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RECYCLING OF AlMgSi1 ALUMINIUM CHIPS BY COLD COMPRESSION

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Preliminary Note – Prethodno priopćenje

Current work elaborates possibilities for direct conversion of AlMgSi1 aluminium chips into solid billets by solid state recycling. Milling chips from an aluminium alloy were cold compressed in a closed cylindrical die by means of a 2,5 MN hydraulic press. Due to low initial relative density of the chips, several pre-compressions were needed. In order to establish the influence of chip geometry on the final density of billets different types of chips were cut by using various milling regimes. The influence of a compression regime due to various chip types were followed by load–stroke diagrams. Up to 97 % of density measured at extruded aluminium was attained for one type of chips. Results show that the shapes of the chips and their size (especially thickness) have a considerable influence on the final integrity of billets.

Key words: aluminium chips, chips consolidation, cold compression, recycling

Recikliranje krhotina legura aluminija AlMgSi1 pomoću hladnog sabijanja. Ovaj rad istražuje mogućnosti za izravnu konverziju krhotina aluminijske legure AlMgSi1 u čvrst pripremak. Aluminijiske krhotine su hladno sabijani u zatvorenoj matrici pomoću 2,5 MN hidrauličke preše. Zbog male početne gustoće krhotina bilo je potrebno izvršiti nekoliko pre-sabijanja u zavisnosti od tipa krhotina. Da bi se istražio utjecaj geometrije krhotine na krajnju gustoću uzoraka, rezanje krhotina je izvedeno različitim režimima. U radu je prikazan utjecaj tipa krhotine na krajnju gustoću uzoraka, kao i dijagram sila – put procesa sabijanja. Relativne gustoće pojedinih uzoraka prilikom sabijanja dostigle su i 97 % od gustoće ekstrudiranog aluminija. Rezultati istraživanja pokazuju da oblik i veličina (a naročito debljina) krhotine ima značajan utjecaj na krajnju gustoću uzoraka.

Ključne riječi: krhotine aluminija, spajanje krhotine, hladno sabijanje, recikliranje

INTRODUCTION

After iron aluminium is the second metal most used in the world. As a chemical element, aluminium is the third most common element in the Earth's crust, with a total weight of about 8 %. This material, produced from bauxite ore, is widely used in industry, mainly due to its low density, good mechanical properties and corrosion resistance. Another valuable asset of aluminium is its good recyclability.

Aluminium foundries are responsible for 1 % of the world's total man-made greenhouse emissions, where 0,4 % is for aluminium production itself and 0,6 % is from electricity needed for this process. In the United States, 1,2 % of all electricity consumed by entire economy is used in aluminium production plants [1]. International Aluminium Institute states that recycling of aluminium uses only 5 % of energy needed to produce this metal from bauxite ore [2]. Today, approximately one third of total world's aluminium production originates from recycling. Main sources of recycled aluminium are found in transportation vehicles, buildings and packaging.

However, conventional recycling of aluminium chips and scrap produced in industry has several disadvantages by reason of energy and material waste. Conventional recycling consists of several time-consuming processes such as aluminium scrap collection, compression into large bricks, shredding, separation, melting and ingot production [2]. Samuel claims [3] that up to 38 % of material (depending on the process) is lost during conventional recycling mainly due to burning and mixing of aluminium with slag. In [4] it is indicated that more that 70 % of energy needed for conventional recycling is used on melting (including repercussions of this phenomenon, such as slag treatment and refining). In order to eliminate melting procedure and therefore reduce energy and material consumption, several authors have performed new direct conversion methods for recycling of aluminium chips into solid billets. These methods consider imposing high pressures on Al-chips in order to obtain proper material bonding.

The main issue in direct Al-chips solidification is the layer of aluminium oxide (alumina) that forms on aluminium surface. This very hard layer forms almost instantly after exposure to oxygen and is 4 nm thick [5]. In order to crack alumina and obtain good solidification, high strains imposed on chips are needed. To ensure that no decomposing of chips takes place, high hydrostatic pressure and good lubrication is a necessity as well [6 to

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8]. This paper examined the influence of the shape and size of chips on cold compression parameters and final densities of billets. Experimental research was conducted at the Faculty for Mechanical Engineering in Ljubljana, Slovenia in the Laboratory for Metal Forming.

