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The Production of Wrought AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 Alloy with Ultrafine Structure

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Abstract

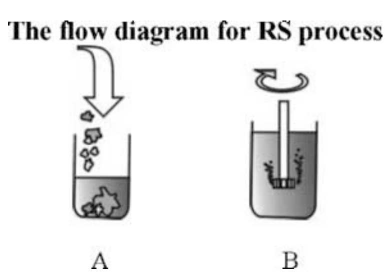
The purpose of this study was to produce by Rapid Solidification process an alloy with Si content exceeding 20%.
An ultrafine grained alloy from the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 system in the form of strips has been fragmented and subjected to the process of consolidation.
The paper presents the technological aspect of the process of casting, fragmentation and plastic consolidation of semi-products.

Introduction

Ultrafine grained alloys are attractive materials mainly owing to their high mechanical, technological and functional properties as compared to alloys cast by conventional routes. Rapid Solidification, by creating quite unique conditions for the alloy solidification, enables producing materials characterized by the chemical composition and properties impossible to obtain by traditional methods. When the thin jet of liquid alloy falls onto the spinning copper wheel, a strip or ribbon is formed. In contact with the wheel surface, the liquid alloy undergoes very rapid solidification, usually within a range of 10^4-10^7 K/s. The melt spinning process has been known since the 60s of the past century, providing opportunities for casting of aluminum alloy strips characterized by ultrafine grained structure and produced at a casting speed of 50 m/s. A ribbon cast by RS from the AlSi30Cu1.5Mg1.2Ni1.5Fe0. 8 alloy has a width of 1400-3000 μm and a thickness of 85-125 μm. This material is used as a feedstock in the next stages of the processing cycle, involving crushing, consolidation and hot extrusion. By alloy melting, casting of strips and their fragmentation, with the subsequent consolidation and hot extrusion it is possible to obtain shaped profiles (Fig. 5) of ultrafine grained structure and improved mechanical properties.

Methodology

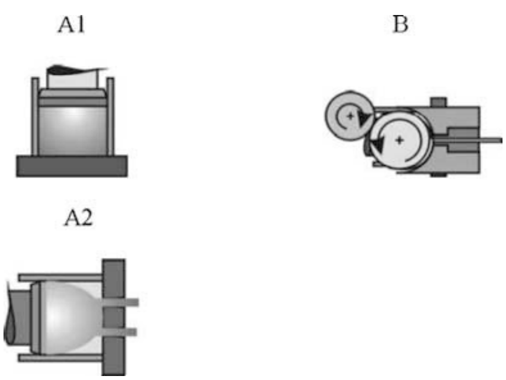
The authors of this study have undertaken the task of making shaped profiles from the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy of ultrafine grained structure according to the following process flow diagram.



A- melting and alloying
B- degassing of alloy melt
Fig. 1. STEP 1: Alloy manufacture by RS

Fig. 2. STEP 2: Alloy casting by melt spinning

Fig. 3. STEP 3: Fragmentation of cast ribbons



A1- consolidation of chips
A2- hot extrusion
B- Continuous Rotary Extrusion process (CRE)

Fig. 4. STEP 4: Consolidation and extrusion of crushed chips by the hot extrusion route and CRE.

Fig. 5. The extruded product

The first step in the technological process was selection of alloy that could be used for parts operating in the air, sea or land transport means. The team responsible for this task has decided to

choose an alloy of the following average chemical composition: AlSi30 Cu1.5 MG1.2 Ni1.5 Fe0.8 (the average numerical values of the elements are expressed as a weight-mass percent). The charge to obtain the alloy melt was composed of primary aluminum A8 (99.8% Al – 1080A) with the silicon addition as a main alloying constituent and elements such as Cu, Mg, Ni, Fe. Silicon has been introduced in the form of lumps, copper and magnesium in the metallic form, and nickel and iron in the form of ALTABNi75 and ALTABFe75 master alloys.
The alloy was melted in a crucible induction furnace with the maximum charge weight of 25kg calculated in terms of Al. The melt was vigorously stirred, and its temperature during the introduction of alloying elements was maintained in a range of 830-850°C until complete dissolution of all the alloying elements took place. The melt refining was done by barbotage (degassing) with argon. It should be noticed that the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy melt was not modified with Sr or Sb, neither was it modified with the lanthanides, or with any other elements in Groups IA and IIA. No heterogeneous grain refiners or phosphorus were used. Final analysis of the alloy chemical composition was done by mass spectrometry, and the results are compared in Table 1.

