MICROSTRUCTURAL CHARACTERIZATION OF COMPACTED AND EXTRUDED SPECIMENS MADE OF ALUMINIUM ALLOY CHIPS

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Received 06 December 2022
Accepted 23 April 2023

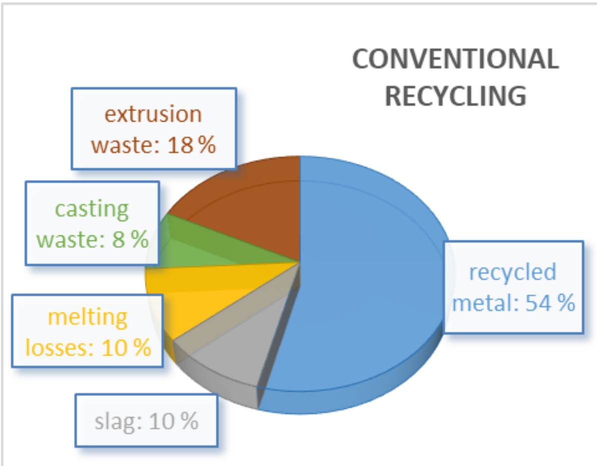
ABSTRACT

The purpose of this research is to characterize compacted and extruded specimens made of aluminium alloys chips using micro computed tomography technique. Specimens were prepared through cold and hot compaction, which yield two types of so-called "compacts". After that the compacts were subjected to hot extrusion to obtain the final extruded products. Results show that, depending on the type of alloy, porosity of compacts varies between (a) 4.55 % and 14.28 % for cold-compacted specimens and (b) between 0.15 % and 2.79 % for hot-compacted specimens. Porosity of extruded specimens is close to zero. It is concluded that the results of this study provide a good basis for further research aimed at finding the optimal process parameters for compaction and extrusion.

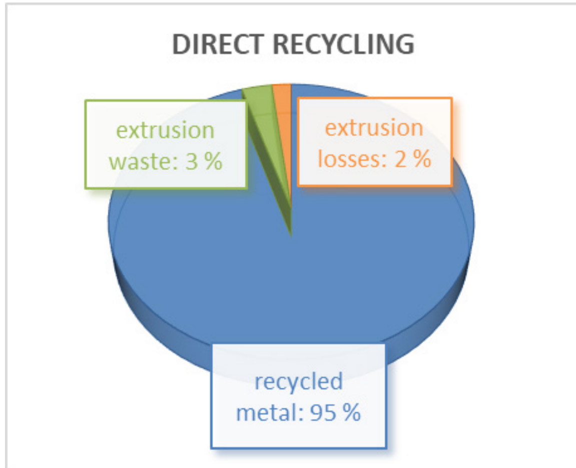
Keywords: aluminium alloy chips, compaction, extrusion, X-ray micro computed tomography.

INTRODUCTION

The main method of recycling aluminium is through re-melting. For many years, this method has been used to recycle metal waste from the automotive industry, construction, aircraft manufacturing, metal casting and other industries, which are the main suppliers of aluminium scrap [1]. However, there is also a significant amount of scrap (15 % - 30 %) in the form of chips (shavings) generated by metalworking enterprises, the processing of which requires special measures [2]. The low density of chips and their large relative surface area covered with oxides and contaminated by mechanical processing make them inconvenient to handle and transport. Their re-melting leads to additional oxidation and burning, and ultimately to metal losses reaching 50 % and more [3]. Therefore, for more than 50 years, an increase in the chips volume density has been applied by the so-called "briquetting". Nevertheless, the loss of metal, already during re-melting is about 20 %. If losses during casting, cutting and plastic deformation (pressing and rolling) are added to this, the yield of the conventional recycling process barely exceeds 50 % (Fig. 1(a)) [3]. Besides, conventional recycling poses potential explosion hazards as a result of the moisture and impurities contained in the compacted chips, as well as environmental pollution from fumes and waste during the melting process. That is why, in recent years, more and more interest has been drawn by the process of so-called direct (solid phase) chips recycling. The direct recycling method avoids the energy- and labour-intensive melting process and enables the recycling of nearly 95 % of the chip scrap (Fig. 1(b)) [3]. It also provides for significant energy savings (26 % to 31 %) and labour costs (16 % to 60 %) compared to the process of conventional recycling [4]. The direct recycling process is relatively simple, with low energy consumption and harmless to the environment. It consists of several basic steps: cleaning and comminution of chips, cold or hot compaction followed by hot extrusion or rolling to obtain a final semi-finished product [5]. Depending on the state of the raw materials and the selected scheme, some of the process steps may be omitted. Direct recycling of aluminium chips is still at the stage of experimental research and proving its potential for obtaining quality products. Despite the



(a)



(b)

Fig. 1. Comparison between conventional (a) and direct (b) recycling of aluminium alloy chips [3].

obvious economic and "green" effects, the adoption of the process by industry is slow and hesitant, mainly due to the perception that the improvement of the properties of the resulting semi-finished products has not yet been unconditionally proven [5].

