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Opinion on the Doctoral Dissertation

***„Deformation – Induced Size Effects on the Structure and Mechanical Properties of Heterogenous L-PBF Fabricated AlSi10Mg Alloys"*,**
developed by Augustine Nana Sekyi Appiah,
Silesian University of Technology

The undersigned, Nedelcu Dumitru, professor at "Gheorghe Asachi" Technical University of Iasi, Department of Machine Manufacturing Technology, was appointed by letter (RDIMa.512.33.2025) from the Head of the Discipline Council of Materials Engineering of the Silesian University of Technology, Professor Adam Grajcar, dated July 8, 2025, to prepare an opinion as an external reviewer of the doctoral dissertation with the title "Deformation – Induced Size Effects on the Structure and Mechanical Properties of Heterogenous L-PBF Fabricated AlSi10Mg Alloys", developed by Mr. MSc Augustine Nana Sekyi Appiah under the Supervisor of Professor Marcin Adamiak and Co-supervisor Doctor Przemyslaw Snopinski.

Upon reviewing the content of the doctoral dissertation, I have formulated the following assessments and conclusions.

1. The importance and opportunity of the research

The doctoral dissertation developed by Mr. Engineer Augustine Nana Sekyi Appiah is well-designed and structured into six chapters, accompanied by a series of three annexes. All the chapters have a logical development that reaches the initially established objectives in the experimental research. The Introduction chapter, in addition to some general aspects, presents the mechanical properties of cast and additively (powder bed fusion – laser beam/metal, PBF-LB/M) manufactured Al-Si alloys, taking into account AlSi7Mg, AlSi10Mg, and AlSi12Mg. Because of its optimal performance properties, AlSi10Mg has become particularly prominent among the Al-Si alloy spectrum. Consistent layer consolidation is promoted by the 10% silicon content, which improves melt fluidity during processing and reduces defects appearance associated with incomplete fusion or balling phenomena. Additionally, during later aging

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treatments, the magnesium addition permits the production of Mg2Si precipitate, which enhances the hardness and tensile strength values. When compared to other formulations like AlSi7Mg and AlSi12Mg, this microstructural characteristic places AlSi10Mg as a balanced composition providing beneficial strength-ductility combinations for structural applications. These performance advantages make AlSi10Mg the main material under consideration in this phd thesis.

Because of their remarkable specific strength values and thermal conductivity performance, Al-Si alloy structures are in high demand in the automotive and aerospace industries, which makes this research significant. When compared to their traditionally cast equivalents, these additively synthesized Al-Si materials have garnered special interest because of their high mechanical property profiles, which include improved strength, formability, and durability.

The primary goal of the phd thesis, which is to strategically optimize the microstructural heterogeneity of AlSi10Mg in PBF-LB/M through controlled post-processing, is well justified by the thesis's author. This research attempts to identify the basic principles regulating strain hardening in these particular heterostructures by methodically linking post-processing conditions with in-depth microstructural characterization and mechanical property evaluation. The goal is to offer a mechanism-based understanding for designing lightweight parts for the aerospace and automotive industries that outperform traditional aluminum alloys without compromising recyclability potential at the end of their useful lives.

2. Analytical considerations

The *Introduction* chapter stands out for its clear justification of the chosen research direction, as mentioned above.

