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Physical Characterization of the Compaction Process of Aluminium Alloy Chips After Machining

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This article presents a study of the compaction process of aluminium alloy chips from a physics-based perspective, focusing on the mechanical behaviour and physical parameters that govern material densification. The research involves experimental analysis of the force–density relationship during uniaxial compaction, with particular attention paid to the role of chip geometry, material fragmentation, and briquette diameter. The compaction process is interpreted through the lens of applied physics, considering stress distribution, particle rearrangement, and changes in bulk density. The results offer insights into the fundamental physics of deformable metallic systems and contribute to the development of efficient, physics-driven approaches to metal waste reduction in machining operations. The findings have potential applications in materials science, solid-state physics, and environmentally oriented industrial physics.

topics: compaction ratio, modulus of elasticity, agglomerate, aluminium alloy chips

1. Introduction

The process of compacting waste materials has been known for many years. Wherever it is advantageous to reduce the volume of post-processing materials for storage, transportation, or preparation for the next stage of the technological process, machines equipped with working assemblies that enforce a reduction in the volume of the working chamber are employed [1]. Most often, these are various types of machines with piston working assemblies. The design process of such machine assemblies requires information on specific parameters related to material properties [2, 3]. These parameters are, in terms of values, entirely different from the properties of solid, non-fragmented, non-waste materials. Therefore, it is necessary to conduct studies to determine these properties, to propose new testing methods and new testing setups that will enable the measurement and determination of specific material property parameters not only as direct input data for design, but also as data for numerical material models used in the simulation of compaction processes [4]. In this article, the authors attempted to determine the basic parameters of the compaction process, namely the compaction ratio, compaction force values, and modulus of elasticity. The material subjected to the tests consisted of aluminium alloy chips obtained from machining processes.

2. Test material and experimental setup

Figures 1–3 present the form of the tested material. These were chips of aluminium alloy with various fractions (EN-AW 5083). The geometry and dimensions of the chips were selected so that they exhibited a clear diversity during the compaction process. Figure 4 shows the experimental setup and equipment. Tests were carried out on an MTS Insight testing machine with a load capacity of 50 kN. Compaction trials were conducted in cylindrical sleeves cooperating with cylindrical pistons with a diameter of 10 mm.

Fig. 1. Material A — chips from machining of EN-AW 5083 alloy.

Fig. 2. Material B — chips from machining of EN-AW 5083 alloy.

Fig. 3. Material C — chips from machining of EN-AW 5083 alloy.

Table I presents the bulk densities of the three tested materials.

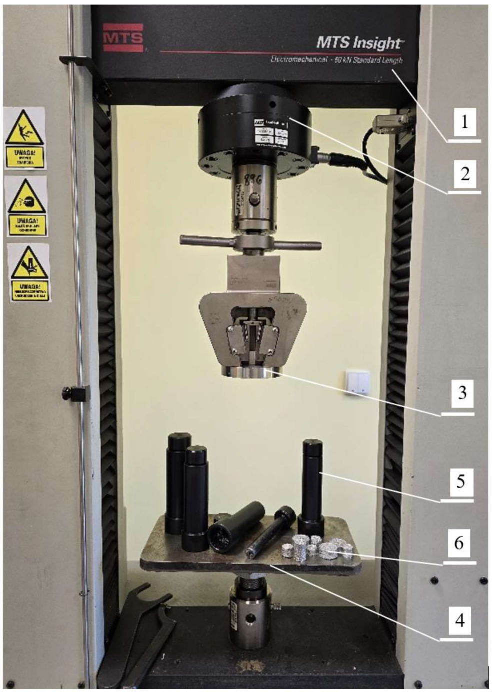

Fig. 4. Experimental setup with equipment: 1 — testing machine, 2 — force sensor, 3 — upper part of the holder, 4 — lower part of the holder, 5 — sleeve and piston assembly, 6 — compacted material.

TABLE I

Bulk densities of the tested materials.

	A	B	C
Bulk density [kg/m^3]	604 ± 8	458 ± 7	866 ± 11

3. Preliminary research results

First, compaction tests were conducted for all types of materials in a sleeve with a diameter of 10 mm, using sufficient force to achieve a compaction pressure of 300 MPa. The purpose of this test was to estimate an effective and economically justified degree of chip compaction. Figures 5–10 present the compaction force as a function of piston displacement and as a function of the degree of compaction. The trend was confirmed that the material with the lower bulk density, under the same compaction stress, achieved a significantly higher compaction ratio. For Material A, it exceeded 20, while for Material C, it was less than 5. The next step is to estimate the effective compaction ratio. The choice of this value can depend on various factors, but the most important is the desired final volume, which influences, for example, the subsequent storage or transportation volume of the compacted material.