The purpose of this research is to characterize compacted and extruded specimens made of aluminium alloys chips using X-ray micro computed tomography (CT) technique.

EXPERIMENTAL

The preparation of the specimens started with compaction (pressing) of the aluminium alloys chips. This is a process in which, by applying pressure on a mould, a specimen with a certain shape, density and porosity is obtained. To accomplish the chips compaction, a special press mould, shown in Fig. 2, was constructed [6].

Four types of aluminium alloys were used in the experiments:

- Two casting alloys: EN AC-48000 (AlSi12CuNiMg) and EN AC-42000 (AlSi7Mg). The first one is eutectic while the second one is sub-eutectic.
- Two plastically deformable alloys: EN AW-2024 (AlCu4Mg1) and EN AW-6082 (AlSi1MgMn).

These alloys are widely used for the production of various details in a number of industries, which implies the generation of large amounts of chips during mechanical processing [7].

Two types of compaction were applied: cold (at 20°C) and hot (at 450°C). Fig. 3 shows the specimens obtained after cold compaction (20°C) - one specimen from each alloy type.

Fig. 4 shows the specimens obtained after hot compaction (450°C) - one specimen from each alloy type.

Samples with cylindrical shape (Ø 41 x 15 mm) were cut from the top of all compacted specimens and prepared for microstructural characterization (Fig. 5). The samples were marked as shown in Table 1.

The specimens obtained from hot compaction were subjected to hot extrusion (at 450°C) using the same press mould, on which an extrusion nozzle was installed.

Fig. 2. Special press mould for chips compaction [6].

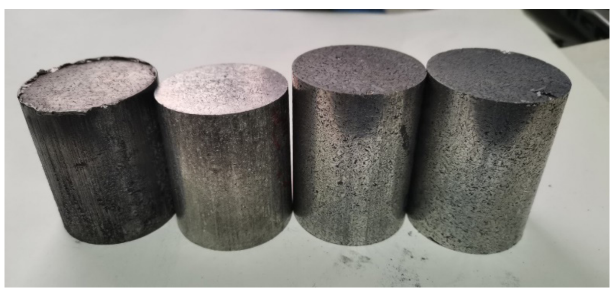


Fig. 3. Specimens obtained after cold compaction.

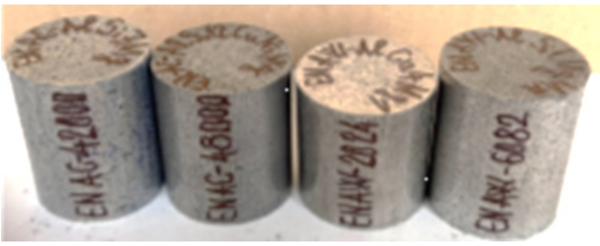


Fig. 4. Specimens obtained after hot compaction.

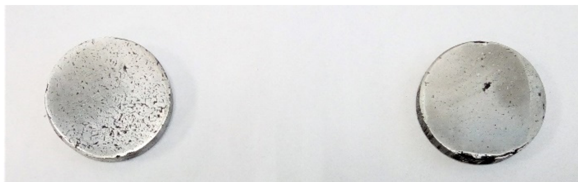
Table 1. Sample marks and respective alloy types.

Sample mark	Alloy type
K1	Cold compacted AlSi7Mg
K2	Hot compacted AlSi7Mg
K3	Cold compacted AlCu4Mg
K4	Hot compacted AlCu4Mg
K5	Cold compacted AlSi1MgMn
K6	Hot compacted AlSi1MgMn
K7	Cold compacted AlSi12CuNiMg
K8	Hot compacted AlSi12CuNiMg

K1 AlSi7Mg K2

K3 AlCu4Mg K4

K5 AlSi1MgMn K6



K7 AlSi12CuNiMg K8

Fig. 5. Samples cut from the compacted specimens.

