.
- In sample APA with CA-RHA15 and CA-SCBA15, sample APA's air content drops to 10% and 13%. In these samples (CA-RHA15 and CA-SCBA15), the ash may fill these gaps with air, reducing air content. This shows how additives and materials affect mortar air entrainment in a sophisticated way.
- In samples of cement-lime mortar vary in compressive strength at 56 and 90 days. The compressive strength of CL-RHA5 with 2% replacement is higher than CL-RHA10 with 10% replacement. At 90 days, sample CL-SBA5, with a 5% replacement, has 28% higher compressive strength. In sample CL-SBA15, when the replacement level rises to 15%, strength increases by 34% after 2 days, then declines to 11%, 12%, and 2% at 7, 28, and 56 days, respectively.
- Flexural strength increases by 31%, 75%, and 31% and 6%, 78%, and 40% at 28, 56, and 90 days in sample CL-RHA5 and CL-RHA10, respectively, compared to the reference cement-lime mortar. For 90 days, extending the curing duration for CL-SBA5 and CL-SBA10 increased flexural strength by 15% and 6%, respectively. This enhanced cure time strength behavior is consistent with cement replacement materials. At 28, 56, and 90 days, 15% SBA enhances flexural strength by 18%, 11%, and 2%.

- The inclusion of fibers in mortar samples yields beneficial results as compared to reference samples. The incorporation of jute in all samples, despite of the amount, leads to an improvement in shrinkage value and decreases the occurrence of cracks.
- MIP research reveals that adding RHA (rice husk ash) and limestone powder ash increases pore size (0.5-1 µm) in all mortar types. This effect is stronger in cement-lime mortar and increases with APA admixture (0.5-10 µm). SCBA has increased smaller-diameter pores. When added to cement-lime mortars, RHA and SCBA ash increase the average pore radius to 0.43 µm and 0.33 µm, respectively. Addition of SCBA ash in cement mortars decreases average pore radius to 0.10 µm, whereas LP (lime powder) increases it to 0.22 µm.In CA mortar with APA admixture, adding RHA ash raised the average pore radius to 8.80 µm, whereas adding CBA ash or lime powder decreased it to 0.71 µm and 1.93 µm, respectively..
- The SEM investigation findings reveal the materials' microstructure. Note that cement-lime grout has a finer microstructure than cement mortar. APA-containing cement has well-developed "needle-like" microstructure. Grout is more permeable, explaining this. Compared to RHA, bagasse ash samples have lesser porosity. This finer matrix increases material strength. Mortar with lime and biomass ash samples had uniform surfaces with fewer pores, improving strength. The cement and ash matrix shows needle-like crystal formations once APA is added. APA also increases water absorption, which expands gaps when dried.
- A conclusion can be drawn on the advantages of natural waste additives over artificial ones. With the amounts of jute 1% and 2% fibers and SCBA 10% ash improve desirable properties over polypropylene and limestone powder.
- Based on results obtained, it can be concluded that the objectives of the work were achieved and thesis of the work was confirmed.

CHAPTER 11

FUTURE PERSPECTIVES

Although the findings and model from this research on developing new materials are valuable, more research is needed for more particular qualities. Future work recommendations:

- Investigation of use of these bio composites for external environments and propose a model to predict long term behavior of structures
- More research into the changes in mechanical and durability attributes related with their use should be conducted in order for natural additives to become competitive in the market. A thorough assessment of the constructability of concretes employing these agricultural by-products is also required, in addition to laboratory workability assessments. In example, it has been noted that the consistency of mortar made from agricultural products can change in a matter of minutes, posing a significant challenge when casting mortar and concrete elements.
- Furthermore, high-quality natural additives with little variation in properties could partially meet the need for new sources of SCMs and natural fiber materials; however, in order for this to happen, there is a clear need to develop a standardized incineration process that would allow producing Natural SCM and proper manufacturing process that can be adapted for the natural fiber materials to avoid problem arises due to the presence of ingredient such as lignin and cellulose with high concentrations .
- The imperative it is necessary to investigate the impact of natural compounds on the durability of OPC mortar with a low water-to-binder ratio (w/b)
- An investigation should be conducted into the impact of different curing conditions on the hardened characteristics of OPC mortar and concrete, encompassing their acid resistance.
- The estimation of CO_2 emission can be examined with the final bio composites products to verify the use of it in commercial aspects.

