ARCHIVES of FOUNDRY ENGINEERING
ISSN (1897-3310)
Volume 7
Issue 3/2007
167 – 170
32/3

An Assessment of the Effect of Process History on the Structure and Mechanical Properties of Hypereutectic Silumins

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Received on: 24.04.2007; Approved for printing on: 27.04.2007

Abstract

An effect of process history of manufacturing the AlSi17Cu3Mg1,5Ni1,5 alloy on its tensile strength R_m, hardness HB, and elongation A_5 was investigated. The individual elements of process history of the alloy fabrication included: type of mould (sand or metal mould), modification process, and type of heat treatment (solutioning and ageing). Basing on a multivariance MANOVA test, it was possible to determine not only the effect of the main parameters, like foundry mould type, modification and heat treatment, but also an interaction of these effects. Consequently it has been concluded that the tensile strength R_m, of the examined alloy is statistically most affected by the process of modification, followed by the type of the applied heat treatment, and the type of foundry mould (metal mould). The strongest interactive effect on the value of R_m had a combination of the modification process and heat treatment.

Keywords: Hypereutectic silumins, Statistical methods, Cast alloys

1. Introduction

A review of technical literature [1-3] as well as the results of own investigations [4,5] indicate that the hypereutectic Al-Si alloys containing from 16 to 18 % Si and additions of Cu, Ni and Mg are characterised by a very promising complex of the mechanical and technological properties. For this reason, these alloys find nowadays growing application in the automotive industry, specially as a material for parts of pistons and cylinder heads operating in I.C. engines. Operating under such conditions, the castings are expected to possess high durability at elevated temperatures and offer failure-free performance. In Poland, at the present moment, no alloys are available which would correspond to those widely used for the above mentioned applications in the countries of Western Europe and USA. Recently, however, it has been noted that there is an alloy which seems to best satisfy the above mentioned requirements. This is the silumin containing about 17% Si and additions of 3% Cu, 1,5% Ni and 1,5% Mg [1-3]. A separate problem is the properly conducted technological process of casting this alloy (sand or metal mould), and the application of modification and heat treatment (solutioning and ageing).

2. Methods of investigation

The investigations were carried out on a hypereutectic silumin containing about 17% Si, 3% Cu, 1,5% Ni and 1,5% Mg in the non-modified condition and after modification with phosphorus in an amount of 0,05% (Cu-P10 master alloy). Melting was conducted in a LEYBOLD-HERAEUS IS5/III induction furnace with crucible made from magnesite refractory material. A protective coating of 2NaF and KCl (in a ratio of 20 to 80%) was used. When the temperature of about 820°C had been reached, the melt was subjected to a refining treatment with Rafglin-3, added in an amount of 0,3% respective of the alloy weight. The temperature of pouring was controlled by a NiCr-NiAl TP-202K-800-1 thermocouple. The alloy was cast into a steel mould and into a sand mould made from the traditional bentonite sand. The specimens of dimensions 12× 100 mm were cast according to EN 10002-1. Some of the specimens were subjected to a heat treatment which consisted in solutioning at 480°C/8h/water and ageing at 210°C/6h/cooling with furnace [1,2,9,10].

Hardness was measured by the Brinell method on a Rockwel-Brinell hardness tester, type 15002P, under a loading of 187,5 kg, with ball diameter of 2,5 mm and the time of measurement 35 s. Mechanical properties (R_m and A_5) were tested on a FPZ 10 HECKERT machine of 20:1 ratio and a constant rate of 5 mm/min. The tensile test was carried out according to EN 10002-1.

Full program of the investigations is specified in Table 1.

Table 1.
Program of investigations

Specimen designation	Type of mould	Modification (Cu-P)	Heat treatment
METAL_	Metal (1)	NO (0)	NO (0)
METAL_MO_	Metal (1)	YES (1)	NO (0)
METAL_OB_	Metal (1)	NO (0)	YES (1)
METAL_OB_MO	Metal (1)	YES (1)	YES (1)
SAND_	Sand (0)	NO (0)	NO (0)
SAND_MO_	Sand (0)	YES (1)	NO (0)
SAND_OB_	Sand (0)	NO (0)	YES (1)
SAND_OB_MO	Sand (0)	YES (1)	YES (1)

3. Results and summary

For an assessment of the effect of process history of the Al-Si alloy fabrication, including:

- mould type (sand or metal mould),
- application of modification process,
- application of heat treatment (solutioning and ageing),

on the selected mechanical properties of this alloy, a multivariance MANOVA test has been used [5-8].