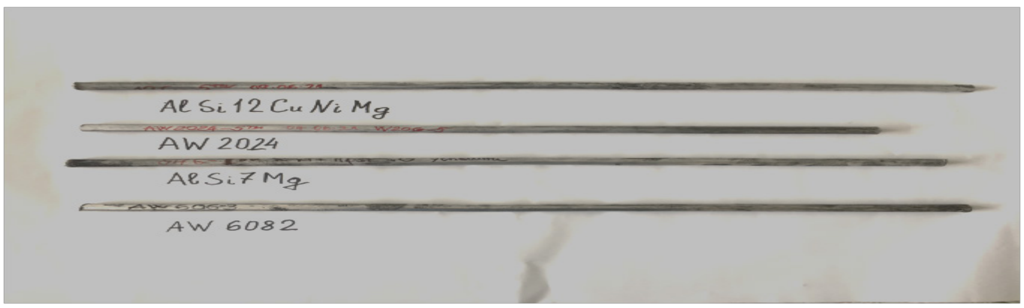
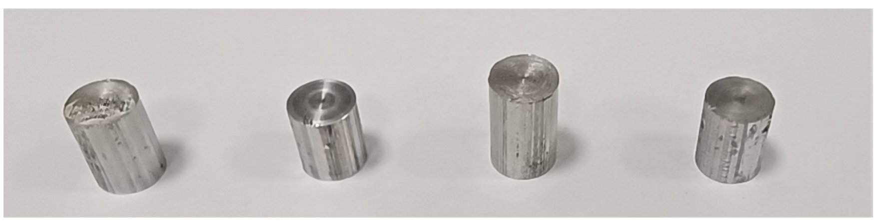


Fig. 6. Extruded specimens.



E2 E4 E6 E8

Fig. 7. Samples cut from extruded specimens.

The extruded specimens are shown in Fig. 6.

Samples with cylindrical shape (Ø 12 x 12-16 mm) were cut from all specimens for microstructural characterization (Fig. 7). The samples were marked as follows: E2 - sample from alloy type AlSi7Mg, E4 - sample from alloy type AlCu4Mg, E6 - sample from alloy type AlSi1MgMn and E8 - sample from alloy type AlSi12CuNiMg.

RESULTS AND DISCUSSION

The samples cut from the compacted and from the extruded specimens were subjected to compute tomography (CT) analysis using a SkyScan 1272 micro computed tomography system by Bruker. A schematic of micro CT system is presented in Fig. 8. This system is intended for quick and non-destructive examination of metallic and non-metallic materials. Detailed information is obtained for: (1) presence of phases with different density in the volume of the studied material, (2) geometrical characteristics of phases with irregular shape and their structure, (3) percentage of total, open and closed porosity, and (4) percentage distribution of pores with different diameters in the volume of the material.

Initially, each sample is positioned in the system chamber using a suitable holder; then suitable irradiation mode (resolution, filter, irradiation step, etc.) is selected. After noise removal, irradiation of the sample is started. When the process is over, so-called “reconstruction” of the sample is performed using NRecon software, in which the obtained X-ray projections are “assembled” and a digital model of the sample is produced. Using CTVox software, sample images are obtained, which can be viewed from all sides to get cross-sectional views. CTAn software was used to calculate various geometrical parameters; in this case data were obtained on closed, open and total porosity.

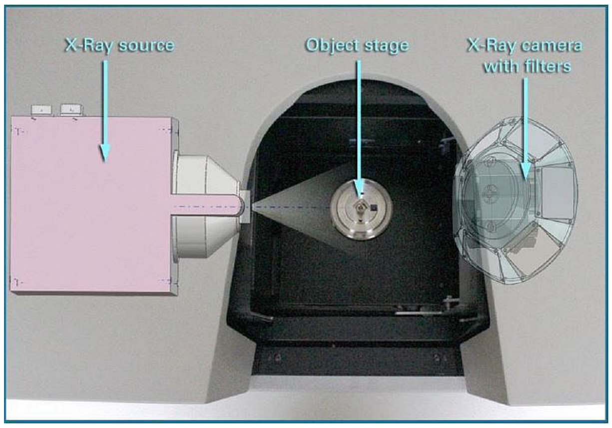


Fig. 8. Schematic of micro CT system.

Samples cut from compacted specimens

The samples were analysed at the following system settings: resolution: 1632 x 1092 pxl, pixel size: 16.2 μm, filter: Cu 0.11mm, source voltage: 100 kV, source current: 100 μA. Due to the large size of the samples (Ø 41mm) the “Oversize/batch scanning” option was used. After reconstruction with NRecon software and processing with CTAn software, porosity data was obtained (Table 2).