On the other hand, it is necessary to estimate the costs of compaction. As the compaction ratio increases, the force increases in a strongly nonlinear manner, meaning that achieving a certain degree of compaction will result in a significant increase in costs for further compaction. For the purposes of further studies, it was assumed that an increase in the compaction force in successive time steps (at constant speed, i.e., related to punch displacement) above a certain value makes the process inefficient. In the present study, this threshold was set at

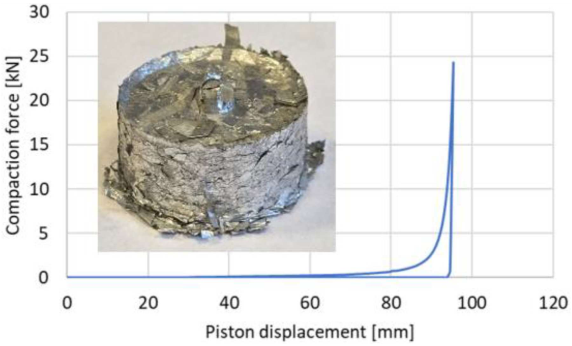

Fig. 5. Compaction force as a function of piston displacement for Material A.

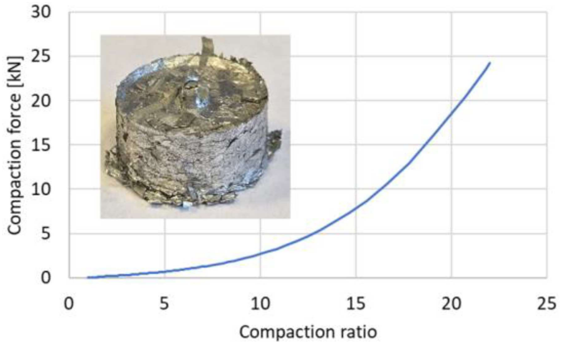

Fig. 6. Compaction force as a function of the compaction ratio for Material A.

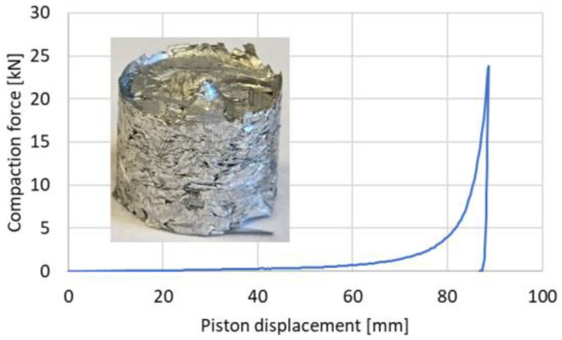

Fig. 7. Compaction force as a function of piston displacement for Material B.

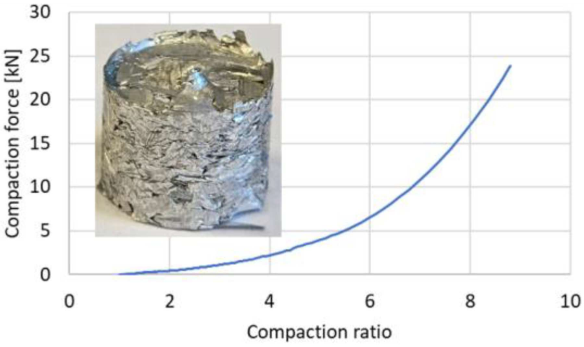

Fig. 8. Compaction force as a function of the compaction ratio for Material B.

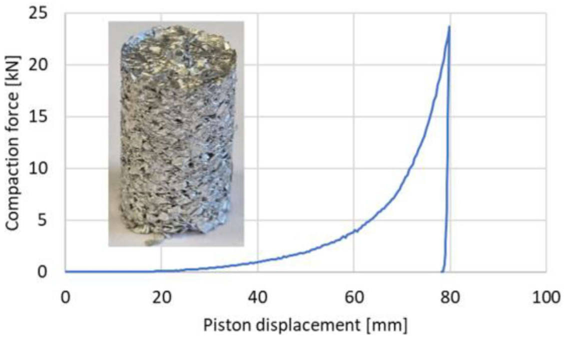

Fig. 9. Compaction force as a function of piston displacement for Material C.

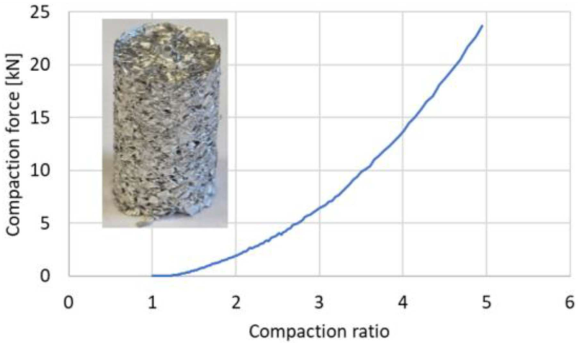

Fig. 10. Compaction force as a function of the compaction ratio for Material C.

a compaction force of 1000 N. Thus, if the increase in compaction force exceeded 1000 N per 0.1 mm of punch displacement, the process was stopped.

