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Hypoeutectic Al-Si Alloy with Cr, V and Mo to Pressure Die Casting

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Abstract

This paper presents the results of hypoeutectic 226 grade alloy as well as prepared on its basis Al-Si alloy containing Cr, V and Mo. The additives tested were added as AlCr15, AlV10 and AlMo8 master alloys. Alloys tested were poured into DTA sampler as well as using pressure die casting. An amount of Cr, V and Mo additives in alloy poured into DTA sampler comprised within the range approximately 0.05-0.35%. Alloys to pressure die casting contained 0.05-0.20% Cr, V and Mo. The crystallization process was examined using the derivative thermal analysis (DTA). The microstructure of castings made in the DTA sampler as well as castings made with use of pressure die casting were examined. The basic mechanical properties of castings made using pressure die casting were defined too. It has been shown in the DTA curves of Al-Si alloy containing approximately 0.30 and 0.35% Cr, Mo, and V there is an additional thermal effect probably caused by a peritectic crystallization of intermetallic phases containing the aforementioned additives. These phases have a morphology similar to the walled and a relatively large size. The analogous phases also occur in pressure die casting alloys containing 0.10% or more additions of Cr, V and Mo. The appearance of these phases in pressure die casting Al-Si alloys coincides with a decrease in the value of the tensile strength R_m and the elongation A. It has been shown die castings made of Al-Si alloys containing the aforementioned additives have a higher R_m and A than 226 alloy.

Keywords: Theory of crystallization, Pressure die casting, Multicomponent Al-Si alloys, DTA method

1. Introduction

In papers [1-3] Al-Cr, Al-V as well as Al-Mo phase equilibrium diagrams has been presented. The lack of the solubility of chromium and molybdenum in aluminum in the solid state results from them. The maximum solubility of vanadium in aluminum is 0.6 wt% (~0.3% at) at the temperature approx. 662ºC, and decreases to 0.0% as the temperature drops. Chromium, vanadium and molybdenum create with aluminum a number of intermetallic phases crystallizing mainly due to the peritectic transformations. These elements increase the liquidus temperature of the aluminum alloys. From Cr-V, Cr-Mo and Mo-V phase equilibrium diagrams presented in papers [4-6] results a mutual unlimited solubility of these elements. The intermetallic phases occurring in the Al-Si alloys containing Cr, V, and Mo can significantly increase their fragility. In case of pressure die casting, when the crystallization process proceeds very intensively the supersaturation of the solid solutions with these elements may takes place.

Therefore, the aim of this study was to investigate the effect of simultaneously added Cr, V, and Mo on the crystallization process, microstructure and mechanical properties of hypoeutectic Al-Si alloy to pressure die casting.

2. Test methodology

The research was performed under the production conditions of the Innovation and Implementation Enterprise Wifama-Prexer Ltd., Poland.

To the study 226 standard hypoeutectic aluminum alloy to pressure die casting was used. Its chemical composition is given in Table 1.

Table 1.
The chemical composition of the 226 Al-Si alloy tested

Chemical compositon, wt%									
Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Ti
9.85	0.89	2.61	0.22	0.28	0.12	0.98	0.02	0.03	0.02

The tested alloy was melted in a gas shaft furnace with a capacity of 1.5 tons and refined with use of Ecosal Al 113.S solid refiner. After smelting and refining the tested alloy was transported to the holding furnace set near to Idra 700S pressure machine with a horizontal cold chamber. Thereafter, a liquid metal was taken from the holding furnace in order to make die castings and DTA tests. The die casting was in the form of the housing roller blinds with predominant wall thickness 2 mm. Both 226 alloy as well as alloys containing Cr, V and Mo were tested. The aforementioned additions were added to alloys as mortars AlCr15, AlV10 and AlMo8. In subsequent melts an amount of each additive was increased by 0.05%. In order to make the die castings an alloy containing 0.00-0.20% Cr, V and Mo was used, while for the DTA tests an amount of the additives was in the range of 0.00-0.35%.

