G. KIESIEWICZ, A. MAMALA, W. ŚCIĘŻOR, P. KWAŚNIEWSKI,
A. KAWECKI, M. SADZIKOWSKI, K. FRANCZAK

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METALLURGICAL SYNTHESIS OF MODIFIED EN-AW 6082 ALLOY WITH DIFFERENT Mg AND Si CONTENT RATIO AND RESEARCH ON BASIC MECHANICAL AND ELECTRICAL PROPERTIES OF OBTAINED MATERIALS

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Research works presented in the article aim to determine optimal ratio of Mg and Si content in chemical composition of commercial EN-AW 6082 aluminium alloy in order to maximize mechanical properties of this material. Various amounts of Si (in the rage of 0,6-1,2 wt. %) and Mg (0,6-1,1 wt. %) along with 0,4 wt. % of Fe, 0,4 wt. % of Mn and 0,05 wt. % of Ti were metallurgically synthesised with the use of gravity die casting process which allowed to obtain 5 different castings. In the next phase of research works all alloys were subjected to mechanical and electrical properties testing in as cast temper and after performed heat treatment.

Keywords: AlMgSi casting, metallurgical synthesis, mechanical properties, electrical properties, Mg2Si phase

INTRODUCTION

Modern railway applications and research works related to this field of scope are concentrated on the use of various non-ferrous metals which are divided into two main groups being responsible to transfer mechanical loads and/or electric current [1,2]. One of the materials which is lately being used more and more often is high strength aluminium alloys, especially from the 6xxx alloy series. One of the most important advantage of these AlMgSi alloys is that they can be subjected to heat treatment which allows for their precipitation hardening due to the variable solubility of basic alloy additives, i.e. magnesium and silicon in the solid state [3]. The final properties of a given 6xxx series aluminium alloy depend mostly on the amount of those two alloying additives forming the Mg2Si phase. It is believed that while increasing the content of magnesium and silicon it also increases the strength and hardness of the alloy, while reducing its plastic properties and increasing the brittleness of the material, especially under the influence of dynamic external forces [4-7]. The main challenge and also the scope of this article is to develop a new material with chemical composition based on the commercial EN-AW 6082 aluminium with optimal Mg:Si ratio. This high-silicon aluminium alloy grade shows high strength properties (similar to basic structural steels) and due to the above it is dedicated for construction applications. In addition, this type of alloy is also characterized by a fine-grained microstructure, thanks to which it is also highly resistant to various types of dynamic loads [8,9]. The final purpose of works presented in this article is to find optimal chemical composition and heat treatment parameters, which will allow to determine the type and amount of the strengthening phase, and thus the level of the final mechanical properties.

EXPERIMENTAL PROCEDURE

During the first phase of research works, based on the conducted literature analysis and own material and technological knowledge in the field of material engineering of aluminium alloys a group of 5 alloys were selected with different amount of Mg in the range of 0,6-1,1 wt. % and Si in the range of 0,6-1,2 wt. % (see Table 1). All selected alloys where next subjected to metallurgical synthesis with the use of induction furnace. Temperature of the melting process in graphite crucible was set at 750 °C. Initially 99,5 % Al wire rod was heated and melted and next all additional alloy additives were introduced to the liquid metal (in crystalline form for Mg and in the form of master alloy for Si, Mn, Fe and Ti).

During the metallurgical synthesis liquid metal was stirred several times (in 5 minutes intervals) with the use of graphite lance. After melting and alloying processes liquid alloy was casted into a secondary graphite crucible in order to speed up the crystallization process. Obtained alloys, after performed chemical composition analysis which confirmed that targeted chemical composition was achieved, were next subjected for their

G. Kiesiewicz (e-mail: gk@agh.edu.pl), A. Mamala, W. Ścieżor, P. Kwaśniewski, A. Kawecki, M. Sadzikowski, K. Franczak - AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Cracow, Poland

Table 1 **Targeted chemical composition of selected aluminium alloys for synthesis and analysis of their properties in as cast temper and after performed heat treatment**

	Alloy-forming element / wt. %					
	Fe	Mg	Si	Mn	Ti	Al
Alloy 1	0,4	1	0,6	0,4	0,05	rem
Alloy 2	0,4	0,9	0,7	0,4	0,05	rem
Alloy 3	0,4	0,8	0,8	0,4	0,05	rem
Alloy 4	0,4	0,6	1	0,4	0,05	rem
Alloy 5	0,4	1,1	1,2	0,4	0,05	rem

hardness and electrical conductivity in as cast temper. Hardness was measured both in the HV5 and HB scale with the use of Wilson Tukon 2500 Vickers Automated Hardness Tester and Innovatest Nexus 300 Brinell tester. Electrical conductivity was measured with the use of Foerster Sigmatest 2.069 instrument which is based on eddy current method. In the next phase all obtained castings were homogenized at 550 °C and 575 °C for 100 hours total and then quenched in water. After solution heat treatment all materials were subjected to artificial aging process in the following temperature and time range: temperature of 170 °C, 190 °C and 210°C for 1 – 24 h period. During the artificial aging process, the hardness and electrical conductivity of each material were again tested after each hour of the process.