The current state of the art in the research field or literature review is part of Chapter II of this thesis. At the very beginning are presented the roadmap of additive manufacturing processes (AM). AM technologies cover a wide range of processes, each distinguished by unique methods for applying energy and managing materials. The ability of powder bed fusion (PBF), which includes PBF-LB/M and electron beam melting (EBM), to create extremely dense and mechanically strong metal parts makes it particularly important. Thus, PBF-LB/M is widely utilized in accuracy-demanding applications because it melts metal powders layer by layer to create parts with accurate geometries and complex shapes. In aerospace and medical device manufacture, where component integrity and dimensional accuracy are crucial, this precision and the capacity to create parts with fine features are priceless. Nevertheless, AM technologies have several drawbacks despite these advantages. It might be difficult to guarantee constant quality in AM-fabricated components due to problems, including porosity and anisotropy in printed parts, which can negatively affect mechanical qualities and durability. The following sections present in detail the stages of the PBF-LB/M 3D printing process, followed by the microstructure, residual defects that may occur, and aspects related to the 3D printing of the AlSi10Mg alloy. The author of the thesis has made some previous contributions outside of research into obtaining structures from these alloys by casting, presenting clear comments on the resulting microstructure. The chapter also contains a theoretical information regarding the dislocations that occur during deformation, dislocation exhaustion rates across deformation stages, melt pool boundaries vs. melt pool interiors, dislocation accumulation and grain refinement, severe plastic deformation (SPD), and strengthening mechanisms. At the end of the chapter, the main objective of the research and the secondary objectives that led to the solution of the research are presented.

Chapter III, entitled *Methodology*, has a logical structure, and the experimental plan is divided into four major stages, as follows: initial additive manufacturing and material selection, sample conditioning, deformation processing, and comprehensive characterization. I would like to highlight this comprehensive and complex experimental plan that is very well structured, thoroughly detailed, and presented. Thus, the methods, the equipment, and the materials used in the experimental part are detailed.

The experimental results are presented in Chapter IV of the doctoral thesis. The comparative study of structures obtained by 3D printing from AlSi7Mg, AlSi10Mg, and AlSi12Mg alloys, based on microstructure, porosity, and microhardness analysis, supported the choice of the AlSi10Mg alloy in the research. Thus, the AlSi10Mg alloy has outstanding flowability and morphological consistency from a powder metallurgy perspective, which are essential for steady layer deposition and defect reduction during PBF-LB/M processing. More, the AlSi10Mg powder showed the narrowest particle size distribution in the current comparison investigation with AlSi7Mg and AlSi12Mg, which directly contributed to its higher structure quality. According to the as-built microstructural study, AlSi10Mg had the lowest porosity and the most refined cellular structure of the three alloys, which was highly correlated with greater Vickers microhardness values. AlSi10Mg had been chosen because of its baseline properties. This is the reason why the proposed research will focus on how the initial cellular microstructure of PBF-LB/M of AlSi10Mg dictates its strain hardening behavior and grain refinement during the SPD process. The chapter continues with a section of results focused on the study of the mechanical properties of three distinct initial states: as-built (Si network), heat-treated (partially ruptured network, Low Temperature Annealing, LTA_280^{0}C for 9 minutes, and fragmented and spheroidized Si particulate structure, LTA_300^{0}C for 30 minutes), PBF-LB/M of AlSi10Mg. To evaluate the impact of thermal treatments on mechanical performance, the study includes Vickers microhardness tests, uniaxial compressive testing, and work hardening behavior analysis. The mechanical testing results are coupled with supporting microstructural investigations to offer mechanistic insight into the observed property changes. The combined goal of these analyses is to clarify how the plastic deformation mechanisms controlling strength and strain hardening in PBF-LB/M AlSi10Mg alloys are influenced by the continuity of the sub-cell network. The results obtained are centralized in a table, which shows that the best results are in the case of as-built samples, with a microhardness value of 115.8±4.5, with a good dispersion of results. These samples were then subjected to both gradual uniaxial compression and severe plastic deformation (SPD) via

Equal Channel Angular Pressing (ECAP) and Twist Channel Angular Pressing (TCAP) at various temperatures and passes. I appreciated the centralization of results for each deformation technology, which shows in which situations the best results are obtained. The results show that the primary factor controlling the alloy's mechanical properties is the continuity of the Si network. The continuous network in its as-built state promotes strong initial strain hardening and significant kinematic hardening (back stress up to about 351 MPa post-ECAP). A crucial pre-conditioning step was found to be the LTA_300 treatment, which breaks up the brittle network. Applying SPD to the ductile LTA_300 pre-conditioned material showed to be a promising key to getting improved characteristics. On the other hand, embrittlement resulted from SPD processing of the as-built material. It was discovered that high-temperature ECAP ($\geq 350°C$) was harmful. These results offer a proven method for creating aluminum parts that are lightweight and resistant to damage for cutting-edge automotive and aerospace applications.