The following conclusions can be drawn by analysing the data in Table 2:

- Samples from alloy type AlCu4Mg (K3 and K4) exhibit the highest porosity in their respective series (K3 - in cold compacted, K4 - in hot compacted).
- Sample with lowest porosity among cold compacted is K7 (AlSi12CuNiMg) while sample with lowest porosity among hot compacted is K6 (AlSi1MgMn).
- The greatest change in porosity for pairs of same alloy type is observed for alloy AlSi7Mg (50 x) while the smallest change is observed for alloy AlSi12CuNiMg (2 x).

Table 2. Porosity data for compacted samples.

Sample mark	Closed porosity, %	Open porosity, %	Total porosity, %	Change in porosity for pairs of same alloy type
K1	2.77	8.90	11.42	
K2	0.05	0.18	0.23	▼50 x
K3	3.1	11.54	14.28	
K4	0.96	1.85	2.79	▼5 x
K5	1.79	5.07	6.77	
K6	0.06	0.09	0.15	▼45 x
K7	1.60	3.00	4.55	
K8	1.08	1.1	2.17	▼2 x

Figs. 9 to 12 show selected visualizations of the analyzed samples. Scale bar is provided in the top left corner of the images. For all images the following applies: (I) Part of the sample is selected with dimensions 25 x 24 mm; (II) Side views of three sections of sample volume are presented and (III) Scan moves from foreground to background (from image 1 to image 3).

Analysing the images shown in Figs. 9 to 12 it can be concluded that the visual observation confirms the data already presented in Table 2.

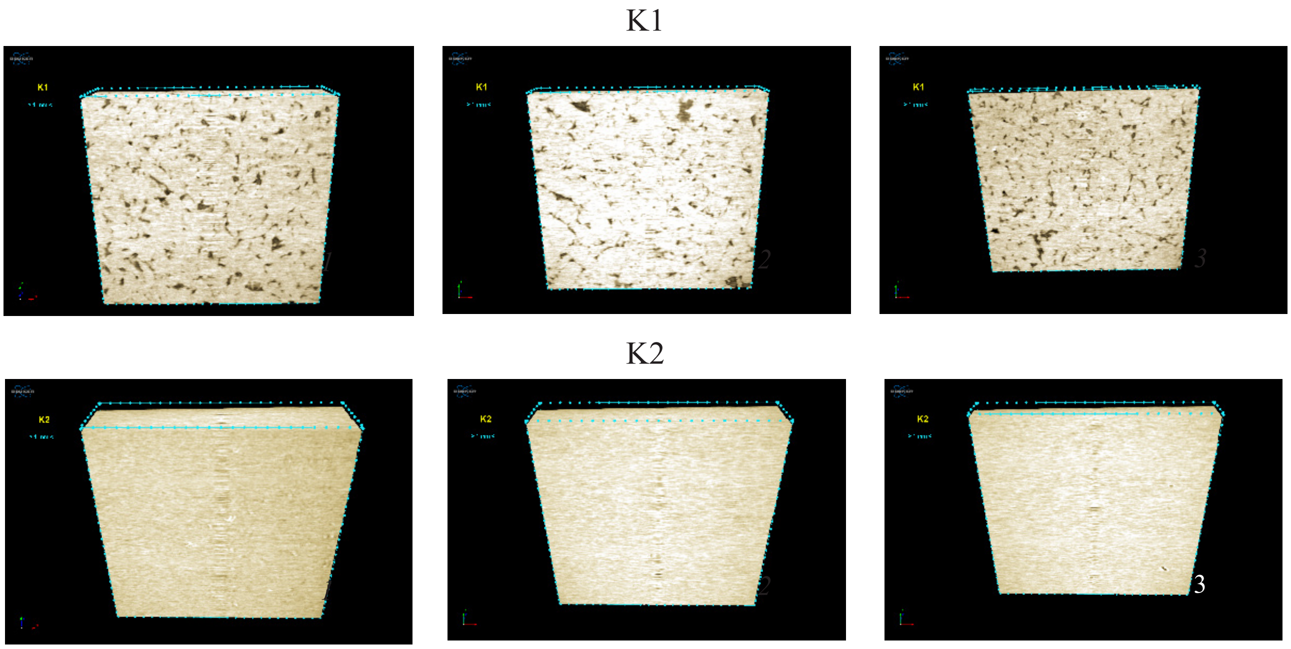


Fig. 9. Side views of sections of samples K1 and K2 (alloy type AlSi7Mg).

