Influence of heat treatment on properties of solid bonded AlSi11 alloys from chips

Wpływ obróbki cieplnej na własności stopu AlSi11 konsolidowanego plastycznie z wiórów

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The paper presents study results on AlSi11 alloy, which was obtained by extruding chips obtained from turning process. Mechanical properties from uniaxial tensile test and Vickers hardness test were determined. The influence of aging conditions on mechanical properties was invetsigated.
KEYWORDS: AlSi11, precipitation hardening, solid bonding, export of aluminum scrap

Recycling of light metals is mainly carried out by melting. In the case of highly-finely divided scrap (for example, chip after machining), the material loss during the process is very high and only about 40% of the batch material can be recovered. Hence, it can be concluded that the export of aluminum scrap from Poland to European and Indian countries (fig. 1) is so high due to the low profitability of recycling. For example, in 2014 the value of aluminum scrap exported from Poland amounted to PLN 844 157. In order to avoid losses, it is possible to use plastic compression technology based on the extrusion method [1-4].

The popularity of silumin in the casting industry is a natural consequence of their exceptional properties such as good durability, crack resistance and low casting shrinkage. Thanks to these features, AlSi alloys have been widely used in the automotive industry. pistons and combustion engine heads and gearbox housings [5]. These properties are partly due to the presence of silicon in the inner structure, which positively influences the

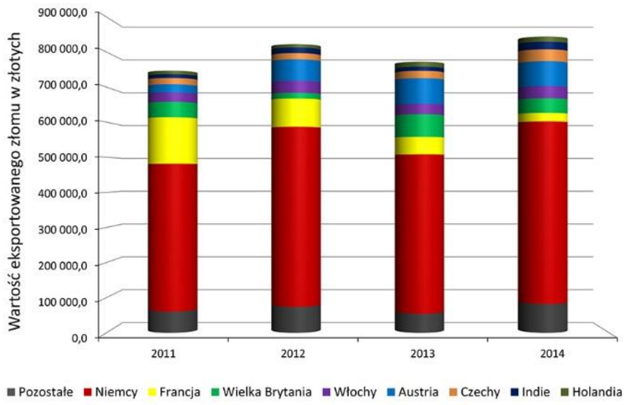

Fig. 1. Main directions and value of aluminum scrap exported from Poland in 2011-2014 [4]

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AlSi alloys have been particularly popular recently. Alloys, such as Cu and Mg, significantly increase the strength of the alloy while reducing its plasticity. In commercial applications, the amount of this element does not exceed 22% [6].strength of these alloys. Sizing at an around-eutectic temperature results in the dissolution of unequal, Cu and Mg-rich particles while the composition of the alloy itself is homogenized. In addition, silicon is subjected to spheroidization during siliconization, which translates into final mechanical properties. The key parameter of the super-saturation process is proper temperature selection. Too low temperatures can cause only partial dissolution of non-equilibrium particles and consequently weakening of the later strengthening effect. A separate problem is iron containing particles (eg, $Al_8Mg_3FeSi_6$, $Al_5Cu_2Mg_8Si_6$), which are particularly difficult to dissolve [7]. In case of AlSiMg alloys, the secretion sequence
during the aging process can be presented as follows [8]:

$$\mathbf{SSS \rightarrow clusters\ (containing\ Mg\ and/or\ Si) \rightarrow zones\ GP \rightarrow \beta'' \rightarrow \beta' \rightarrow \beta}$$

As a result of aging, the over-saturated solution contains clusters rich in Si and Mg, which are subsequently transformed into zones GP and metastable, coniferous β". These particles are responsible for a significant increase in the strength of the secretory strengthening process. Further annealing can lead to melt stop and produce metastable β' phases. In quaternary alloys such as AlSiCuMg, there may be additions of Q and Θ' [9].

Methodology of research

The starting material for the study was AlSi11 alloy chips (fig. 2a), which were obtained in a rolling process without the use of a cooling agent on a TUM 35 lathe (alloy composition is shown in Table I). The cutting process was carried out at a spindle speed of 315 rpm, with a knife feed of 0.2 mm/s in the direction of the material axis. The resulting chips are labeled AlSi11 TM. The next preparatory stage was pre-compaction of the chips in the hydraulic press with a maximum pressure of 100 tf. The 25 grams of weight was placed in a cylindrical press chamber, and then the piston was pushed with a pressure of 30 tf by means of a punch. In this way, eight moldings with a diameter of ⌀38 mm and a height of 10 mm were obtained, which constituted the charge for the extrusion process (fig. 2b).