- Study on relationships between physical-mechanical properties of mortars (air content, shrinkage, strength) and microstructural parameters.
- Study on synergistic effects when using in mortars natural waste fibers and ashes simultaneously

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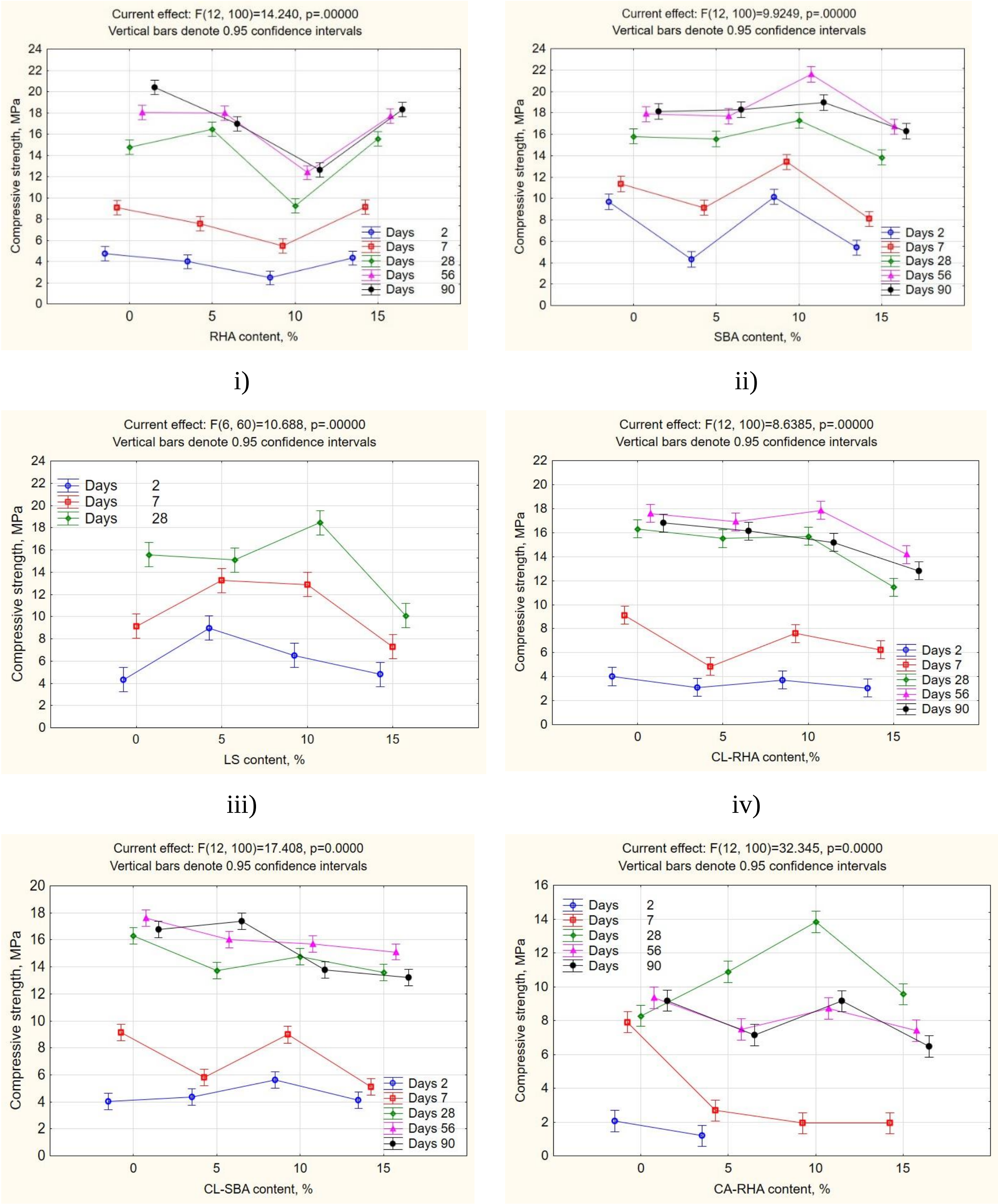
Annex 1

Figure A.