Table 1. The chemical composition of AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy

Element	[wt %]
Al	63.454
Si	30.820
Fe	0.890
Cu	1.308
Mn	0.007
Mg	1.121
Cr	0.001
Ni	1.580
Zn	0.011
Ti	0.023
V	0.009

As a next step, the resulting alloy was cast into metal molds to form 2 kg ingots and was used as a starting material for casting on the melt spinning device.

The second step in the technological process involved casting of ribbons from the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy by spinning the melt onto a copper wheel in the Rapid Solidification process. The device for melt spinning used in this experiment was originally designed and built for casting of aluminum alloys and was used in studies conducted under previous projects. Feeding of liquid alloy onto the surface of the spinning wheel was done from the top by means of a dispensing nozzle. The RS holding furnace was used in the casting process mainly to stabilize the liquid alloy temperature, while melting of ingots was carried out in a co-operating induction furnace which allowed rapid melting of charge combined with simultaneous intense stirring of the melt. This technique of melting reduced holding of the melt and subsequent segregation of alloying elements in the resistance furnace used for melt spinning. The alloy pouring temperature of 820-825°C (Figs. 6, 7 and Table 2) was calculated from the CC and FD curves plotted during the thermal analysis of AlSi30 Cu1.5 MG1.2Ni1.5Fe0.8 alloy performed in a UMSA5/MTC_MG device (Universal Metallurgical Simulator and Analyzer). The superheating temperature of 80-85°C protected magnesium contained in the alloy from rapid oxidation.

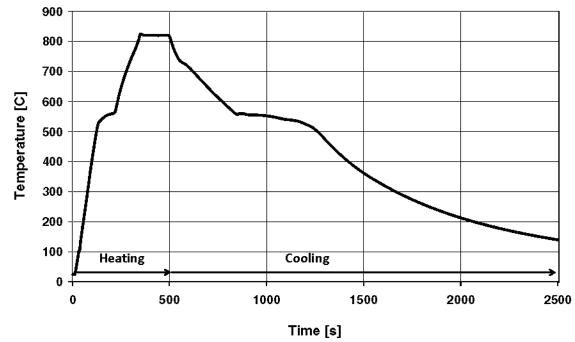


Fig.6. The heating and cooling curves of AlSi30 alloy cast into metal mold

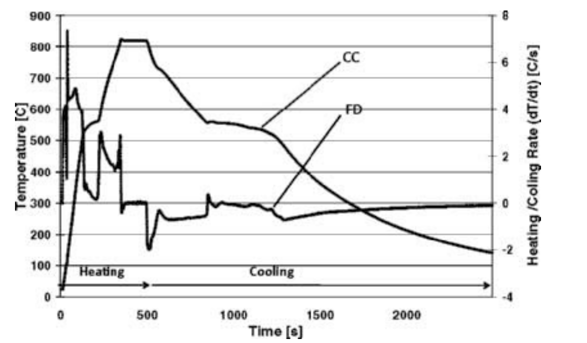


Fig.7. Time-related overlapping of the cooling curve (CC) and its first derivative (FD) plotted for the AlSi30 alloy cast into metal mold

Table 2. The results of thermal analysis obtained for the cooling cycle of AlSi30 alloy

Thermal characteristic	[°C]
Liquidus temperature	740
Nucleation of Al-Si eutectic	560
Solidus temperature	490

The linear speed of the ribbon casting was selected by experiments and set at a value of 30 m / s. The pressure ejecting the alloy from the dispensing nozzle did not exceed 0.4 bar. Thus selected values of the casting parameters allowed producing each time the ribbons shown in a bulk form in Figure 8.

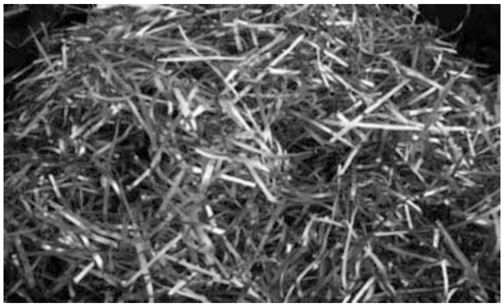


Fig. 8. Ribbons cast in AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy

The image of a cast ribbon surface as seen at a magnification of 50x is shown in Figures 9A and 9B.