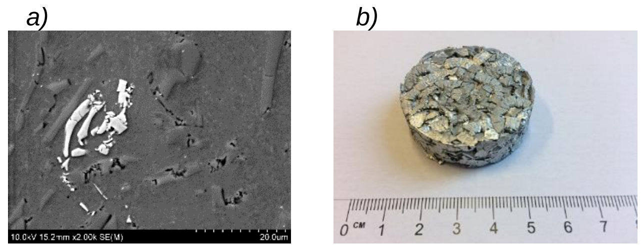

Fig. 2. Microstructure of AlSi11 alloy chip (a), compacted from AlSi11 alloy chips (b)

TABLE I. Composition of the test alloy, % mass

Si	Mg	Fe	Cu	Mn	Cr	Ni	Zn	Ti	Zr	Al
10,58	0,28	0,38	0,51	0,24	0,03	0,12	0,10	0,011	0,06	rest

The co-extrusion using concurrent technique was carried out at 450 °C with an extrusion speed of 1 mm/s. In comparison, a solid aluminum alloy ingot was affixed under the same conditions as AlSi11 IM. The squeezed bars were ⌀8 mm in diameter.

The rods were subjected to Vickers hardness tests according to PN-EN ISO 6507-1 using 19.61 N (HV2) load. The test specimens, prepared from the extruded bar, were placed in an oven heated to 525 °C. They were kept at this temperature for 30 min and then transferred to water. Artificial aging was then carried out at 160 °C and 180 °C with different aging times. After heat treatment, Vickers hardness measurement was performed. For a material aged at 160 °C for 4 hours, a single-axis tensile test at ambient temperature according to EN ISO 6892-1 was performed.

Test results

TABLE II. Mechanical and physical properties of tested materials after extrusion

	AlSi11 IM	AlSi11 TM
Tensile strength *Rm*, MPa	189	200
Yield strength $R_{0,2}$, MPa	85	87
Elongation *A*, %	14,5	17,5
Hardness, HV	72	67
Density, g/cm^3	2,66	2,65

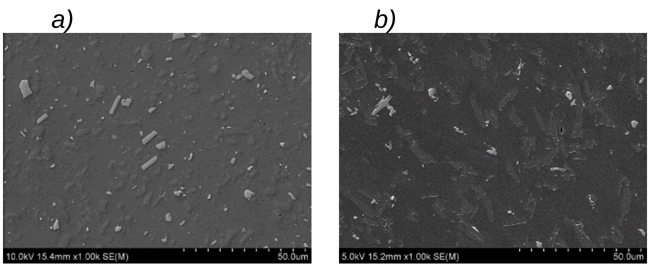

Fig. 3. Microstructure of AlSi11 chip alloy bar (a), AlSi11 solid alloy bar structure (b)

TABLE III. Mechanical properties of tested materials after heat treatment, determined on the basis of fig. 6

	Tensile strength *Rm*, MPa	Yield strength $R_{0,2}$, MPa	Elongation *A*, %
AlSi11 IM T6	336	190	11,9
AlSi11 TM T6	329	188	10,9