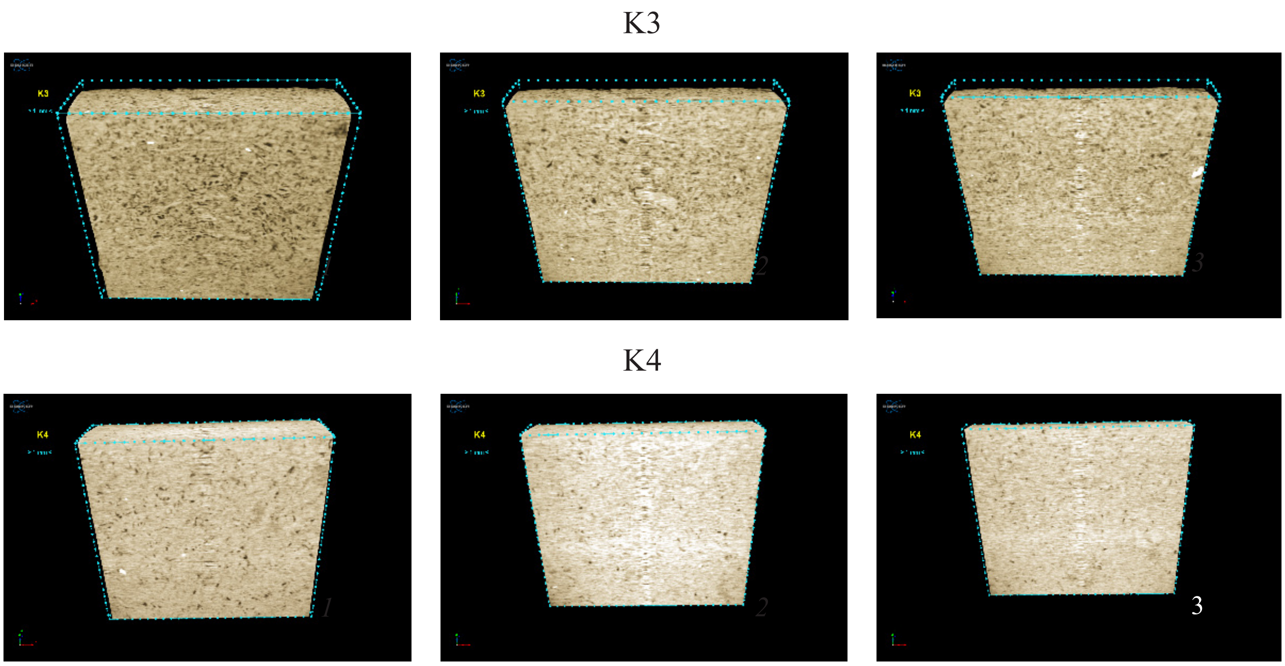
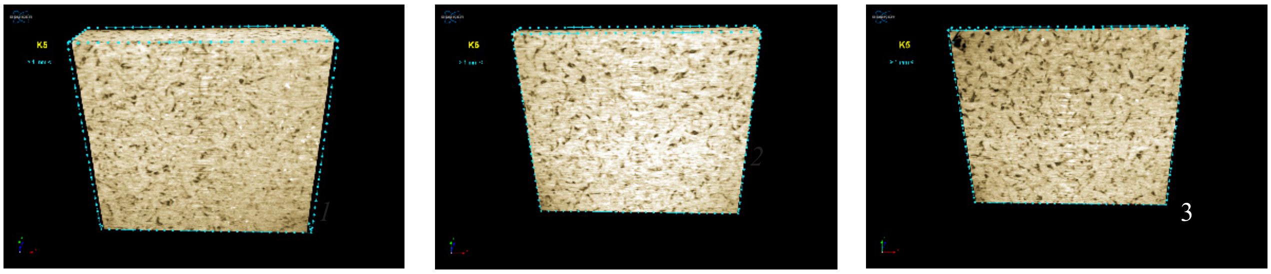


Fig. 10. Side views of sections of samples K3 and K4 (alloy type AlCu4Mg).