Table 2 and Figure 1 show the results of an assessment of the effect of process history on the tensile strength R_m of the investigated alloy.

Table 2.
The effect of process history on the tensile strength R_m of an Al-Si-Cu-Mg-Ni alloy

Rm [MP	The investigated AlSiCuMgNi alloy							
			modification				modification	
	sand mou	metal mou	sand mou	metal mou	sand mou	metal mou	sand mou	metal mou
					heat treatment		heat treatment	
Mean	**176,38**	**188,33**	**195,38**	**215,92**	**192,50**	**207,58**	**221,75**	**235,27**
Median	177,0	188,0	196,0	216,0	192,0	208,0	222,0	236,0
Std. dev.	3,75	3,21	3,72	3,07	3,88	4,19	2,88	2,59
SEM	0,521	0,445	0,516	0,426	0,538	0,581	0,399	0,359
Minimum	167	179	187	211	185	199	215	228
Maksimum	184	196	203	222	201	215	228	240
Quartile 25%	174	186	193	213	190	204	220	234
Quartile 75%	179	190	199	219	195	211	224	237
N	52	52	52	52	52	52	52	52

As proved by the MANOVA test (Table 3, Fig. 2), in terms of statistics, the strongest and most significant effect on an increase of the tensile strength R_m had the process of modification, almost two times weaker effect had the heat treatment, and almost three

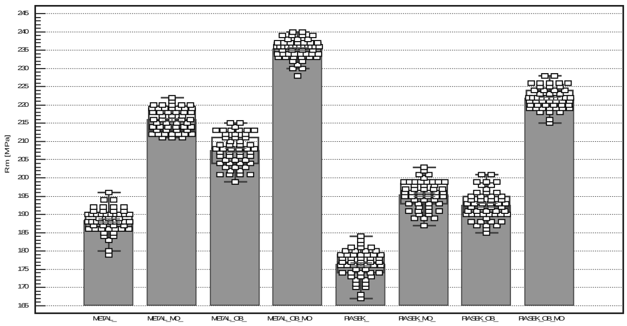

Fig. 1. The effect of process history on the tensile strength R_m of an Al-Si-Cu-Mg-Ni alloy

At the same time, a statistically significant effect of the mould type*modification process*heat treatment interaction on an increase of the examined resultant characteristic, i.e. on the tensile strength R_m, has been proved. The effect of interaction was the strongest in the case of modification process combined with heat treatment.

Table 3.
The results of statistical assessment of the effect of process history on the tensile strength R_m of an AlSiCuMgNi alloy

Parameter	SS	MS	F	p
Free term	17335928	17335928	1455535	0,0000
Mould	24248	24248	2036	**0,0000**
Modification	69681	69681	5850	**0,0000**
Heat treatment	42728	42728	3587	**0,0000**
Mould*Modification	322	322	27	**0,0000**
Mould*Treatment	98	98	8	**0,0043**
Modification*Tratment	696	696	58	**0,0000**
Mould*Modification*Tratment	670	670	56	**0,0000**
Error	4859	12		

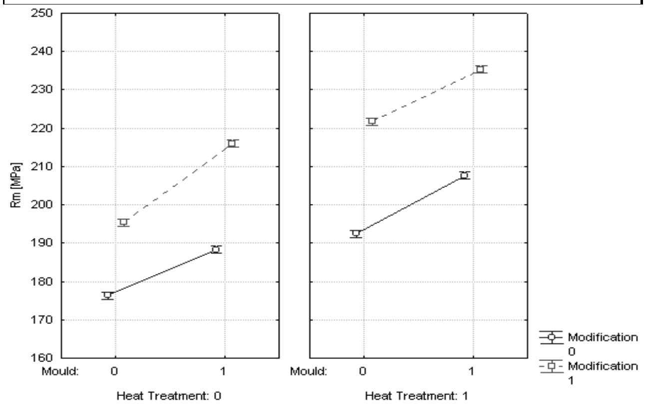

Fig. 2. The effect of process history on the tensile strength R_m

Table 4 and Figure 3 show the results of an assessment of the effect of process history on hardness HB of the investigated alloy.

