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Modification of Selected Bioactive and Mechanical Properties of Polydimethylsiloxane for External Medical Applications

Abstract

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Advancements in materials engineering, particularly in polymeric materials, alongside the increasing demands of the medical industry, drive the search for new alternative solutions, often based on biomaterials and/or biofillers. The selection of polymeric materials and the modifications applied, including fillers, is conditioned by the application area and the associated requirements. Such materials must exhibit biocompatibility and often possess additional properties relevant to their application, such as antibacterial, antifungal, or anti-allergic characteristics.

Various solutions utilizing inorganic and organic fillers are known, often employing mechanisms of synergistic interaction that simultaneously influence the biological and physicochemical properties required for potential applications. A thorough literature review clearly indicates that it is possible to modify polymeric materials with organic fillers for medical applications. Polymers are used in many areas, including as components of medical equipment, implants, hygiene products, and dressings, which determine their operational characteristics. Despite a range of different solutions, there is a justified need to develop new materials that could serve as alternatives to currently used dressings, particularly for long-term use on wounds while maintaining the required antibacterial properties, which are crucial for the healing process. A promising response to these defined needs could be biocomposites based on elastomeric materials modified for antibacterial properties.

The research problem addressed in this work involved the development of an elastomeric dressing material that combines both antibacterial activity and the required physicochemical properties. The research focused on developing new materials with bioactive properties based on polydimethylsiloxane (PDMS) modified with various forms of plant-derived fillers. Polydimethylsiloxane is a synthetic elastomer from the siloxane group. Its biocompatibility, high gas permeability, chemical inertness, and thermal stability make PDMS highly desirable in applications requiring both flexibility and durability. In the medical sector, PDMS is used in implants, contact lenses, scaffolds, patches, and wound dressings, which serve to protect wounds from infection and facilitate the healing process. Various types of dressings modified with inorganic additives are known, but they involve time-consuming production processes, increased costs, and the need to use various chemical substances. In this study, the developed materials address these challenges by utilizing widely available organic additives. The preparation process is characterized by reduced time and financial investment, as well as limited use of chemical substances.

To improve the bioactive properties, herbal fillers were introduced into the matrix selected based on criteria such as polyphenol content, availability, antimicrobial activity, and health benefits. These included thyme, sage, and rosemary, which are rich in polyphenols and exhibit antioxidant, anti-inflammatory, and antibacterial properties. The study developed a technology for modifying the fillers and producing biocomposites based on polydimethylsiloxane with herb content of 2.5%, 5%, 7.5%, and 10% by weight.

The obtained biocomposites were subjected to a series of tests to evaluate the impact of the fillers, varied in form and material, on the physicochemical properties (density, contact angle, absorbance, crystallinity degree), mechanical properties (rebound resilience, hardness, abrasion, static tensile testing), and biological properties (antibacterial activity, cell viability), as well as aging studies in an artificial plasma environment. Based on FTIR spectra analysis, the influence of modification and aging on structural changes in the material was determined.

The results indicate that introducing modified thyme, sage, and rosemary into polydimethylsiloxane alters the antibacterial activity level depending on the filler's type and content. The highest antibacterial activity was obtained for PDMS modified with sage; however, it is noteworthy that all biocomposites exhibit bacteriostatic properties. Considering the overall results, the best solution is the introduction of modified thyme at a weight ratio of 2.5%.

Moreover, some materials exhibited high cell viability during fibroblast tests, suggesting they promote cell proliferation. Although the functional properties of the materials were altered, in many cases, these changes did not disqualify the materials from external applications, such as wound dressings. The developed materials represent a significant advancement in the field of medicine, particularly in wound dressing applications. Furthermore, these composites, based on naturally derived additives, are environmentally friendly and pose no threat during production, use, or disposal, in accordance with the principles of sustainable development.