On the specimens taken from the die casting the basic mechanical properties of Al-Si alloy were evaluated. The assumed range of additives allowed to observe changes in the properties examined. To the DTA tests a greater range of additives was assumed; it amounted to 0,00-0,35%. It allowed to demonstrate the changes in the crystallization process of alloy containing the relatively high amount of aforementioned additives.

The derivative thermal analysis (DTA) is an universal method to study the crystallization process of different alloys. It was previously used to study: iron, aluminum, copper, magnesium and cobalt alloys [7-11]. For recording DTA curves PtRh10-Pt thermocouple placed inside the DTA10-TUL sampler was used. The sampler was made of resin sand.

During the tensile test the tensile strength R_m, yield strength $R_{p0.2}$ and elongation A were determined. The strength tests were performed on samples cut from the housing roller blinds castings. For each tested chemical composition three specimens were cut from one casting. They had a rectangular cross section with dimensions of 2/10 mm as it is recommended by the standard [12]. Tensile tests were performed on a Instron 3382 machine using speed 1 mm/min. The accuracy of the load and handle displacement is up to 1% of the indicated value.

Hardness tests were performed on HPO-2400 hardness testing machine. The ball with 2.5 mm diameter and 613 N load were used to the test. The accuracy of the hardness measurement on the device used is ± 1%.

The microstructure was investigated on specimens taken from die castings as well as from DTA sampler. Metallographic specimens were etched with 2% aqueous solution of HF and tested at a magnification of ×100 and ×1000 on metallurgical microscope Nikon Eclipse MA200.

3. Results

DTA curves of 226 alloy are shown in Figure 1. The crystallization process of this alloy as well as its microstructure obtained in a casting made in the DTA sampler and in die casting are presented in paper [13].

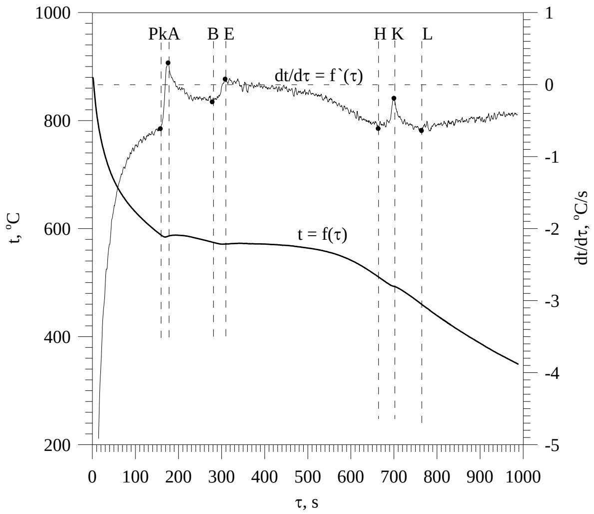

Fig. 1. The representative DTA curves of 226 Al-Si alloy

There are three thermal effects on the curves presented (Fig. 1). The first one is marked as PkAB was caused by the crystallization of the solid solution α(Al), the second one (BEH) came from the triple eutectic crystallization $\alpha + Al_9Fe_3Si_2 + \beta$ while the third (HKL) was caused by the quadruple eutectic crystallization $\alpha + Al_2Cu$ + AlSiCuFeMgMn + β. Chromium, vanadium and molybdenum additions in amount 0.05-0.25% did not change the course of DTA curves, the additional thermal effects did not occur. It has been assumed that additions were located in the most complex intermetallic phase in the quadruple eutectic. This phase in aluminum alloys with Cr, V, and Mo can be described as AlSiCuFeMgMnCrVMo. The increase in additives content to 0.30-0.35% caused the occurrence of an additional thermal effect on DTA curves.

Figure 2 shows DTA curves of alloy containing approximately 0.35% Cr, V and Mo (each of them). The new thermal effect is indicated in Fig. 2 as PkA"A' and it was probably caused by a peritectic crystallization of intermetallic phases containing aforementioned elements. The others thermal effects occurring on these curves (Fig. 2) are similar as for alloys containing 0.05-0.25% of additives tested. Therefore, there are thermal effects: A'AB caused by the crystallization of the solid solution α as well as BEH and HKL from the triple and quadruple eutectic crystallization, respectively. The summary of the temperature values at the characteristic points on DTA curves of 226 alloy and containing 0.05÷0.35% Cr, V and Mo is presented in Table 2.