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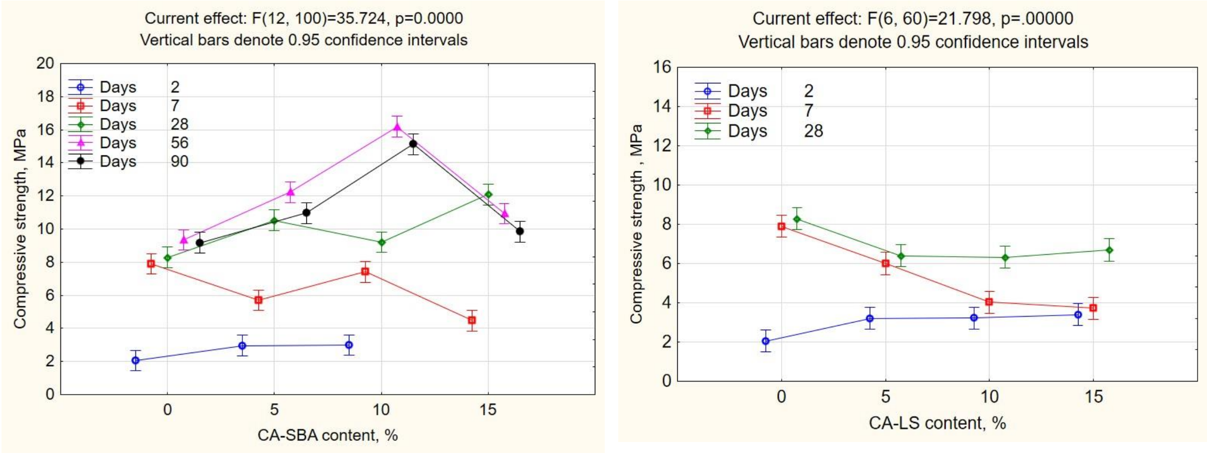
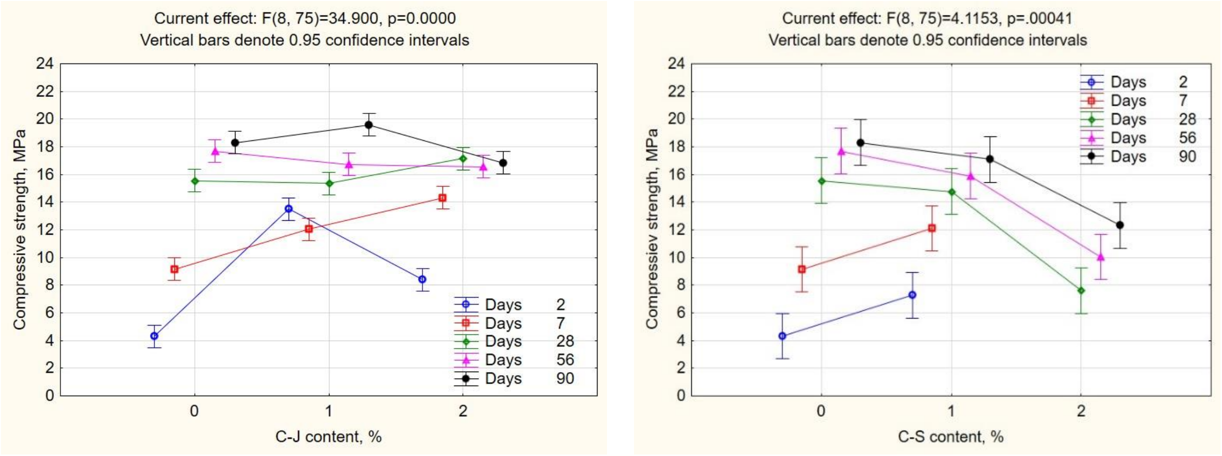


vii) viii)

Figure. A. Compressive strength of mortars with ashes: i) C-RHA, ii) C-SBA, iii) C-LS, iv) CL-RHA, v) CL-SBA, vi) CA-RHA, vii) CA-SBA and viii) CA-LS

Annex 2.