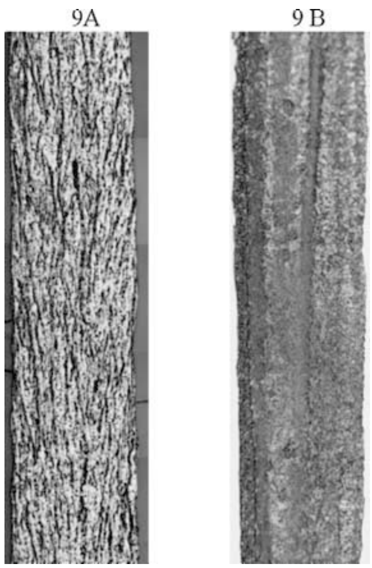


Fig.9A Ribbon surface facing the casting atmosphere side.
Fig.9B Ribbon surface facing the copper wheel side.

It is easy to notice a difference in the morphology of the ribbon side facing the atmosphere (Fig. 9A) and the wheel-side surface (Fig. 9B). Close examination of the ribbon cross-section (Fig. 10) has revealed the presence of two layers with the two different microstructural constituents:

the saturated AlSi solution, and

the AlSi solution with different rosette-shaped silicon precipitates of the 1-4µm size.

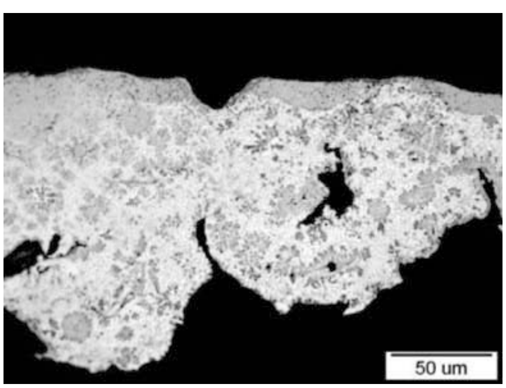


Fig. 10. Microstructure of AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy ribbon cast by melt spinning.

By measuring with micrometer the dimensions of the randomly selected cast ribbons, for a series of 1000 measurements, the values of the ribbon width (Table 3) and thickness (Figs. 11, 12, 13) were statistically determined.

Table 3. The width of ribbons cast from AlSi30 alloy.

Unit	[um]
Mean	2670
Standard deviation	190
Maximum	2993
Minimum	1998

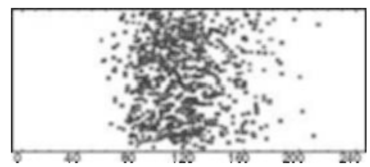


Fig. 11. A scatter plot of the thickness measurement results for ribbons cast from AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy

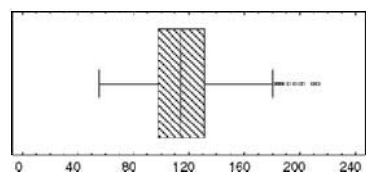


Fig. 12. A box-and-whisker type plot with marked quarters and a median for the thickness of ribbons cast from AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy

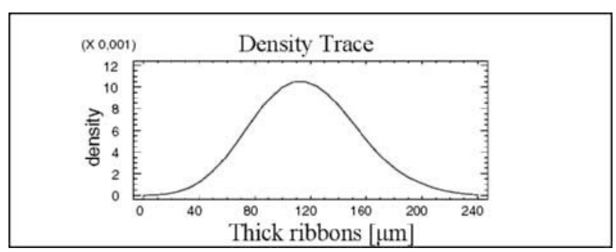


Fig. 13. Normal distribution of the thickness values for ribbons cast from AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy

Step 3 of the process was related with the fragmentation of cast ribbons characterized by ultrafine grained structure. The as-cast ribbon is not directly suitable for consolidation, but has to be fragmented into smaller pieces first. This operation was performed in a high-speed mill with scissors-like cutting action. Additionally, the mill chamber was equipped with a 1mm mesh grading sieve, which enabled producing material with the grain size below this value (Fig. 14).

Fig. 14. Ribbons cast from AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy fragmented to the form of chips.

