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THE POSSIBILITY OF INCREASING PRODUCTION EFFICIENCY OF AL ALLOYS APPLYING ELECTROMAGNETIC FIELD

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Preliminary note – Prethodno priopćenje

The relationships between electromagnetic frequency, microstructure and mechanical properties of continuous casting aluminum alloys were studied in this paper. EN AW 2024 and EN AW 2007 aluminum alloys ingots were produced by electromagnetic continuous casting process. The microstructure and mechanical properties of as cast ingots were examined. The results showed that electromagnetic field, especially low frequency electromagnetic field, greatly influenced the microstructure and mechanical properties of as cast ingots. The significant energy savings and product quality can be achieved by the application of a proper frequency.

Key words: Al alloy, electromagnetic field, casting

Mogućnost povećanja efikasnosti proizvodnje Al legura primjenom elektromagnetnog polja. U radu je prikazan utjecaj frekvencije na mikrostrukturu i mehanička svojstva Al legura dobijenih kontinuiranim elektromagnetnim postupkom ljevanja. Ispitivanja su obavljena sa dvije legure EN AW 2024 i EN AW 2007. Mikrostrukturna i mehanička karakterizacija urađena je na uzorcima u ljevanom stanju. Rezultati istraživanja pokazuju da elektromagnetno polje, posebno polje niže frekvencije, utječe na mikrostrukturu i mehanička svojstva ljevanih ingota. Na osnovu dobijenih rezultata može se zaključiti da se primjenom elektromagnetnog polja odgovarajuće frekvencije može postići značajna ušteda energije kao i poboljšanje kvaliteta dobijenih ingota.

Ključne riječi: Al legura, elektromagnetno polje, ljevanje

INTRODUCTION

Aluminum alloys of high strength have diverse and wide application in almost all fields of industry. Due to their specific properties, mainly the strength to mass ratio, even though their production price is higher compared to iron alloys, these alloys took up a significant position at the world market. Alloys applied in this investigation are EN AW 2007 (AlCu4PbMg) and EN AW 2024 (AlCu4Mg1Mn). They are heat treatable alloys and are intending for plastic processing.

They belong to high strength group of alloys with wide application in almost all fields of industry. They have long production and processing time, because they involve a series of technological operations (modification, casting, homo-genization, pressing forming and thermal treatment). The homogenization is a long-lasting and expensive process, because of high consumption of electrical energy. The main idea is shortening this process for increasing production process. It is well know that conventional horizontal or vertical continuous casting process due to unbalanced strengthening conditions, leads to appearance of many defects [1-3]. These are inhomogeneous microstructures, porosity, hot cracks, non-uniform grain size and crystal segregation in the ingot. All this leads to deterioration of mechanical properties of strength and toughness first of all. The electromagnetic casting of aluminum alloys is of great interest in metallurgical industry and intensive study has been made in recent years, because it presents the ability of improving product quality which could never been achieved by conventional casting process. In this new process, the induction coil surrounds the ingot mold, an alternating current is applied, thus the coil generates a time varying magnetic field and the melt can be inductively stirred [4, 5]. In that way, the more balanced temperature field is established. The experiment shows that this process is an efficient dynamic method of grain refinement, surface quality can be improved and the thickness of the segregation layer can be also reduced because of the contact line between the metal and the mold can be adjusted. Moreover, this method can be put into industrial practice relatively easily.

EXPERIMENTAL

The chemical composition of used alloys EN AW 2007 (AlCu4PbMg) and EN AW 2024 (AlCu4Mg1Mn) is shown in Table 1.

For melting alloys, induction furnace of medium frequency with capacity of 100 kg was used. The both ingots, of alloy 2007, with diameter ∅ 50 mm and of alloy

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Table 1 **The chemical composition of used alloys / wt. %**

Wt./% / Alloy	Si	Fe	Cu	Mn	Mg	Pb
2 007	0,3	0,3	3,9	0,8	0,9	1,1
2 024	0,1	0,2	4,1	0,6	1,2	-

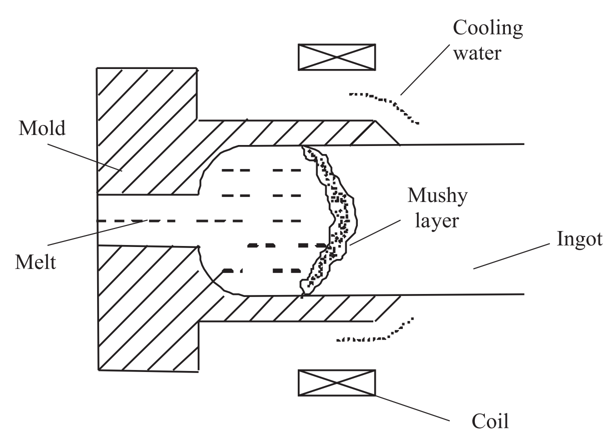


Figure 1 Schematic illustration of the electromagnetic process

2024, with diameter ∅ 60 mm were obtained by horizontal continual casting with pulse draw-out. At the bottom of the furnace there is a drainpipe with graphite crystallizer that is intensively cooled with water. The electromagnetic field is present around the crystallizer itself, Figure 1.

