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Investigations of the Influence of the Zone of Chills on the Casting Made of AlSi7Mg Alloy with Various Wall Thicknesses

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Abstract

The influence of the chill on the AlSi7Mg alloy properties after the heat treatment T6, was realised in the system of the horizontally cast plate of dimensions 160x240 mm and thickness of 10 and 15 m. The cooling course in individual casting zones was recorded, which allowed to determine the solidification rate. Castings were subjected to the heat treatment T6 process. Several properties of the alloy such as: hardness BHN, density, tensile strength UTS, elongation %E were determined. The microstructure images were presented and the structural SDAS parameter determined. The performed investigations as well as the analysis of the results allowed to determine the influence zone of the chill. The research shows that there is a certain dependence between the thickness of the casting wall and the influence zone of the chill, being not less than 2g, where g is the casting wall thickness. The next aim of successive investigations will be finding the confirmation that there is the dependence between the casting wall thickness and the influence zone of the chill for other thicknesses of walls. We would like to prove that this principle is of a universal character.

Keywords: Mechanical properties, Thermal characteristics, Cooling rate, Chills, AlSi7Mg alloy

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1. Introduction

Al-Si alloys, as a material with favourable technological properties, dominate in the manufacturing of castings for the automotive, aviation and other sectors of industry [1]. The influence of the chill on the AlSi7Mg alloy properties after the heat treatment T6, was realised in the system of the horizontally cast plate of dimensions 160x240 mm and thickness of 10 and 15 m. The cooling course in individual casting zones was recorded, which allowed to determine the solidification rate. Castings were subjected to the heat treatment T6 process. Several properties of the alloy such as: hardness BHN, density, tensile strength UTS, elongation %E were determined. The microstructure images were presented and the structural SDAS parameter determined.
This study constitutes the continuation of investigations of the solidification rate influence on the AlSi7Mg alloy properties [2].
The ability of a fast heat abstraction by the casting mould in crucial places of the solidifying casting allows to minimise unfavourable results of the process. In the traditional casting based mainly on sand moulds technology, we are often dealing with the occurrence of micro-shrinkages, shrinkage cavities and similar defects which decrease properties or even cause scrap castings [3-8]. Oxide contaminations non-metallic inclusions porosities related to alloy gasification should be eliminated by

means of refining at a preparation stage of the liquid casting alloy. The correctly designed casting, properly placed in the mould, correctly selected gating system and eventual feeders should warrant obtaining castings of a soundness quality. Increasing the solidification rate in the given zone, it means the so-called local acceleration of the process by the chills application allows to achieve castings desired quality. Placement of chills in sand moulds is aimed at increasing cooling rates of casting walls causing structure refinements and in effect improving casting properties. The chill directly influencing the casting solidification changes all features and properties of the material (casting walls). Thus, the operation range of the chill can be determined by detecting one or a few features (e.g. density) or one property (e.g. UTS) in samples taken from places in various degrees distant from the chill edge. Such method of assessing the operation zone of chills applied in the casting production of Al–Si alloys was applied in the hereby study [2].

2. Investigation methodology

The plate of dimensions 160x240 mm and thickness of 10 and 15 mm was horizontally cast in two variants: without a chill and with the chill placed above the plate. Technical copper was the material for the chill of dimensions 50x50x50 mm. Copper as well as its alloys are characterised by the highest thermal conductivity. To determine the solidification rate of the plate, which was cast in the sand mould with water glass (5%) as a binder, thermocouples were placed inside the plate in such way that the temperature was measured in the half of the plate thickness. Schematic presentation of the plate is shown in Figure 1.