The crushed material was subjected to microscopic examinations (Fig.15). The image of the as-cast alloy shows the precipitates of primary silicon and the supersaturated AlSi solution, similar to what has been observed in the ribbons.

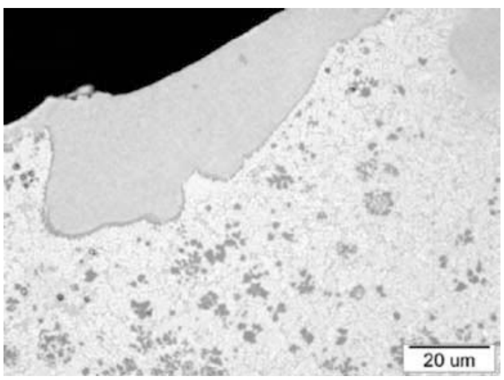


Fig.15. Microstructure of AlSi30 alloy chips.

RS chips were subjected to granulometric analysis to determine the finest fractions and their content. Knowing the content of individual fractions, it is possible to evaluate if the process of fragmentation has been done correctly or not.
Generally speaking, 83% of the granulate had the particles comprised in a size range of <1; 0.20 mm (Fig.16).
The performed studies were based on the PN-EN 24497:1993 Standard "Metallic powders. Determination of particle size by dry sieving."

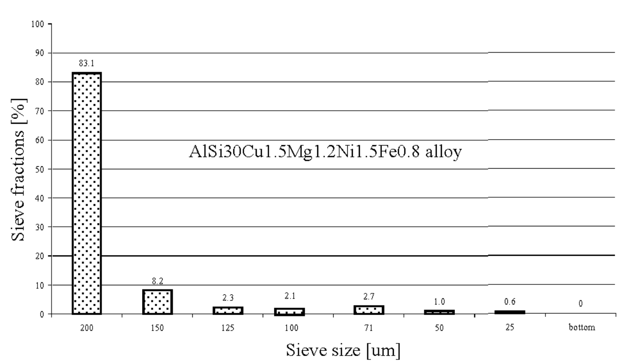


Fig. 16. Graph showing the content of ≤200 μm fractions calculated by the granulometric measurements of the crushed AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy chips

For the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy powder, its bulk density and apparent density were determined. The calculated value of the bulk density of the fragmented chips was comprised in a range of 680-720 g/l, while apparent density assumed the values of 950-1000g/l.

The fourth step in the process covered the consolidation and extrusion of fragmented strips using a 60T capacity press and a continuous rotary extrusion device (CRE) to produce rods of ø 8 mm and ø 15 mm, respectively.
The extrusion using a vertical press was carried out as a two-step process. The first step was cold pre-consolidation of powder, and the next step was hot extrusion of ø 8 mm rods at λ = 14 and a temperature of 460°C.
The extrusion of ø 15mm rods by CRE in an MC-260 device was carried out at 350°C in a single-step operation.
In both cases of the extrusion, i.e. of ø 8mm rods in a press and ø 15mm rods by CRE, satisfactory results of the work were obtained.
Below, microstructures of materials produced by both processes are shown.