Figure B.



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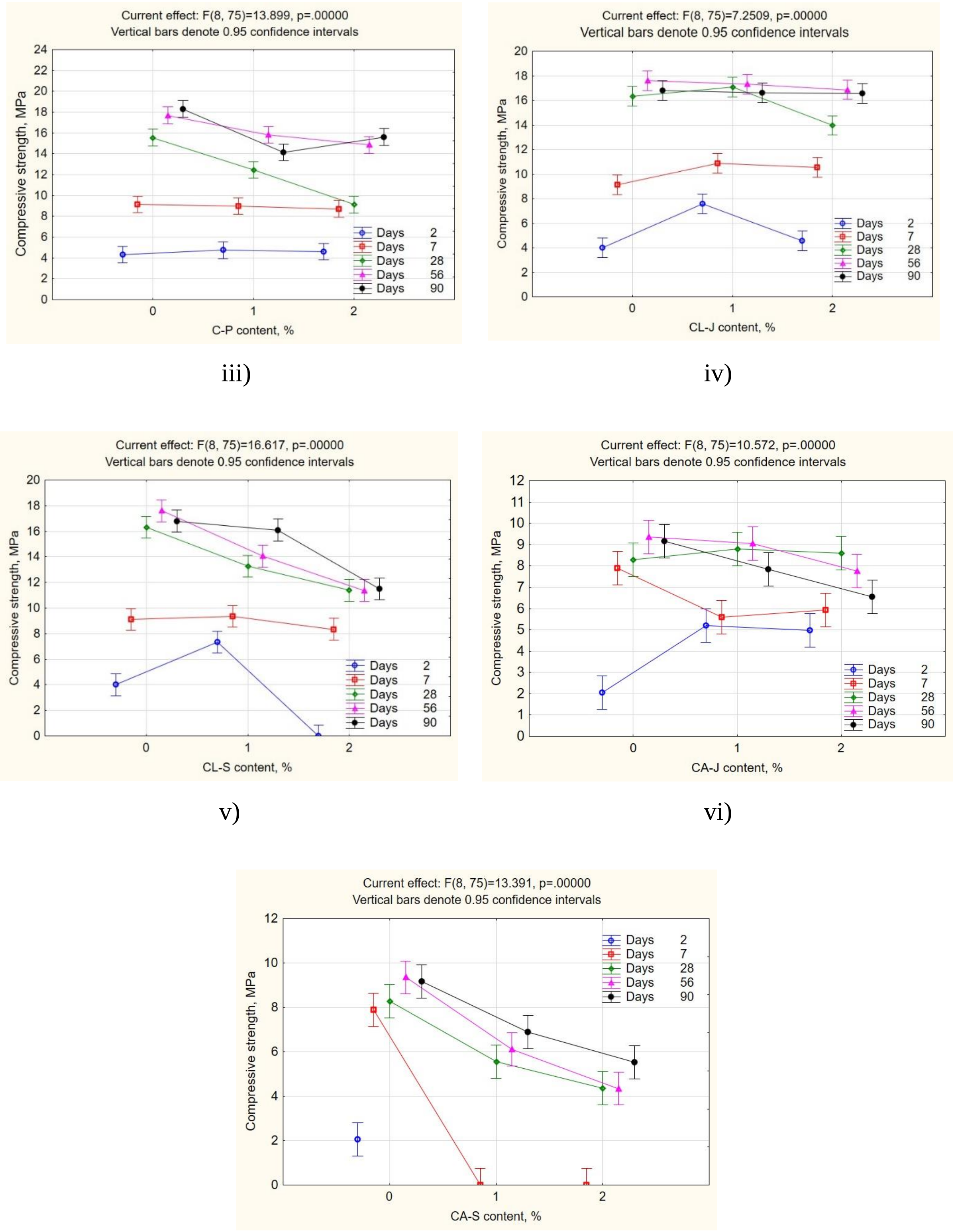

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Figure. B. Compressive strength of mortars with fibers: i) C-J, ii) C-S, iii) C-P, iv) CL-J, v) CL-S, vi) CA-J, and, vii) CA-S