Table 4.
The effect of process history on alloy hardness HB

Hardness I	The investigated AlSiCuMgNi alloy							
			modification				modification	
	sand mould	metal mould	sand mould	metal mould	sand mould	metal mould	sand mould	metal mo
					heat treatment		heat treatmen	
Mean	**100,19**	**116,56**	**125,42**	**140,42**	**136,98**	**149,50**	**141,38**	**162,12**
Median	101,0	116,5	126,0	140,0	137,0	150,0	142,0	162,0
Std. dev.	4,08	3,82	3,83	2,75	3,92	4,71	3,28	3,16
SEM	0,572	0,529	0,531	0,381	0,543	0,654	0,455	0,438
Minimum	91	110	116	134	128	133	133	155
Maksimum	106	124	133	146	149	158	148	169
Quartile 25%	97	114	123	139	135	146	139	160
Quartile 75%	104	119	128	142	139	153	144	164
N	52	52	52	52	52	52	52	52

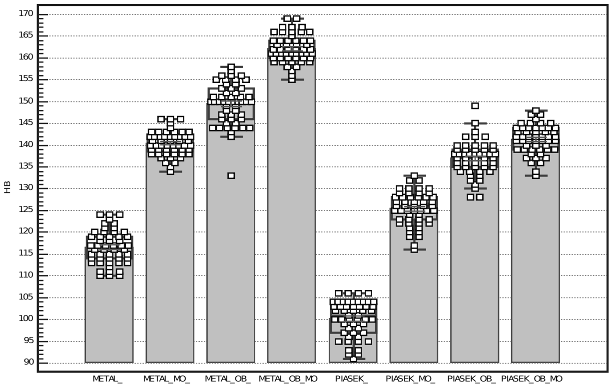

Fig. 3. The effect of process history on alloy hardness HB

As proved by the MANOVA test (Table 5, Fig. 4), in terms of statistics, the strongest and most significant effect on an increase of hardness HB had the heat treatment, almost two times weaker effect had the modification process and casting of metal into metal mould. At the same time, a statistically significant effect of the mould type*modification process and modification process*heat treatment interaction was observed, with simultaneous interaction of the mould type*modification process*heat treatment effect on an increase of the examined resultant characteristic, i.e. on hardness HB. The strongest interactive effect had a combination of the modification process and heat treatment.

Table 5.
The results of statistical assessment by MANOVA test of an effect of process history on alloy hardness HB

Parameter	SS	MS	F	p
Free term	7477738	7477738	535447	**0,0000**
Mould	27138	27138	1943	**0,0000**
Modification	28413	28413	2035	**0,0000**
Heat treatment	74954	74954	5367	**0,0000**

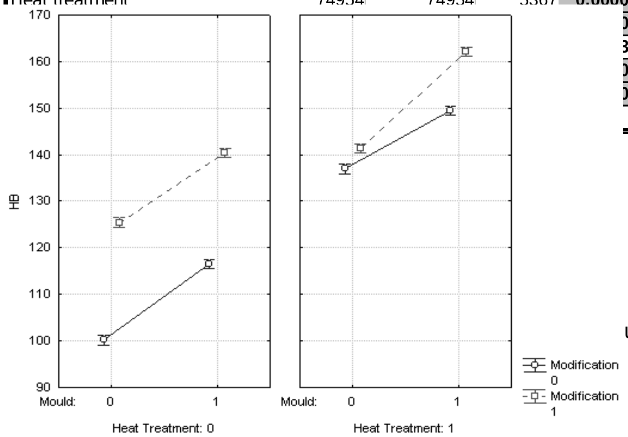

Fig. 4. The effect of process history on alloy hardness HB

Table 6 and Figure 5 show the results of an assessment of the effect of process history on elongation A_5 of the examined alloy.