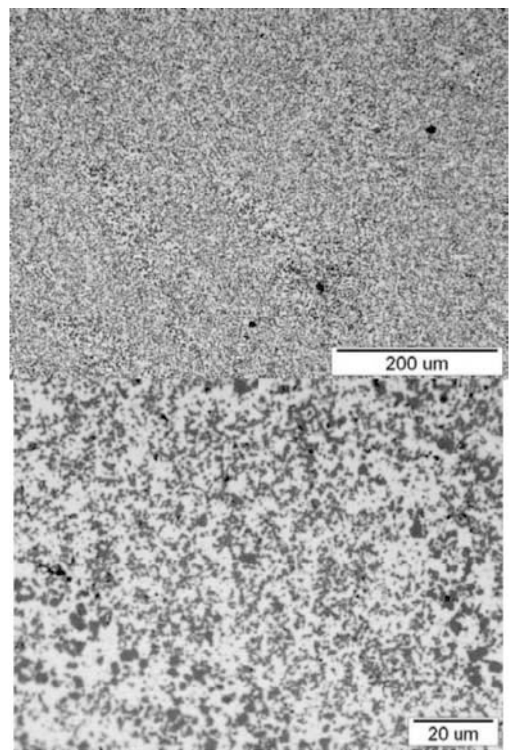


Fig. 17 Microstructure of AlSi30 alloy consolidated by direct hot extrusion

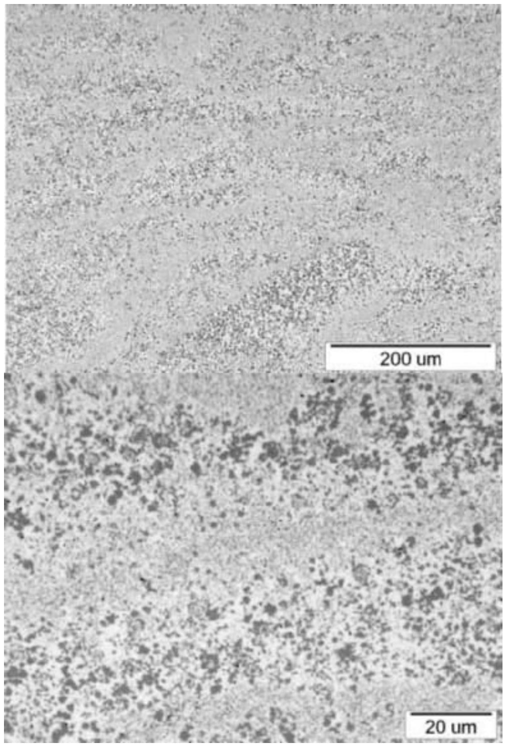


Fig.18 Microstructure of AlSi30 alloy consolidated by CRE.

Additionally, the mechanical properties of materials in as-extruded state were compared (F). The comparison is shown in a table and on a sample chart.

Table 4. Mechanical properties compared for the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy cast into metal mold and extruded in a 60T press.

Properties	Metal mold	RS
Rm [MPa]	76	341
$Rp_{0.2}$ [MPa]	-	271
A [%]	-	0,6
HBW	138	136
HV	177	176

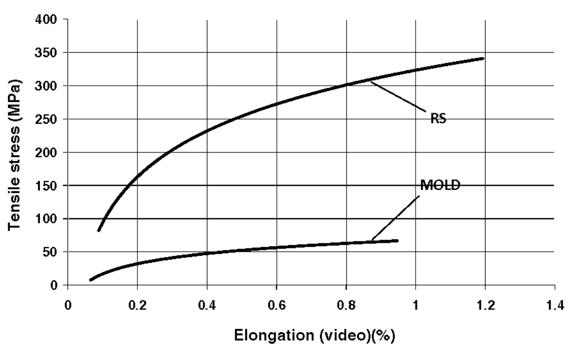


Fig.20. A comparative diagram of the AlSi30 alloy extruded in a press and cast into metal mold; in both cases examined by static tensile test.

Summary and conclusions

By taking the steps in production technology proposed and described in this paper, final extruded products were made from the AlSi30Cu1.5Mg1.2Ni1.5Fe0.8 alloy of ultrafine grained structure.

The material after fragmentation was consolidated during final extrusion to form a solid profile offering the mechanical properties superior to those that are commonly obtained in materials of the same composition but different structure, cast into metal molds.

Compared with the alloy cast into metal mold, the microstructure of RS alloy showed different morphology of the primary silicon precipitates and the presence of two zones easily distinguished in the cast material.

An important feature of the process is that the AlSi30Cu1.5Mg1. 2Ni1.5Fe0.8 alloy subjected to Rapid Solidification is capable of offering much better mechanical properties than alloys of the same composition but solidifying more slowly in a metal mold. Hence a conclusion folows that this method of casting can enhance the technical value of alloys so far neglected because of inferior properties and may extend the spectrum of new alloys including new compositions.

The components made of RS alloys may have thinner wall sections while maintaining an adequate level of the strength required. This relationship given reduced weight to parts of the transport equipment and directly translates into a reduced fuel consumption and lower emission rate of harmful compounds.

Another important conclusion refers to the recycling of waste products made from RS materials. When remelting the scrap of ultrafine grained structure in a furnace together with other alloys made by the traditional technology, no special means are required to separate these materials as, contrary to the case of composites, they pose no threat to the melt purity.

Compared with composites and traditional aluminum alloy stock, the RS materials are certainly superior as regards both the mechanical properties and recycling process.

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