CHIPS FABRICATION

Chips were cut from extruded AlMgSi1 feedstock of φ130 mm diameter on two different milling machines in various regimes without a lubricant so that several types of chips were obtained. Milling of Al-ingot was performed at the Laboratory for Cutting at the Faculty of Mechanical Engineering Ljubljana by using the following machines:

- Mori Seiki Frontier (CNC machine),
- ALG 100 (Conventional machine).

Alloy AlMgSi1 was chosen due to its wide application in mechanical and electrical industries. Table 1 presents different types of chips obtained from milling operations and milling parameters.

All types of chips differ both in length and width as well as in thickness. Types A and B express significantly lower thicknesses than C, D and E types.

COLD COMPRESSION

Cold compression of chips was carried out on a 2,5 MN double-stroke hydraulic press in a φ32 mm closed die. Schematics of the compression process and a photograph of the used tools are given in Figure 1.

An amount of approx. 33 g of Al-chips was used for each compression to ensure the final specimens' heights of 15-17 mm depending on the chip type.

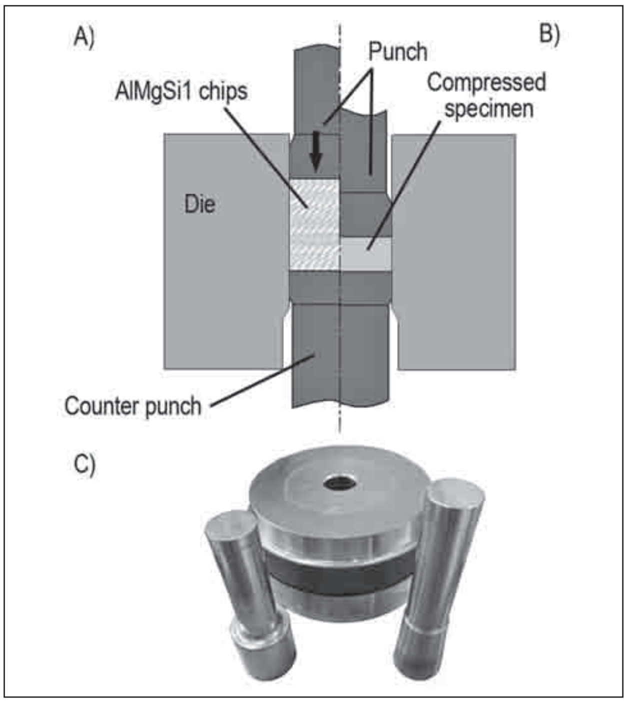
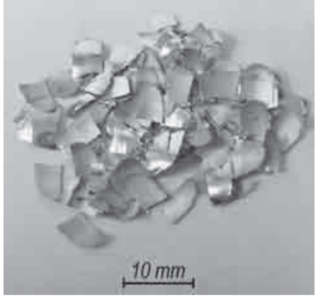
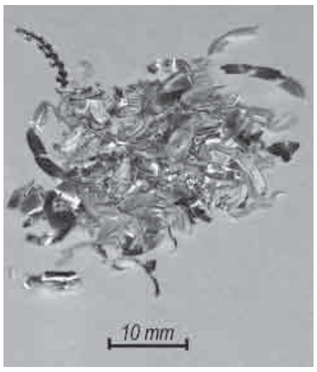
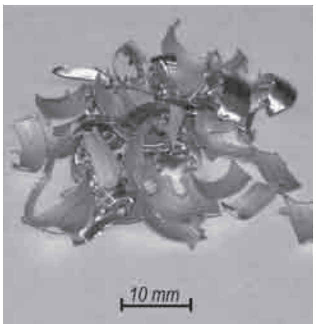
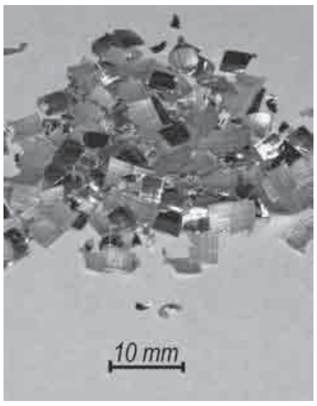


Figure 1 Cold compression of Al-chips:
A – beginning of the process, B – end of the process,
C – photograph of counter punch, die and compression punch