RESULTS AND DISCUSSION

All casts after metallurgical synthesis process were analysed in terms of their chemical compositions correctness. It was found out that all materials have very similar to the previously indicated composition. For example, for alloy no. 1, the magnesium composition was at the level of 1,01 wt. % which is only 0,01 wt. % higher than previously assumed. In most cases measurements showed the difference from 0,01 – 0,05 wt. %, and in the extreme cases the difference from was at the level of 0,08 wt. % (see Figure 1).

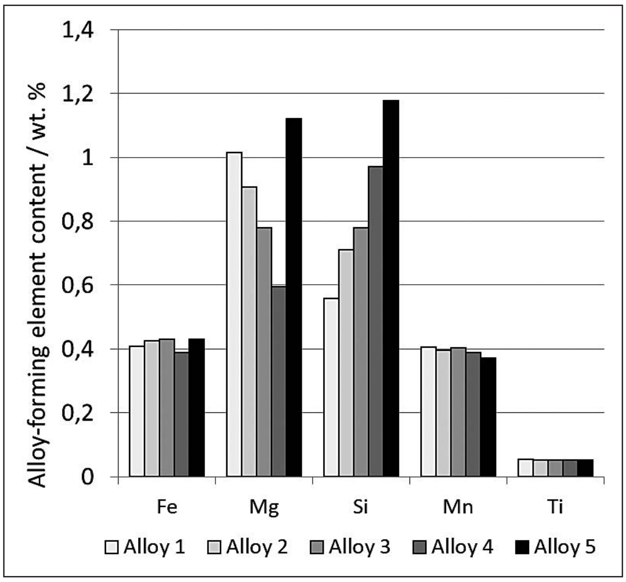

Figure 1 Chemical composition analysis results done for all 5 alloys after their metallurgical synthesis process

After chemical composition analysis electrical conductivity tests were conducted. Average value taken from five individual measurements for five different castings, starting from alloy no. 1 and ending with alloy no. 5, were successively 20,7, 21,2, 21,4, 21,1 and 20,7 MS/m.

Hardness measurement were done with the Vickers and Brinell method. On the Figure 2 a set of all hardness results were shown (along with electrical conductivity) in form of average value calculated from five individual indentations for every analysed material. It was found out that alloy 1 have an average value of 48 HV5. For alloy 2, where the ratio of Mg:Si was 0,9 to 0,7, results of hardness were at the level of 54 HV5. Results for alloy 3 indicate the average hardness at 55 HV5. Alloy 4 with more silicon than magnesium has a hardness of 54 HV5. The last alloy 5 had a hardness value of 58 HV5.

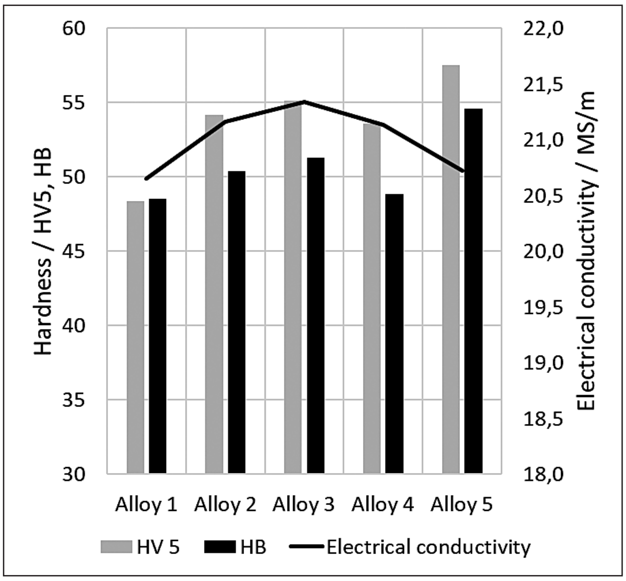

Figure 2 Research results of hardness and electrical conductivity tests for all 5 analysed aluminium alloys in as cast temper

All samples were next subjected to heat treatment processes (homogenization, solution heat treatment and artificial aging). Research results showed that after homogenization and solution heat treatment processes alloy 1 had an electrical conductivity of 24 MS/m and a Vickers hardness of 59 HV5. Alloy 2, when tested just after homogenization and supersaturation, had an electrical conductivity of 23,4 MS/m and hardness 71,8 HV5. Properties of Alloy 3 are 24,3 MS/m and Vickers hardness of 70 HV5. Alloy 4 with increased silicon content, had a conductivity of 24 MS/m and hardness of 60,9 HV5. The last alloy 5 had electrical conductivity of 22,2 MS/m and the hardness of 77 HV5. During artificial aging, the hardness values increased to a certain critical point, then began to decrease. Alloy 1, aged at 170 °C, achieved the highest mechanical strength at the level of 99 HV5 with an electrical conductivity of 25