K5



K6

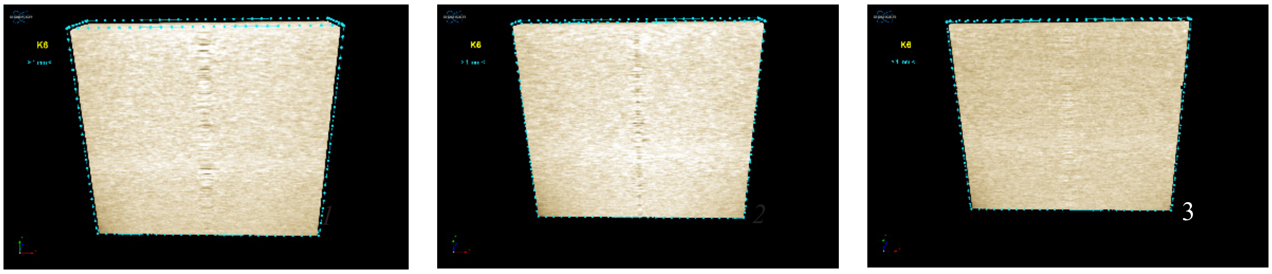
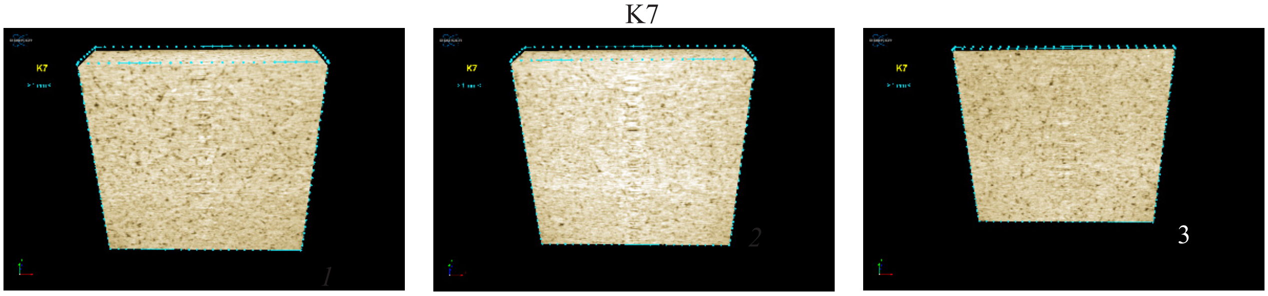


Fig. 11. Side views of sections of samples K5 and K6 (alloy type AlSi1MgMn).

K7



K8

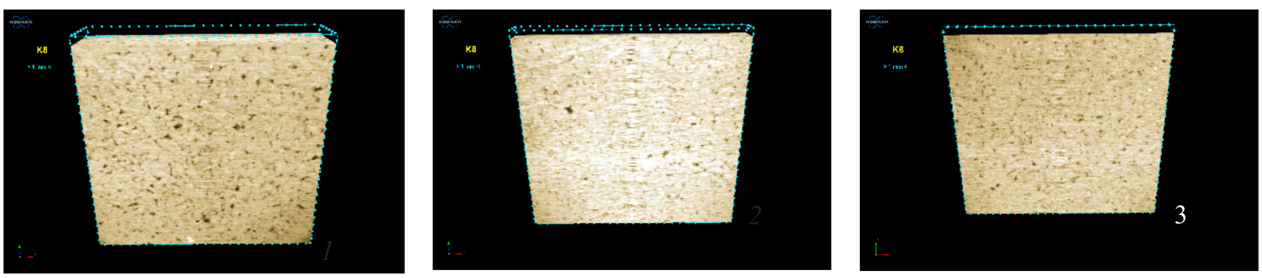


Fig. 12. Side views of sections of samples K5 and K6 (alloy type AlSi12CuNiMg).

Samples cut from extruded specimens

Figs. 13 to 20 show selected visualizations of the analysed samples in top and side views obtained after processing with CTVox software. Scale bar is provided in the top left corner of the images.

The following conclusions can be drawn by analysing the images in Figs. 13 to 20:

- Practically, no porosity is observed in the extruded samples. The only voids that are registered in them are the cavities that are visible in the images. However, the applied software methodology for calculation of pores percentage is not adequate for the calculation of cavities volume.
- Only in one sample (E2) peripheral cavity is observed while in the other three (E4, E6 and E8) radial cavities are observed.
- The largest cavity is observed in sample E6 while the smallest one – in E8.
- The observed cavities are presumably due to the extrusion process.

E2 (AlSi7Mg)

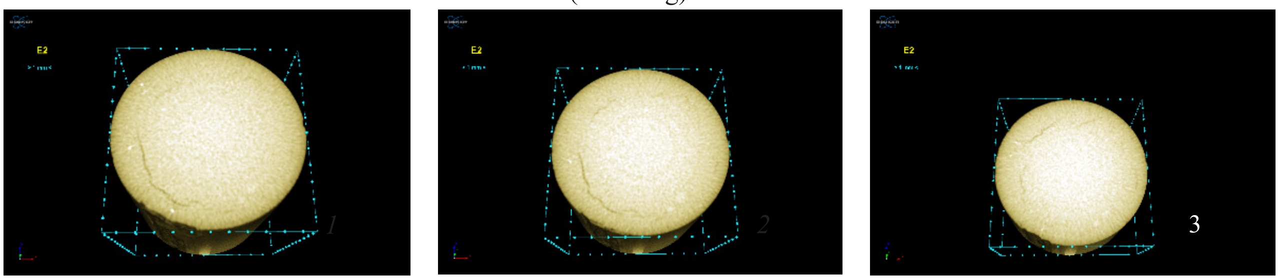


Fig. 13. Sample E2: top view, three slices, scan moves from top to bottom (1 to 3), peripheral cavity observed.