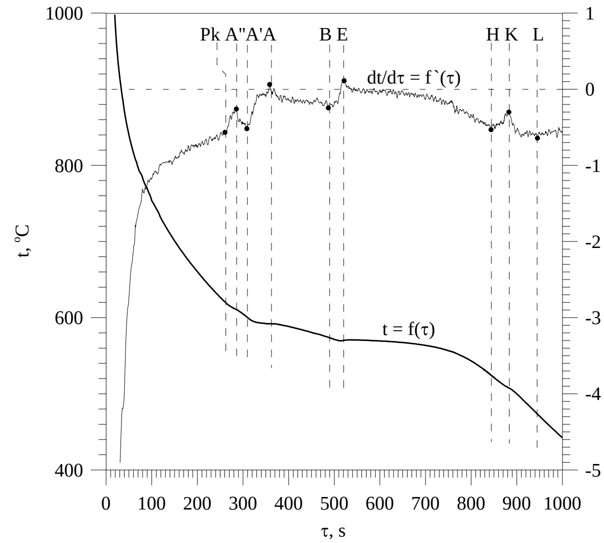

Fig. 2. The representative DTA curves of Al-Si alloy containing approx. 0.35% Cr, V and Mo

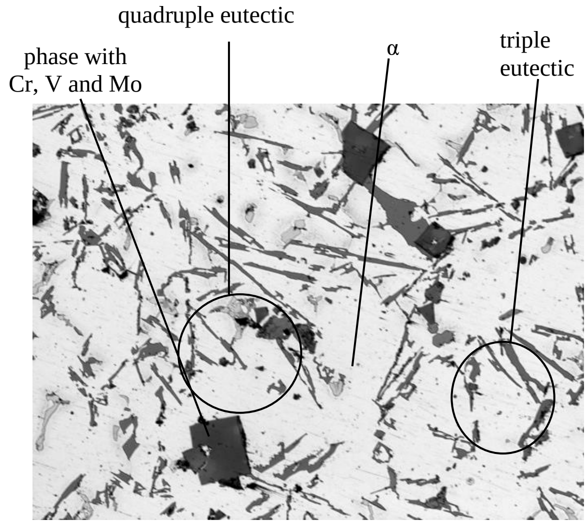

Fig. 3. The microstructure of the alloy containing 0.35% Cr, V and Mo from DTA sampler: α, α + $Al_9Fe_3Si_2$ + β, α + Al_2Cu + AlSiCuFeMgMnNiCrVMo + β

Table 2.
Summary of the temperature values at the characteristic points on DTA curves of 226 alloy and alloy containing 0.05÷0.35% Cr, V and Mo

Cr, V and Mo, wt%	Temperature t, °C								
	Pk	A''	A'	A	B	E	H	K	L
0.00	589	-	-	586	575	571	511	493	460
0.05	590	-	-	587	576	573	517	497	469
0.10	595	-	-	590	578	574	520	496	476
0.15	598	-	-	591	576	573	516	497	472
0.20	598	-	-	593	578	575	517	503	474
0.25	599	-	-	592	572	569	518	497	462
0.30	607	603	597	592	576	572	517	506	476
0.35	621	611	601	592	574	570	524	508	473

From the presented data it follows chromium, vanadium and molybdenum cause an increase in the temperature of the crystallization start (point Pk). In the tested alloys containing approximately 0.30 and 0.35% Cr, V, and Mo, the temperature of the crystallization start "t_{Pk}" is definitely the highest and amounts to 607 and 621ºC, respectively. It is caused by the crystallization of the intermetallic phases containing the additives tested (thermal effect PkA"A') at a relatively high temperature, higher than the solid solution α crystallizes. Phases occur in the casting from DTA sampler made of alloy containing 0.35% Cr, V and Mo are shown in Figure 3. The phases identification in Al-Si alloys containing Fe, Cr, V, W, and Mo is presented inter alia in [14-17].