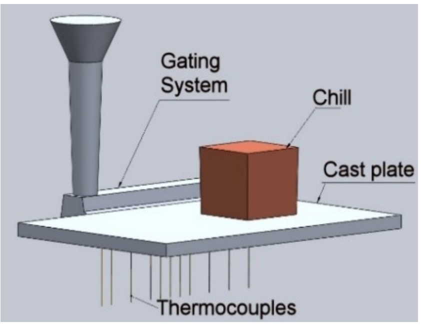

Fig. 1. Schematic presentation of the system of the horizontal plate casting, of dimensions 160x240x10/15 mm [1]

The tests were carried out using: Vickers-Brinell hardness tester HPO-250, SPECTROMAXx emission spectrometer with spark excitation, NIKON Eclipse LV 150 microscope (OM). The INGSTRON model115 was used for strength tests, and RADWAG PS210.R2 for determining the density of samples.
The AlSi7Mg alloy, which was used for making the casting of the plate was melted in the induction thyristor furnace of a medium frequency (temperature: 720-750^{o}C). Then alloying additions such as copper - in a form of the AlCu50 foundry alloy - and magnesium were introduced and the metal was subjected to refining by argon 5.0 for 3 minutes. The composition of the obtained alloy is presented in Table 1. The casting temperature was 720^{o}C.

Table 1.
Chemical composition - on the bases of the spectral analysis - of the tested alloy, (selected elements)

Elements	Si	Fe	Cu	Mn	Mg	Cr
Con. (wt.%)	7.51	0.306	1.09	0.133	0.64	0.024
Elements	Ni	Zn	Ti	Na	Zr	Al
Con. (wt.%)	0.011	0.105	0.141	0.0015	0.0013	90.04

The castings of the plates were subjected to the heat treatment T6 - quenching 540^{o}C /4h and aging 180^{o}C /12h in the resistance chamber furnace. Then, on the properly prepared samples, investigations of: hardness BHN (in the plate cross-section 5 mm, acc. PN-EN ISO 6506-1:2002), tensile strength UTS (samples of 5 mm diameter, acc. PN-EN ISO 6892-1) and density „ρ" were performed. Microscopic investigations were also performed and the casting porosity P was calculated.

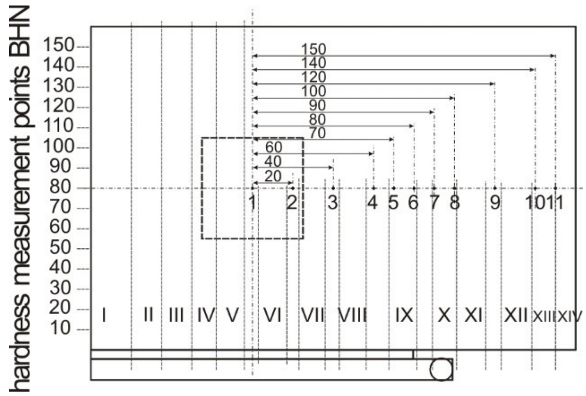

Fig. 2. Schematic presentation of the distribution of measuring points of temperature and hardness as well as cutting points of the plate casting on individual samples I –XIV

The performed measurements of the cooling course in individual plate points allowed to determine temperatures characteristic for transitions occurring during the casting solidification. The example of thermal analysis ADT with the determined characteristic points is presented in Figure 2.

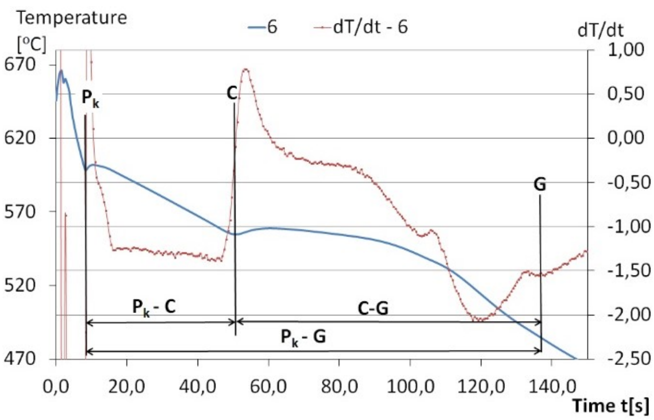

Fig. 3. Example of the cooling course and the determined characteristic transitions

Stages on the cooling curve, used in this study at determining solidification rates coefficients are segments: "$\mathbf{P_k}$ - **C**" - crystallisation of solution α, "**C - G**" - crystallisation of eutectic α+β (together with multicomponent eutectics and intermetallic phases), "$\mathbf{P_k}$ **- G**" - total crystallisation period of the casting [9,10].