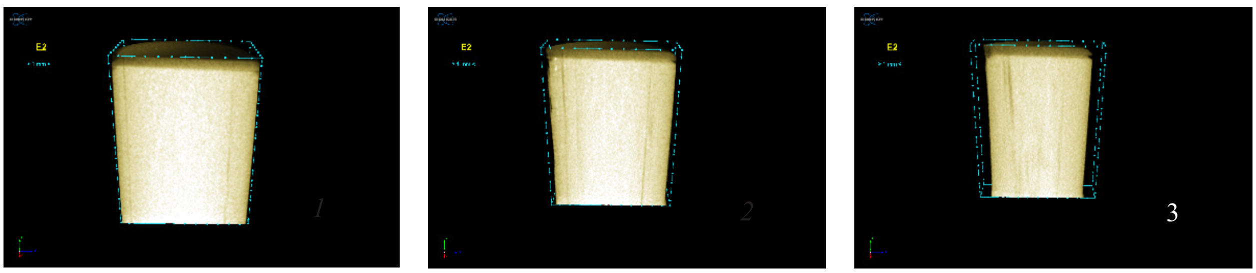


Fig. 14. Sample E2: side view, three slices, scan moves from foreground to background (1 to 3), peripheral cavity observed.

E4 (AlCu4Mg)

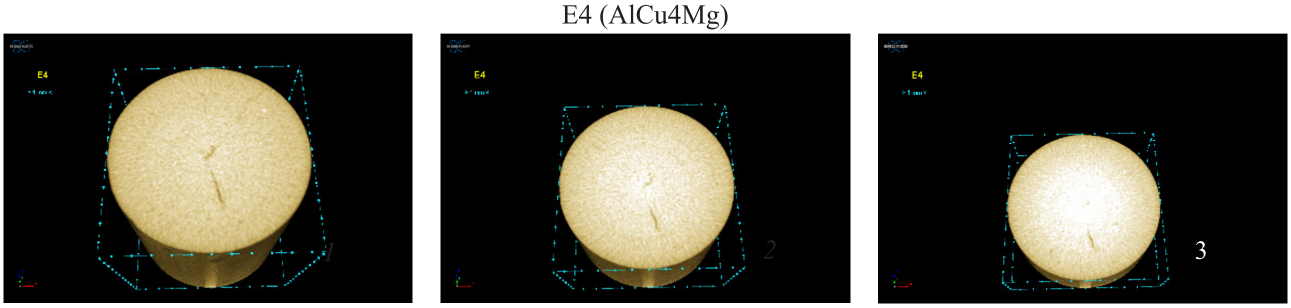


Fig. 15. Sample E4: top view, three slices, scan moves from top to bottom (1 to 3), radial cavity observed.

E6 (AlCu4Mg)

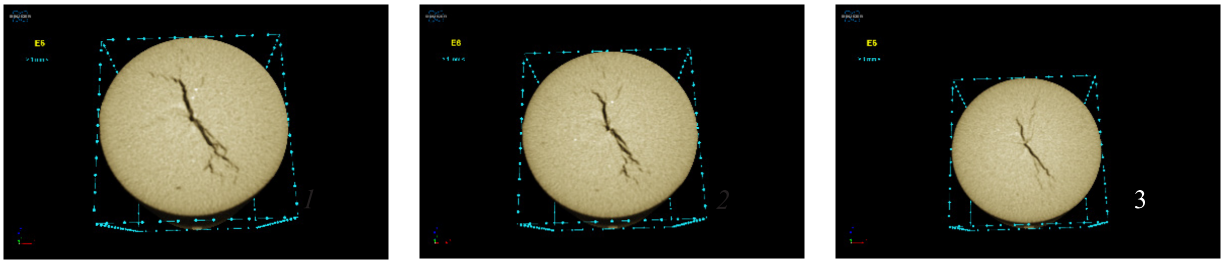


Fig. 17. Sample E6: top view, three slices, scan moves from top to bottom (1 to 3), radial cavity observed (more pronounced that in E4).