These phases have the morphology similar to the walled, and their sizes can reach up to 100 microns. An analogous phases are also present in the die castings made of Al-Si alloy containing approximately 0.10; 0.15 and 0.20% Cr, V and Mo. These phases occurring in the die casting are exemplified in Figure 4 for alloy containing approx. 0.20% additions tested.

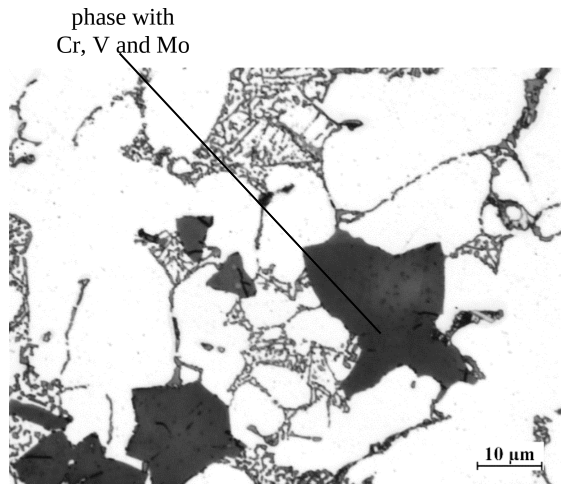

Fig. 4. The microstructure of die casting made of the Al-Si alloy containing approximately 0.2% Cr, V and Mo: α, α + $Al_9Fe_3Si_2$ + β, α + Al_2Cu + AlSiCuFeMgMnNiCrVMo + β

The walled phases presented in Fig. 4 can reach the size ~30 microns, so they are considerably smaller than the analogical phases in castings made in the DTA sampler. However, they significantly exceed the phases size which occur in alloys from die castings.

Table 3 presents the results of the basic mechanical properties of the tested Al-Si alloys and the standard deviation σ.

The presented data suggest the possibility of increasing the tensile strength R_m, elongation A and hardness of the tested Al-Si alloy by addition Cr, V and Mo. The maximum values of these properties were obtained for alloy containing approximately 0.05% of the tested additives. They amounted to R_m = 293 MPa; A = 5.8% and HB = 117.

Table 3.
The mechanical properties of Al-Si alloys, with and without Cr, V and Mo

Cr, V and Mo, wt%	Mechanical properties							
	R_m, MPa	σ	$R_{p0,2}$, MPa	σ	A, %	σ	HB	σ
0.00	261	16.1	151	4.7	3.0	0.68	114	0.5
0.05	293	4.1	137	6.5	5.8	0.37	117	2.0
0.10	285	13.5	140	1.7	5.2	0.87	114	0.5
0.15	279	5.7	138	3.2	5.3	0.30	110	1.0
0.20	270	11.1	136	7.6	4.8	0.87	113	1.0

It gives an increase the tensile strength by 12%; an elongation by 93% and hardness by 3% in comparison to the 226 alloy. The highest yield strength $R_{p0.2}$ = 151 MPa has 226 alloy. The increase in hardness is negligible. Taking into account an error of the hardness tester machine it was assumed that Cr, V and Mo do not substantially affect on the Al-Si alloy hardness. The largest increase was obtained for elongation and the tensile strength. From presented data results both R_m as well as A reach a maximum at a concentration of approximately 0.05% Cr, V and Mo and next their value decreases. The increase in R_m and A values is probably caused by the supersaturation of solid solution α with studied additives. Their next decrease was caused by formation of intermetallic phases containing Cr, V and Mo. They are characterized by unfavorable walled morphology and a relatively large size. The slight increase in elongation value from A = 5.2% for 0.10% Cr, V and Mo to A = 5.3% for 0.15% additives is within the range of an testing machine error.