MS/m after 18 hours. For the aging temperature of 190 °C, the highest value of hardness was recorded at the level of approx. 100 HV5 after 10 hours with a simultaneous electrical conductivity of 26,2 MS/m. For the temperature of 210 °C, the highest Vickers hardness values were noticed after 3 and 4 hours at the level of 93 HV5. Alloy 2 showed increase in electrical conductivity to the level of 24,9, 27,6 and 28,2 MS/m for artificial aging temperatures of 170, 190 and 210 °C respectively. Accordingly, the hardness value reached over 103 HV5 within 13 hours; value of 98 HV5 within 10 hours, and for the highest temperature of artificial aging 98 HV5 was achieved. Alloy 3 indicated electrical conductivity values of 26,2 MS/m, 28,3 MS/m and 28,5 MS/m (for temperatures of 170, 190 and 210 °C, respectively) with hardness of 104, 101 and 102 HV5, achieved in 10, 8 and 2 hours respectively. For the alloy 4, in the case of an aging temperature of 170 °C, the best strength and electrical results were achieved at the level of 26 MS/m with a hardness of 110 HV5 during 13 hours. With an aging temperature of 190 °C, the highest conductivity value of 27,7 MS/m and a hardness value of 103 HV5 was reached after 5 hours. For the highest temperature of artificial aging, an increase in electrical conductivity to the level of 27.6 MS/m and in hardness of 100 HV5 was observed after just 2 hours. The last alloy configuration (alloy 5) with artificial aging temperatures of 170, 190 and 210 °C allowed to observe an increase in electrical conductivity to 25,1, 26,7 and 28,2 MS/m, respectively. The highest HV5 hardness results for individual artificial aging temperatures (170, 190, 210 °C, respectively) are 112, 106 and 107 HV5 and were achieved after 12, 3 and 2 hours.

CONCLUSIONS

Analysis of obtained hardness results, shows that in the temperature of 170 °C the highest values were achieved within 10-15 hours for all alloys. At the higher temperature of 190 °C, the maximum hardness values were obtained in less than 10 hours (generally after about 3 to 5 hours of aging). For the highest temperature of the artificial aging process (210 °C), the maximum hardness results were shown by the samples after aging not longer than 3 hours (generally after 2 hours of aging), followed by a sharp decrease in value due to the aging of the tested alloys.

Alloy 5 had the highest level of hardness (both at the beginning of this research, after the homogenization process, and as well after the artificial aging process). This alloy reached its maximum overall hardness after 12 hours of artificial aging at 170 °C with 112 HV5. In the case of alloy 1, the highest increase in hardness was observed during aging at 170 °C (from about 56 HV5 to about 99 HV5). Alloy 5 has the highest hardness value also at the aging temperature of 190 °C, reaching its maximum at the level of 106 HV5. For the highest temperature of the artificial aging process i.e. 210 °C, also alloy 5 had the highest hardness among the all tested alloys, reaching its maximum after 1 hour of artificial aging - 107 HV5.

The electrical conductivity increases with aging process to its maximum, generally reached after 24 hours of heat treatment. The highest values of electrical conductivity are achieved by alloys 3 and 4. At the aging temperature of 170 °C, after 24 hours, these samples achieved an electrical conductivity of 26 MS/m. At the aging temperature of 190 °C, alloy 3 had the highest electrical conductivity of approx. 28,4 MS/m. Similarly, for a temperature of 210 °C, the highest electrical conductivity for alloy 3 was 28,7 MS/m, and then for alloy 5 - 28,4 MS/m.

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REFERENCES

[1] F. Kiessling, R. Puschmann, A. Schmieder „Contact lines for electric railways" Publicis, Munich (2001),

[2] E. P. Burch "Electric Traction For Railway Trains" Mcgraw-Hill Book Company, London (1911),

[3] J. E. Hatch „ Aluminum: Properties and Physical Metallurgy" ASM International, Ohio (1984),

[4] G. Al Marahleh „Effect of Heat Treatment Parameters on Distribution and Volume Fraction of Mg2Si in the Structural Al 6063 Alloy" American Journal of Applied Sciences (2006) 3/5 p. 1819-1823

[5] M. Cai, D. P. Field, G. W. Lorimer „A systematic comparison of static and dynamic ageing of two Al–Mg–Si alloys" Materials Science and Engineering A (2004), 373/1-2, 65-71

[6] K. P. S. Chauhan „Influence of heat treatment on the mechanical properties of aluminium alloys (6XXX series): A literature review" International Journal of Engineering Research & Technology (2017), 6/3, 386-389

[7] G. A. Edwards, K. Stiller, G. L. Dunlop, M. J. Couper „The precipitation sequence in Al–Mg–Si alloys" Acta Materialia (1998), 46/11, 3893-3904

[8] B. V. R. Ravikumar, B. L. N. Krishna Sai, S. Rajashekhar „Evaluation of Mechanical Properties of AA6082 - T6 Aluminium Alloy Using Pulse & Non-Pulse Current GTAW Process" International Journal of Innovative Research in Science, Engineering and Technology (2014), 3/12, 18139-18146

[9] Y. Birol, E. Gokcil, M. Ali Guvenc, S. Akdi „Processing of high strength EN AW 6082 forgings without a solution heat treatment" Materials Science and Engineering A (2016), 674/30, 25-X

Note: The translator responsible for English language: Paweł Strzępek, Krakow, Poland.