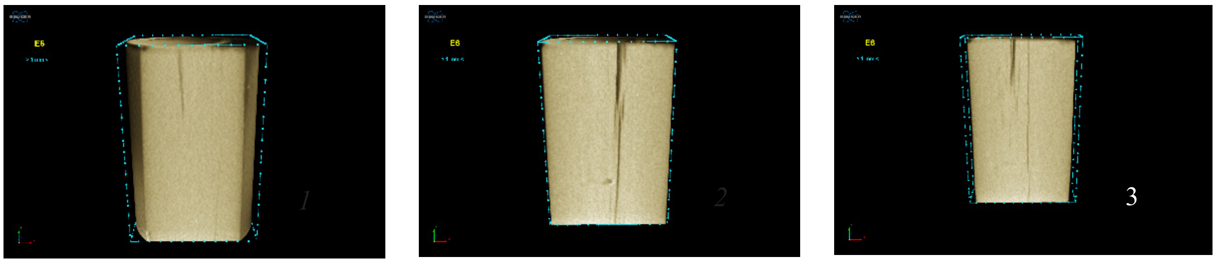


Fig. 18. Sample E6: side view, three slices, scan moves from foreground to background (1 to 3), radial cavity observed (more pronounced that in E4).

E8 (AlSi1MgMn)

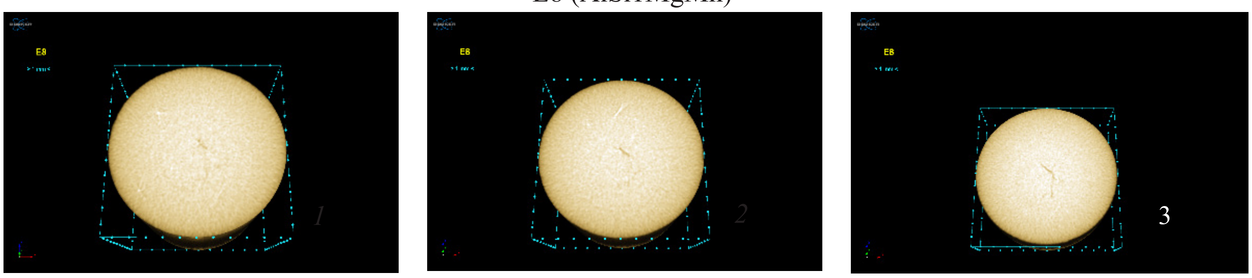


Fig. 19. Sample E8: top view, three slices, scan moves from top to bottom (1 to 3), radial cavity observed (less pronounced that in E4).

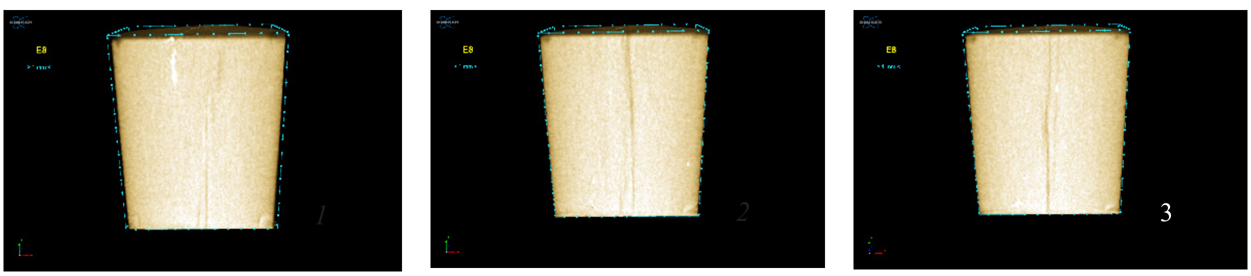


Fig. 20. Sample E8: side view, three slices, scan moves from foreground to background (1 to 3), radial cavity observed (less pronounced that in E4).

CONCLUSIONS

The results obtained from this study show that depending on the alloy type porosity of compacts varies between (a) 4.55 % and 14.28 % for cold-compacted specimens and (b) between 0.15 % and 2.79 % for hot-compacted specimens. Porosity of extruded specimens is close to zero. These results provide a good basis for further research aimed at finding the optimal process parameters for compaction and extrusion i. e. the ones which yield semi-finished products with improved porosity, density and microstructure.

Acknowledgements

This study was made possible thanks to contract "КП-06-Китай/14 (МОН 08/20/4)". The purchase of equipment and experimental units used in this work are result of project BG05M2OP001-1.001-0008 "National Center for Mechatronics and Clean Technologies", funded by the Operational Program "Science and Education for Smart Growth" 2014-2020, co-financed by the European Union through the European Fund for Regional Development.

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