4. Conclusions

From the data included in this paper the following conclusions can be drawn:

- on the DTA curves of the tested alloy without Cr, V and Mo, and containing 0.25% of aforementioned additives, there are three thermal effects coming from the crystallization of: phase α (Al) as well as the triple and quadruple eutectic, respectively;
- the addition 0.30 and 0.35% Cr, V and Mo caused the occurrence an additional PkA"A' thermal effect on DTA curves coming from the crystallization of intermetallic phases containing probably Cr, V, and Mo;
- there were similar phases in the microstructure of die castings with the addition of 0.1-0.2% Cr, V and Mo;
- the highest values of mechanical properties amounted to: R_m = 293 MPa; A = 5.8% and HB = 117 in alloy containing 0.05% Cr, V, Mo and $R_{p0.2}$ = 151 MPa for 226 alloy.

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References

[1] Okamoto, H. (2008). Al-Cr (Aluminum-Chromium). *Journal of Phase Equilibria and Diffusion*. 29(1), 111-112. DOI: 10.1007/s11669-007-9225-4

[2] Alloy Phase Diagrams. ASM Handbook Vol. 3. 1992.

[3] Okamoto, H. (2010). Al-Mo (Aluminum-Molybdenum). *Journal of Phase Equilibria and Diffusion*. 31(5), 492-493.

[4] Zheng, F., Argent, B.B. & Smith, J.F. (1999). Thermodynamic Computation of the Mo-V Binary Phase Diagram. *Journal of Phase Equilibria*. 20(4), 370-372.

[5] Smith, J.F., Bailey, D.M. & Carlson, O.N. (1982). The Cr-V (Chromium-Vanadium) System. *Bulletin of Alloy Phase Diagrams*. 2(4), 469-473.

[6] Venkataraman, M. & Neumann, J.P. (1987). The Cr-Mo (Chromium-Molybdenum) System. *Bulletin of Alloy Phase Diagrams*. *8*(3), 216-220.

[7] Pisarek, B.P. (2013). Model of Cu-Al-Fe-Ni Bronze Crystalization. *Archives of Foundry Engineering*. 13(3), 72-79.

[8] Rapiejko, C., Pisarek, B., Czekaj, E. & Pacyniak, T. (2014). Analysis of the Crystallization of AZ91 Alloy by Thermal and Derivative Analysis Method Intensively Cooled in Ceramic Shell. *Archives of Foundry Engineering*. 14(1), 97-102.

[9] Kacprzyk, B., Szymczak, T., Gumienny, G. & Klimek, L. (2013). Effect of the Remelting on Transformations in Co-Cr-Mo Prosthetics Alloy. *Archives of Foundry Engineering*. 13(3). 47-50.

[10] Pezda, J. (2015). Effect of the T6 heat treatment on change of mechanical properties of the AlSi12CuNiMg alloy modified with strontium. *Archives of Metallurgy and Materials*. 60(2), 627-632.

[11] Piątkowski, J. & Gajdzik ,B. (2013). Testing phase changes in Al-Si cast alloys with application of thermal analysis and differential calorimetric analysis. *Metalurgija*. 52(4), 469-472.

[12] PN-EN 1706:2011. Aluminum and aluminum alloys. Castings. The chemical composition and mechanical properties. (in Polish).

[13] Szymczak, T., Gumienny, G. & Pacyniak, T. (2015). Effect of tungsten on the solidification process, microstructure and properties of silumin 226. *Transactions of the Foundry Research Institute*. 55(3), 3-14.

[14] Pietrowski, S. (2001). *Silumins*. Łódź: Publishing house of Lodz University of Technology.

[15] Pietrowski, S., Władysiak, R. & Pisarek, B. (1999). Crystallization, structure and properties of silumins with cobalt, chromium, molybdenum and tungsten admixtures. In International Conference Light Alloys and Composites, 13-16 May 1999 (77-83).

[16] Pietrowski, S. & Szymczak, T. (2009). Silumins alloy crystallization. *Archives of Foundry Engineering*. 9(3), 143-158.

[17] Pietrowski, S. (2007). Complex silumins. *Journal of Achievements in Materials and Manufacturing Engineering*. 24(1), 101-105.