3. Description of achieved results of own researches

The precise determination of the solidification rate in individual points of the plate casting allowed to find the influence zone of the chill. The solidification curves AT of the AlSi7Mg alloy in point 1, are presented in Fig. 4. The larger thickness of the plate wall casting (15 mm) decreases significantly the solidification rate. On the other hand, it is possible to observe a similar character of the chill influence in both plates castings. Differences in solidification rates, being the results of various thickness of the casting wall do not disturb the determination of the chill influence zone – Fig. 5. In order to make the identification of castings easier, the following symbols were introduced:

– BO10 for the casting of the plate 240x16x10mm cast without the chill application,
– OCH10 for the casting of the plate 240x16x10mm cast with the chill application,
– BO15 for the casting of the plate 240x16x15mm cast without the chill application,
– OCH15 for the casting of the plate 240x16x15mm cast with the chill application,

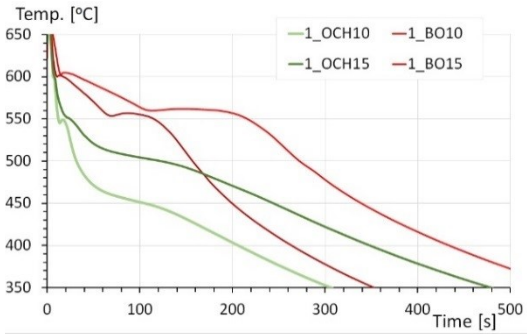

Fig. 4. Examples of the solidification curves AT of the AlSi7Mg alloy in point 1, of the plate castings with different wall thicknesses

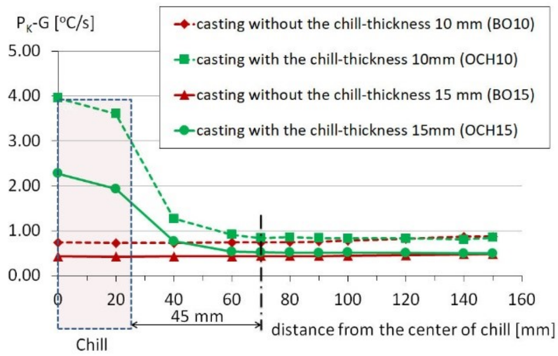

Fig. 5. Graphical presentation of the solidification rates P_k-G of the plate casting without the chill (BO) and with the chill (OCH)

The zone of the chill placement is marked by the black dashed line. Differences in solidification rates of both castings are significant. The maximum solidification rate for the whole process, stage P_k-G, was found under the chill: 3.96 °C/s (casting without the chill-thickness 10 mm). The solidification rate of the plate without the chill, in the same place was equal 0.74 °C/s. The larger thickness of the casting wall (15mm) caused decreasing of the solidification rate to 2.28 °C/s and 0.43 °C/s, respectively.
The successive investigations of: hardness BHN, tensile strength UTS and density „ρ" allowed for their listing together with the solidification rate (P_k - G), structural parameter *SDAS* (spacing between arms of the secondary dendrites of α phase) and the casting porosity P. The obtained results are listed in Table 2.
The graphical presentation of averaged hardness values shown in Figure 6, allows to read the accurate influence zone of the increased cooling rate - caused by the influence of the chill - of plate castings of different wall thicknesses. The highest hardness BHN of the tested alloy is obtained directly under the chill and approximately 20 - 30 mm from the chill wall. The plate casting of the wall thickness being 15 mm obtains lower hardness values than the plate casting of the wall thickness of 10 mm, but the character of the chill influence is similar.