The temperature of casting was 710 – 720 °C and average casting speed was 1,5 mm/s. The operating parameters, during the casting of ingots, were strictly controlled and defined by various values of current (A), frequency (Hz) and strength of electromagnetic field (A_t). The number of turns in the coil was N=40. Table 2 shows some of operating parameters of casting.

Table 2 **Operating parameters upon casting of samples**

Sample mark	Alloy	Frequency/ Hz	Number of turns /N
1	2007	0	40
2	2024	50	40
3	2024	30	40
4	2007	1 100	40
5	2007	1 830	40

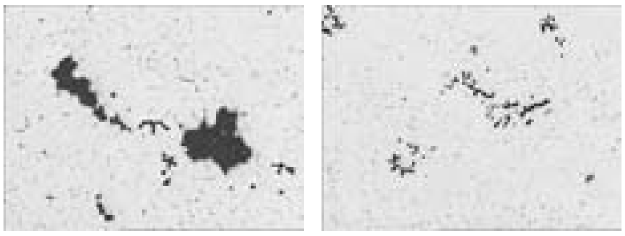
Frequencies were selected in broad diapason ranging from 1 830 to 30 Hz. There are literature data only for low frequencies (< 100 Hz). Since we had the opportunity to test the influence of high frequencies as well, such tests were also performed on the alloy 2007, similar with the alloy which is the main subject of our interest, i.e. 2024. The sample 1 was casted without the presence of electromagnetic field to enable the observation of field effect on mechanical properties and microstructure with other samples.

Before the mechanical characterization was done the complete microstructure assessment was carried out. The microstructure parameters describe the structure dispersivity and directly affect the mechanical properties of the alloy. The microstructure was examined on a cross section of a sample after the usual metallographic preparation and etching in Keller's reagent (revealing morphology of Al segregation-solid solution and inter-metallic phase) and anode oxidation with Barker's reagent (revealing size and shape of the grain in presence of dendrite segregation). For the quantitative microstructure analysis the image analysis device Leica Q500MC was used. Dendrite arm spacing (DAS), interdendritic space width (L_{IMF}), where inter-metallic phases and eutecticum were separated, as well as their volume fraction, were acquired using linear method, through the measuring of total length of the line segments belonging to each phase and calculating the amount of intersects with phase boundaries. These parameters are the consequence of the solidification conditions.

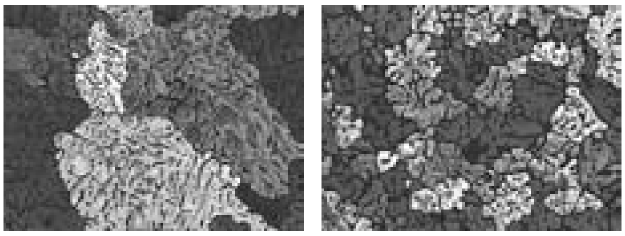
RESULTS AND DISCUSSION

The microstructure obviously has shown that Al segregation from the solid solution resulted in celluar/dendritic morphology, [6,7]. Upon that, the structures of sample 1, without the electromagnetic field effect, and samples 4 and 5, with electromagnetic field of high frequency, are more dendritic compared to the samples 2 and 3, which are casted with the presence of low-frequency electromagnetic field. It is obvious that the application of high frequency has no effect on the improvement of microstructure. Quite oppositely, at 1 830 Hz the structure was rougher compared to one obtained without the influence of electromagnetic field. On the other hand, the regions of extracted inter-metallic phase, in the form of eutecticum or individually, become finer by the introduction of electromagnetic field and by decreasing of frequency, (from 50 Hz in sample 2 to 30 Hz in sample 3). The decrease of microstructural parameters DAS and $L_{IMF,}$ observed in samples 2 to 3, was confirmed by the analysis of cumulative distribution curves. However, the effect of electromagnetical field on parameter DAS is greater compared to L_{IMF}. By detailed analysis of samples, the presence of interdentritic type was established, as can be seen in Figure 2.

It is determined that the porosity of interdendritic type is reduced from sample 2 (50 Hz) towards the sample 3 (30 Hz), i.e. with the decrease of electromagnetic field frequency. It is also found that the grain size is significantly reduced from the sample 2 to the sample 3. This is important because the less amount of porosity



(a) sample-2 (b) sample-3
Figure 2 The porosity of interdentritic type



(a) sample-2 (b) sample-3
Figure 3 The grain size

and the smaller grain contributes the better quality of ingots and thus to mechanical properties.

Since it was concluded that there are no positive effects of high frequency to the obtained microstructure, the further investigation included only the mechanical properties of samples obtained by application the frequency of 50 Hz and 30 Hz, and also of the one obtained without the influence of electromagnetic field from the same alloy EN AW 2024. For mechanical testing, the Zwick/Roell Z 100 device was used. The samples for this tensile testing were prepared according to JUS C.A4.002 and for the hardness according to JUS C.A4.103.