Table 1 **Different types of chips used in research**

Chip type	Machine and cutting regime	
A	CNC milling machine	
	Cutting regime: 2000 rpm F1200	
	Cutting depth/width: 2,5 x 2,5 mm	
B	CNC milling machine	
	Cutting regime: 2000 rpm F1200	
	Cutting depth/width: 5 x 5 mm	
C	Conventional milling machine	
	Cutting regime: 1000 rpm 35 mm/min	
	Cutting depth/width: 5 x 5 mm	
D	CNC milling machine	
	Cutting regime: 2000 rpm 0,2 mm/tooth	
	Cutting depth/width: 2 x 2,5mm	
E	CNC milling machine	
	Cutting regime: 2000 rpm 0,1 mm/tooth	
	Cutting depth/width: 2 x 15 mm	

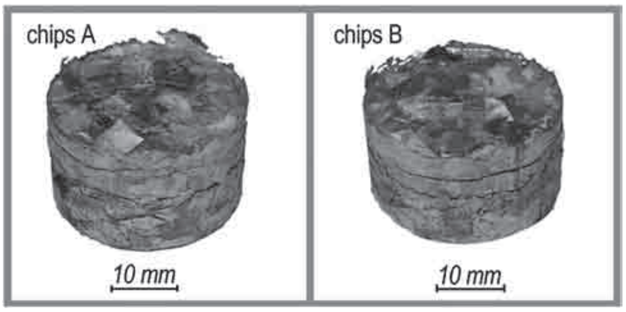


Figure 2 Low integrity of specimens compacted by 300 kN force (chip types A and B)

Relative density was used to compare and qualify compression processes. Relative density (ρ_{rel}) is defined as:

$$\rho_{rel} = \frac{\rho_s}{\rho_{ex.\ Al}} \cdot 100\ \% \qquad (1)$$

where specimen's density (ρ_s) is calculated by measuring specimen's geometry and weight. Extruded aluminium density ($\rho_{ex.Al}$) is 2,7 g/cm^3.

Initially, Al-chips were compressed with 300 kN final axial force (370 MPa pressure on specimen's surface), which has proved to be insufficient as compressed specimens experienced low density and integrity (Figure 2). Relative density of the specimens compressed with 300 kN force amounted to 83 % for chips A and 86 % for chips B.

Further final compressions were carried out with higher loads of 400 kN. These loads induced 500 MPa pressures on the surfaces of billets, which was sufficient for proper solidification. Several specimens for each type of chips were obtained.

Compression procedure. Due to low relative filling density of the chips, the total amount of chips prepared for each specimen could not fit into the die at once. Therefore, a couple of pre-compacting operations were needed prior to final compression. Table 2 presents compression regimes for different chips types. Pre-compacting was performed with the same tool-set and on the same hydraulic press while the number of pre-compacting operations varied on the type of the chips. In Figures 3 and 4 load–stroke diagrams for pre-compression operations for each type of the chips are given.