The experimental data reported in Chapter IV are thoroughly analyzed and interpreted in this chapter. Clarifying the complex interactions of alloy composition, thermal behaviour, and deformation processing on the microstructural development and ensuing mechanical characteristics of Al-Si-Mg alloys produced by additive manufacturing is the goal of the discussion. The results are explained in the context of severe plastic deformation, dislocation theory, and physical metallurgy. The discussions cover absolutely all the results obtained and are explained very clearly.

The final chapter of the doctoral thesis presents the general conclusions and contributions of the author, Mr. Augustine Nana Sekyi Appiah.

3. Assessments and conclusions

The scientific level of the doctoral dissertation developed by the engineer. Augustine Nana Sekyi Appiah is a high one demonstrated by the original results obtained. I believe that this scientific level corresponds to the requirements of a doctoral thesis, the basis of this statement is the aspects previously presented in detail.

a. The thesis presentation

-The clear presentation of the methods and techniques used, the writing of the chapters, the elaboration of the graphic material are of a high standard, which demonstrates the real researcher qualities of the author;

-The doctoral thesis structure is very well directed in order to fulfill the initially established objectives and has a favorable relationship between the written and the graphic part, between the analysis and synthesis part of the current stage of the research and its originality part;

-Mr. Augustine Nana Sekyi Appiah demonstrates a very good theoretical training, manifested in the way of designing and following the research program, as well as the ability to analyze and synthesize both the studied articles and of their own research.

b. Author contributions

I have noted the following contributions by the author in this thesis:

-conducting an important study in the technical literature on the use of AlSiMg alloys in obtaining structures through 3D printing in a well-defined parallel with conventionally processed alloys;

-EDS spectra and quantitative chemical composition of Al-Si powders;

-microstructures of PBF-LB/M AlSi7Mg, AlSi10Mg, AlSi12Mg under Light Optical Microscopy and under the Scanning Electron Microscopy;

-diagrams of porosities of all alloys highlighted above;

-diagrams of Vickers microhardness along the cross-section for Al-Si alloys;

-microstructures of the as-built PBF-LB/M AlSi10Mg from EBSD analysis and from TEM;

-microstructures after annealing at 280 °C for 9 minutes, LTA_280 under LOM, SEM, EBSD, and the same in case of LTS_300;

-diagrams of stress-strain behavior at different strain levels (5% strain compression, 20%, and maximum strain compression before and after heat treatment;

-XRD spectra after compression at 5%, 20% and maximum strains;

-microstructures, microhardness diagrams, after ECAP and TCAP processing.

The thesis's findings could be used in demanding industries like aerospace and automotive to fabricate lightweight, fuel-efficient, and damage-tolerant brackets, chassis elements, and other structural parts that are currently made of more complicated multi-material assemblies or heavier materials.

Based on the above comments and evaluations, I find that the doctoral thesis developed by Mr. Augustine Nana Sekyi Appiah has both a high scientific and applied level, for which a significant amount of work has been submitted in the analysis and synthesis of the specialized references, and for the realization of his own research. The doctoral thesis contains numerous original contributions, meets the requirements expected of such a work, and I recommend that it be accepted for defense. In conclusion, the submitted dissertation fulfills the legal requirements for the doctoral degree and can proceed to the next stages.

Iaşi, September 3rd, 2025

Prof. D. Nedelcu

/podpis odręczny/

*wyłączenie jawności w zakresie danych osobowych oraz ochrony prywatności osoby fizycznej na podstawie art. 5 ust. 2 ustawy z dnia 6 września 2001 r. o dostępie do informacji publicznej (tj. Dz.U. z 2016 r., poz. 1764)