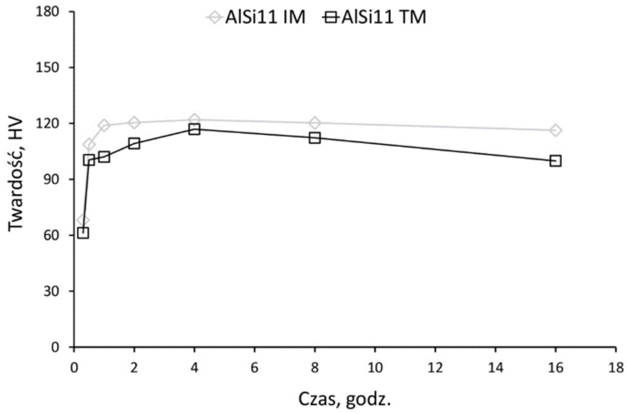

Fig. 4. Changes in hardening of AlSi11 (TM and IM) alloys hardened at 160 °C

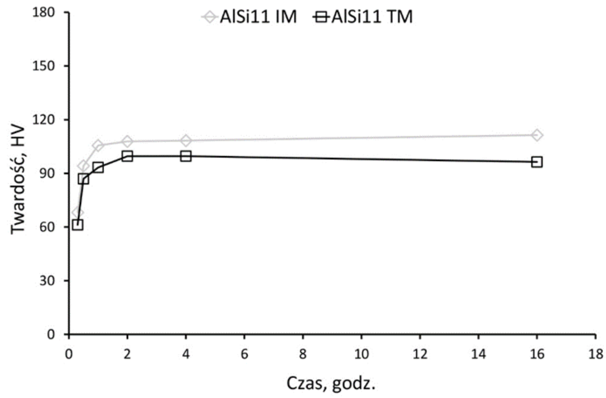

Fig. 5. Changes in hardening of AlSi11 (TM and IM) alloys hardened at 180 °C

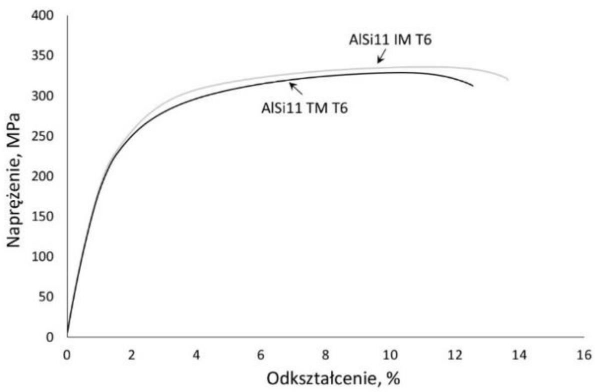

Fig. 6. AlSi11 (IM and TM) alloy stretching curves after heat treatment to T6 condition - combined with aging (aging at 160 °C for 4 h)

Analysis of results

Low efficiency of fine scrap processing results in large material losses. The recycling concept based on the plastic consolidation process offers the opportunity to reduce these losses and significantly reduce the energy consumption of the process. Consolidation of AlSi11 alloys by extrusion at elevated temperatures results in bars with a smooth, glossy surface, comparable to extruded solid material. The selection of appropriate parameters of the plastic consolidation process (450 °C and extrusion speed of 1 mm/s) allowed to produce material which is characterized by lack of surface defects (cracks, delamination).

In the structure of the bar extruded from chips, the presence of brittle, primary crystalline silicon crystals with sharp edges and fragile AlFeSi intermetallic phases were observed. The chip extruded from the chips is characterized by a significant fragmentation of the Si and AlFeSi phases as compared to the phases visible on the microstructure of the rod extruded from the solid ingot (fig. 3). This shows that the silicon has been crushed during the cutting process. Release of silicon has a significant impact on the improvement of AlSi strength properties.

The mechanical properties of the squeezed bars were tested in a tensile test and a hardness test. Extruded bars exhibit similar strength properties with slightly higher elongation values for AlSi11 TM alloy (Table II). The hardness of AlSi11 IM was 72 HV, while AlSi11 TM - 67 HV (Table II).

The material extruded from the chips has a comparable density with the material extruded from the solid ingot. Alloys (Si, Mg) improve the strength properties and favorably affect the material's ability to heat. The optimum time-temperature conditions for the curing process were determined by artificially aged materials at 160 °C and 180 °C (fig. 4, fig. 5). After aging at 180 °C for 4 h, the hardness of the materials was 108 HV for AlSi11 IM and 100 HV for AlSi11 TM and did not change even after artificial aging for 16 h (no visible effect). From the point of view of maximizing the strength properties of the material obtained from chips, it is possible to consider artificial aging at 160 °C for 4 h, which results in a hardness of 117 HV as the most favorable (fig. 4). This hardness is the maximum on the aging curve, and when this value is exceeded, there is a decrease in the strength properties associated with the effect of the aging.

The hardness results for the rod obtained from the chips are similar to those for the bar extruded from the solid material. Aging at 160 °C for 4 h gives a tensile strength of 329 MPa for AlSi11 TM and a yield strength of 188 MPa. It should be stressed that these results are slightly worse than those for AlSi11 IM alloy (fig. 6, Table III). The curing process has resulted in a significant increase in the strength properties of both solid and chip extruded materials. The used AlSi11 recycling method allowed the material to obtain mechanical properties comparable to that of the solid material of the solid ingot.

Conclusions

- Because of the high loss of recycled aluminum scrap, its exports from Poland are quite high.
- Pre-pressing of chips and selection of suitable extrusion parameters allowed to obtain material characterized by good consistency and lack of porosity.
- Molded materials - both solid and chip - are characterized by hardness of 60 HV. The bars have a high tensile strength (about 200 MPa) and an elongation of 15%.
- Artificial aging AlSi11 aluminum alloy foundry has a significant impact on the strength properties. Heat treatment for T6 (super-saturation and aging) results in a high strength of the materials at a slight decrease in plasticity relative to the starting material.
- Through the plasticity of the alloys AlSi11, a rod has been obtained with properties comparable to the properties of the extruded bar of the solid ingot.

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