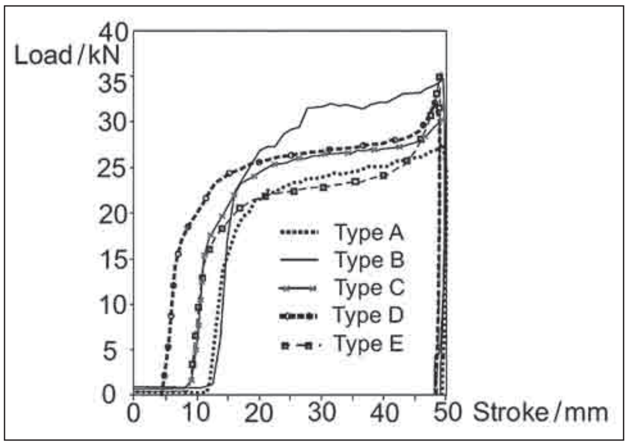


Figure 3 Pre-compression with 30-35 kN maximum load

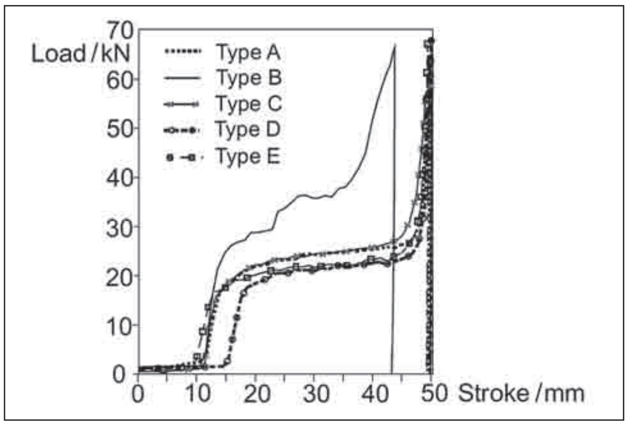


Figure 4 Pre-compression with 60-70 kN maximum load

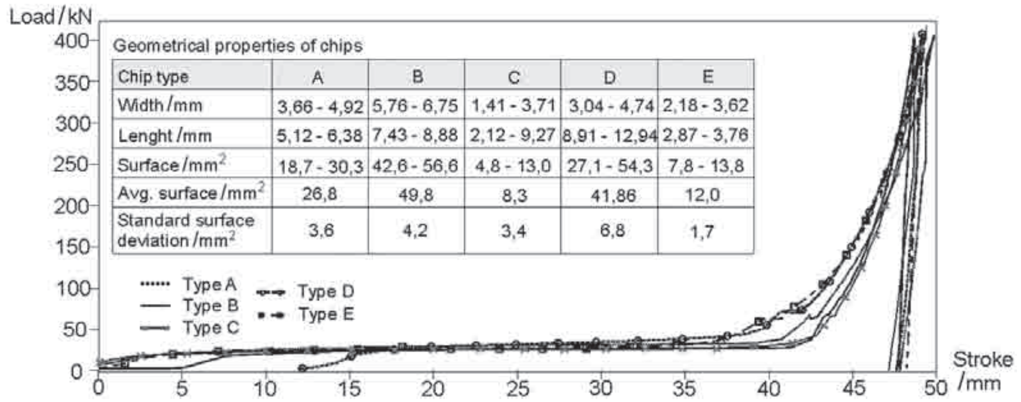
Table 2 Number of compression operations for each chip type

Chip type	A	B	C	D	E
First pre-compressions	3	3	1	2	2
Second pre-compressions	4	4	4	2	4
Final compression	1	1	1	1	1

Low pressures were applied in pre-compacting operations in order to avoid a formation of layered structures in specimens.

Figure 5 presents load–stroke diagrams of final compressions for all types of chips. Figure 5 provides a comparison of chip size (length, width and thickness).

Types A and B required the highest number of pre-compacting operations as they have the smallest thickness (and therefore lowest filling densities). Figure 6



Geometrical properties of chips

Chip type	A	B	C	D	E
Width / mm	3,66 - 4,92	5,76 - 6,75	1,41 - 3,71	3,04 - 4,74	2,18 - 3,62
Lenght / mm	5,12 - 6,38	7,43 - 8,88	2,12 - 9,27	8,91 - 12,94	2,87 - 3,76
Surface / mm^2	18,7 - 30,3	42,6 - 56,6	4,8 - 13,0	27,1 - 54,3	7,8 - 13,8
Avg. surface / mm^2	26,8	49,8	8,3	41,86	12,0
Standard surface deviation / mm^2	3,6	4,2	3,4	6,8	1,7

Figure 5 Final compressions with 400 kN maximum load

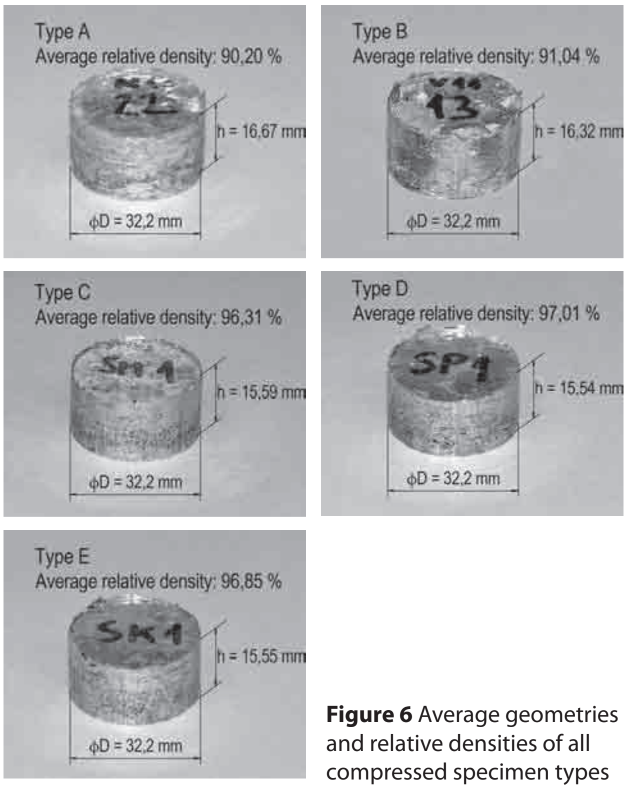


Figure 6 Average geometries and relative densities of all compressed specimen types

provides photographs of specimens, their average geometries and relative densities for all types of chips. The obtained specimens showed fairly good compactness and homogeneity.