Table 6.
The effect of process history on alloy elongation A_5

Elongatio A_5 [%]	The investigated AlSiCuMgNi alloy							
			modification				modification	
	sand mould	metal mould	sand mould	metal mould	sand mould	metal mould	sand mould	metal mo
					heat treatment		heat treatment	
Mean	**1,03**	**1,21**	**1,64**	**1,94**	**1,19**	**1,33**	**1,87**	**2,17**
Median	1,0	1,2	1,6	1,9	1,2	1,3	1,9	2,2
Std. dev.	0,22	0,21	0,24	0,18	0,17	0,19	0,15	0,15
SEM	0,003	0,029	0,033	0,026	0,024	0,026	0,020	0,021
Minimum	0,5	0,7	1,1	1,5	0,8	1,0	1,5	1,8
Maksimum	1,5	1,6	2,2	2,3	1,7	1,8	2,2	2,5
Quartile 25%	0,9	1,1	1,5	1,8	1,1	1,2	1,8	2,1
Quartile 75%	1,2	1,4	1,8	2,1	1,3	1,5	1,9	2,3
N	52	52	52	52	52	52	52	52

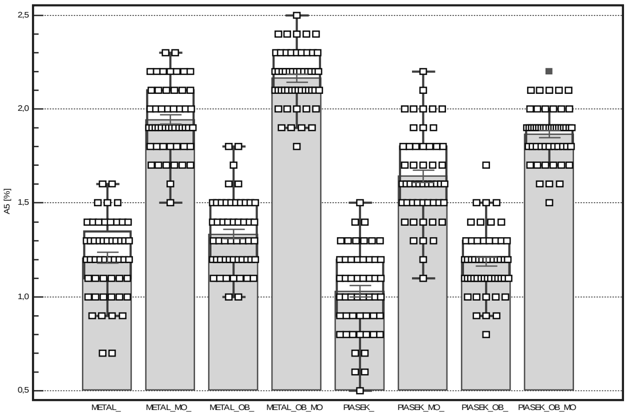

Fig. 5. The effect of process history on alloy elongation A_5

As proved by the MANOVA test (Table 7, Fig. 6), in terms of statistics, the strongest and most significant effect on an increase of the elongation A_5 had the modification process, almost ten times weaker effect had casting into metal mould, and almost twenty times weaker effect had the application of heat treatment.

Table 7
The results of statistical assessment by MANOVA test of the effect of process history on alloy elongation A_5

Parameter	SS	MS	F	p
Free term	996	996	27139	**0,0000**
Mould	6	6	152	**0,0000**
Modification	53	53	1451	**0,0000**
Heat treatment	3	3	95	**0,0000**
Mould*Modification	0	0	13	**0,0003**
Mould*Treatment	0	0	0	**0,6452**
Modification*Tratment	0	0	5	**0,0321**
Mould*Modification*Tratment	0	0	0	**0,7203**
Error	15	0		

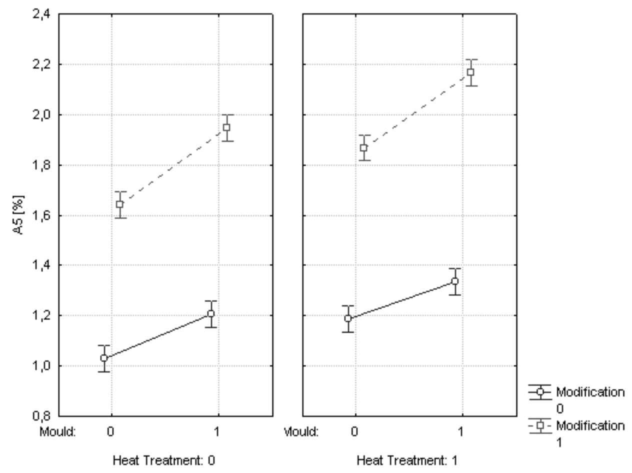

Fig. 6. The effect of process history on alloy elongation A_5

At the same time, a statistically significant effect of the mould type*modification process and modification process*heat treatment interaction was reported as regards an increase of the examined resultant characteristic, i.e. the value of elongation A_5 The strongest effect had the combined mould type*modification process interaction.

The results reported in this article are based on a Research Project 3 T08 B 014 27 financed from the resources of KBN Polish Committee of Scientific Research.

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