The values of mechanical properties are given in Table 3.

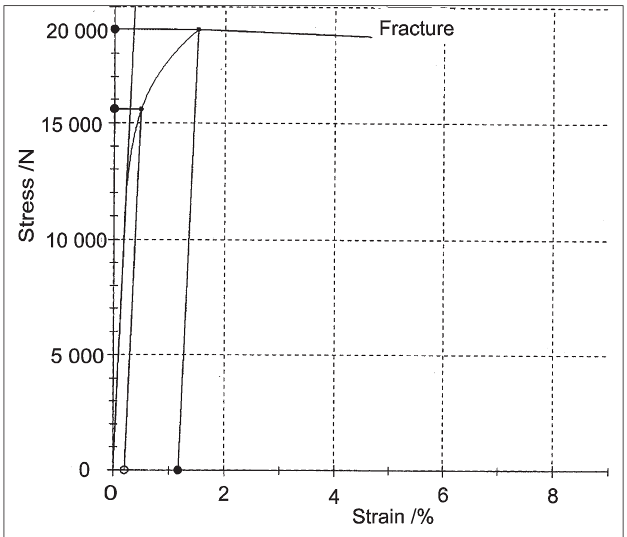
Table 3 **Mechanical properties of alloy 2024 ingots**

Sample mark	R$p_{0.2}$ /Mpa	Rm /Mpa	A /%	$HB_{5/25/30}$
2	198,1	243,2	1,2	93,5
3	246,6	274,2	0,7	107,0

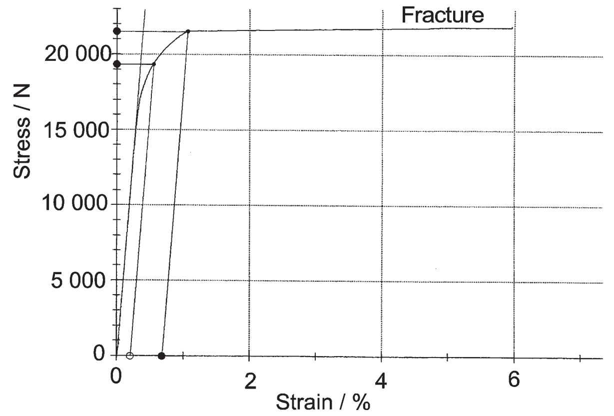
The stress-strain curves can be seen in Figure 4.

On the basis of previous microstructural analysis, such trend of change of alloy resistance properties, i.e. their increase, could have been expected. However, the decrease of plasticity for specimen 3 can be interpreted by the appearance of rough continually extracted particles of IMF, Figure 5, in relation to specimen 2. This continually grid of IMF particles has detrimental effect on mechanical properties, especially on plasticity. Furthermore, one should bear in the mind the fact that the values of mechanical properties for specimens of alloy 2024 casted without the influence of electromagnetic field were: R$p_{0.2}$= 162,5 MPa, Rm=179,9 MPa and A=0,49 %. i.e. they were the lowest.

This means that by the good combination of casting operating parameters, a priori frequency, the increase of



(a) sample 2



(b) sample 3
Figure 4 Stress-strain curves

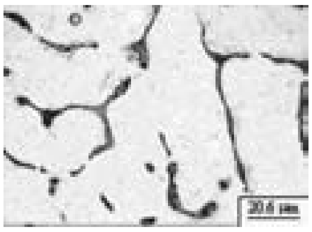


Figure 5 Interdendrite extracted inter-metallic phase

resistance properties can be achieved, and also the plasticity increase by the use of microstructure control. This is significant because the good mechanical properties, in the initial stage of production process, mean a great savings in all the following production stages.

CONCLUSION

The investigations results of alloy EN AW 2024 and EN AW 2007 ingots obtained with different operating conditions, with or without the presence of electromagnetic field, clearly show its effect on the microstructure and mechanical characteristics. It has been proved that only the application of low frequency electromagnetic field (≤ 50 Hz) has the positive effects, which obviously change strengthening conditions. Namely, when the frequency decreases (from 50 Hz in sample 2 to 30 Hz in sample 3), the DAS and grain size decrease as well, that is noticeable through the finer microstructure and its uniformity throughout the cross-section. It is also determined that the porosity of interdendritic type is reduced from sample 2 (50 Hz) towards the sample 3 (30 Hz). All of this contributes the better mechanical properties and thus the quality of ingots. The better mechanical properties in the initial stage of production process provide less consumption of electrical energy. Obtained results indicate that some steps in current technological process can be avoided, namely better surface quality contributes the surface machine processing elimination. Besides, the finer microstructure contributes the shortening or eliminating of homogenization process, one of the longest and the most expensive processes during the aluminum alloys production. The literature data show that the intensity of electromagnetic field has also great effect on microstructural and mechanical properties, [8,9]. So, the further work in this area should be focused towards the intensity of electromagnetic field and encompass the other aluminum alloys which are aimed for forging.

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Note: The responsible for English language is the lecturer from Institute (ITNORM), Belgrade, Serbia.