As evident in Figures 6 and 7, specimens obtained from chips A and B possess the lowest average relative density (90,20 % and 91,04 %). Specimens obtained from types C, D and E chips exhibit a very high average relative density (over 96 %).

CONCLUSIONS

Solid state recycling is a novel technique for recycling metal scrap originated in industry. This paper presented the influence of a chip type on the final density and integrity of chips in cold compression operations.

Various types of chips were obtained by different milling regimes. Types A and B were cut on a CNC milling machine with similar regimes. Both types have a quadrant shape and exhibit a very low thickness. They differ only in size (B type is larger). Types C, D and E possess a thickness which is considerably higher compared to that of A and B types. They differ among each other both in shape as well as in size.

Due to low initial density of the chips, several pre-compacting operations were performed prior to major compression. Chips with smallest volumes (types A and B) required more pre-compacting operations.

Major compression was performed with 400 kN axial force or 500 MPa on specimen's surface. Compactions with lower forces (300 kN) provided insufficient final integrity of specimens.

Types A and B, which exhibited lowest thickness, resulted in poorest specimen density and integrity after cold compression. Larger B type chips reached a slightly higher average density than A type. Types C, D and E reached more than 96 % of average relative density after compaction. Therefore, it can be concluded that chip thickness has a significantly more influence on the final density of the specimens than the shape and size of chips. A repercussion of smaller thickness is a larger surface area of all chips combined and therefore a higher amount of aluminium oxide needed to be dissolved.

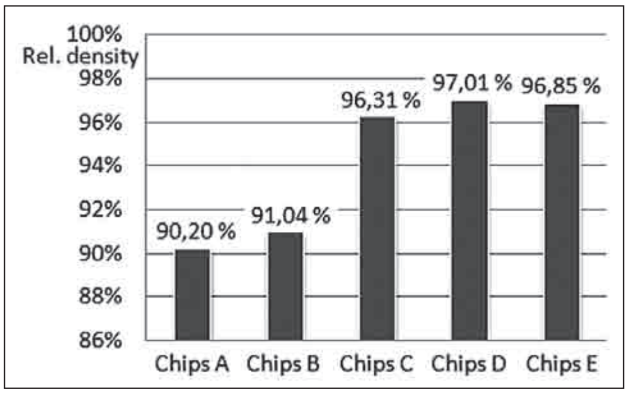


Figure 7 Influence of chip types on average relative densities of final billets

Although all chip types reached sufficient densities and integrity after cold compression, the quality of compactness still remains an issue. Therefore, future research would consider improving mechanical properties of the obtained specimens by imposing further severe deformations.

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REFERENCES

[1] US energy requirements for aluminium production, US department of energy, Industrial Technologies Program, 2007.
[2] Global Aluminium Recycling – A cornerstone of Sustainable Development, International aluminium institute, 2009, http://www.world-aluminium.org
[3] M. Samuel, A new technique for recycling Al scrap, Journal of Materials Processing Technology, 135 (2003), 117-124.
[4] Mark Schlesinger: Aluminium Recycling, Taylor and Francis Group, 2006.
[5] T. Campbell et all.: Dynamics of Oxidation of Aluminum Nanoclusters using Variable Charge Molecular-Dynamics Simulations on Parallel Computers, Physical Review, 82 (1999), 4866-4869.
[6] J. Horsinka, J. Kliber, K. Drozd, I. Mamuzić, Approximation model of the stress-strain curve for deformation of aluminium alloys, Metallurgy, 50(2011)2, 81-84.
[7] P. Drasnar, J. Kudlacek, V. Kreibich, V. Kracmar, M. Vales, The properties of electrolytically deposited composite Zn-PTFE coatings, MM Science Journal, (2011), 248-251.
[8] J. Kliber, I. Mamuzić, Selected new technologies and research themes in materials forming, Metallurgy, 49(2011)3, 169-174.

Note: The English text was revised by N. Henigman, Ljubljana, Slovenia.