Figure 11 shows the values of compaction force increments (per 0.1 mm) as a function of piston displacement. Taking these limitations into account, further compaction tests were conducted with the following compaction force values: Material A — 6200 N (79 MPa), Material B — 11000 N (140 MPa), and Material C — 23500 N (300 MPa). The greatest savings were achieved by reducing the compaction force for Material A. Figure 12 presents the graphs of compaction force as a function of piston displacement for forces of 23500 and 6200 N. A nearly fourfold reduction in compaction force results in only a slightly lower compaction ratio.

After determining the effective degree of compaction, which should be defined individually (for example, according to the proposed method), it is possible to determine additional physical parameters of the compacted material. One of the most frequently sought parameters is the modulus of elasticity. Determining it for compacted material is challenging and is often done based on the unloading curve [5]. For even more detailed insight into these values, several compaction and unloading

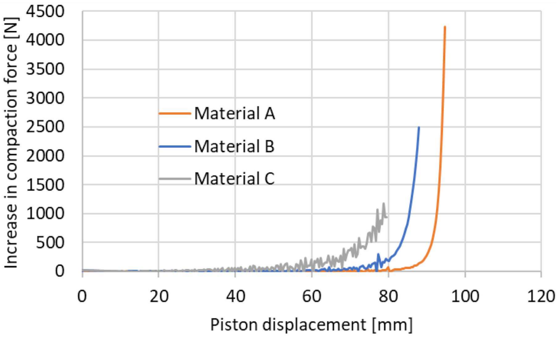

Fig. 11. Increment of compaction force (per 0.1 mm) as a function of piston displacement.

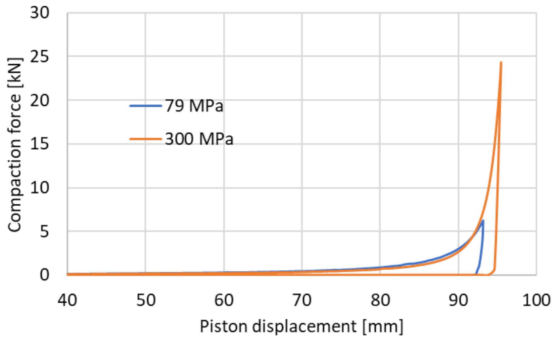

Fig. 12. Compaction force as a function of piston displacement for Material A.

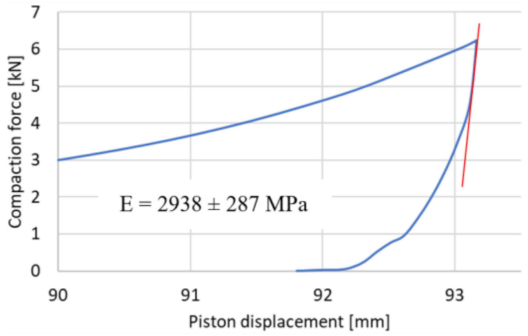

Fig. 13. Compaction force as a function of piston displacement for Material A.

cycles can also be performed with increasing compaction force. Figures 13–15 show the method for determining the modulus of elasticity for the tested materials, taking into account the values of the effective compaction force.

4. Conclusions

Identifying physical material parameters is extremely important when planning the compaction process of waste materials. It is necessary to conduct an analysis of the compaction process's efficiency. Then, for established maximum compaction forces, identification of physical strength parameters can be carried out. The methods presented in this article can serve as a universal procedural algorithm when initiating the design process of the working assembly of a machine for compacting a selected waste material.

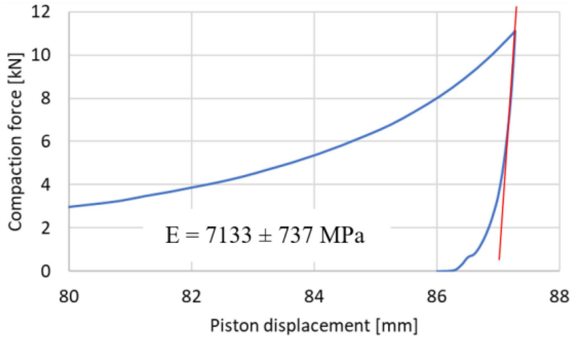

Fig. 14. Compaction force as a function of piston displacement for Material B.

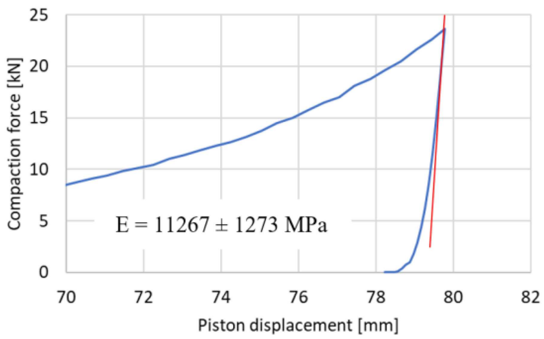

Fig. 15. Compaction force as a function of piston displacement for Material C.

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