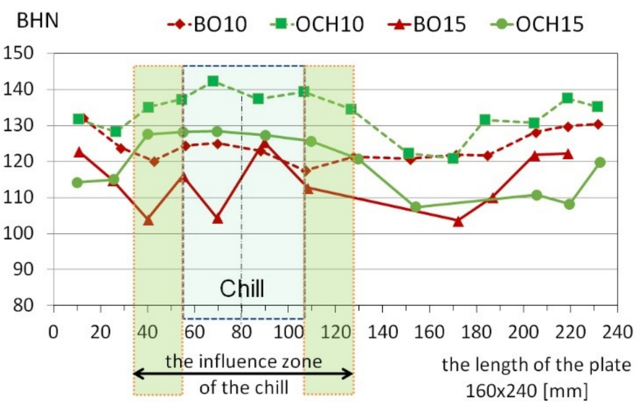

Fig. 6. List of the hardness values BHN in selected places (70, 80, 90) of the plate castings of different wall thicknesses, cast of the tested AlSi7Mg alloy (BHN through the center of the plate in place of the thermocouples)

Table 2.
Compilation of the obtained results, arranged with respect to the solidification rate (P_k - G)

C.S	S.N.	Pk-G	*SDAS*	UTS	%E	BHN	Density	Porosity
	-	[°C/s]	[µm]	[MPa]	[%]	-	[g/cm3]	[%]
BO15	VII	0.426	49.0	222	0.05	113	2.586	6.468
BO15	V	0.429	48.2	169	0	104	2.589	6.361
BO15	VI	0.429	56.5	197	0.01	125	2.588	6.391
BO15	VIII	0.431	48.8	-	-	94	2.544	7.965
BO15	IX	0.438	51.7	-	-	98	2.558	7.486
BO15	X	0.442	55.1	198	0	97	2.602	5.881
BO15	XI	0.451	46.9	228	0.04	104	2.605	5.754
BO15	XII	0.466	48.7	246	0.01	110	2.616	5.383
BO15	XIII	0.479	48.9	243	0.05	122	2.641	4.472
BO15	XIV	0.484	44.1	278	0.1	122	2.653	4.019
OCH15	XIII	0.497	49.4	262	0.14	108	2.607	5.682
OCH15	XIV	0.498	47.2	279	0.03	120	2.636	4.648
OCH15	XII	0.501	48.8	229	0.03	111	2.594	6.168
OCH15	XI	0.512	51.2	-	-	69	2.515	9.016
OCH15	X	0.515	40.6	-	-	80	2.495	9.761
OCH15	IX	0.518	48.5	205	0	107	2.589	6.363
OCH15	VIII	0.652	41.5	283	0.04	121	2.633	4.766
BO10	VII	0.730	44.0	262	0.07	118	2.620	5.242
BO10	VIII	0.735	46.5	231	0.02	121	2.629	4.892
BO10	VI	0.735	47.9	260	0.04	123	2.632	4.782
BO10	V	0.735	48.5	286	0.08	125	2.650	4.134
BO10	IX	0.745	43.9	251	0.06	121	2.629	4.904
BO10	X	0.770	46.4	270	0.09	122	2.639	4.539
BO10	XI	0.800	40.8	188	0.01	122	2.643	4.410
OCH10	XII	0.820	40.1	352	0.15	131	2.671	3.371
OCH10	XI	0.830	43.8	310	0.08	132	2.660	3.794
OCH10	XIII	0.830	42.6	335	0.15	138	2.674	3.264
OCH10	X	0.835	38.9	269	0.04	121	2.640	4.512
BO10	XII	0.845	44.6	300	0.1	128	2.671	3.365
OCH10	XIV	0.850	36.6	377	0.32	135	2.684	2.906
OCH10	IX	0.850	42.3	363	0.24	122	2.670	3.405
BO10	XIV	0.870	40.4	353	0.34	130	2.675	3.234
BO10	XIII	0.870	50.0	324	0.17	130	2.680	3.053
OCH10	VIII	1.095	34.1	386	0.79	135	2.689	2.725
OCH15	VII	1.351	39.1	328	0.19	126	2.658	3.852
OCH15	VI	2.107	26.0	343	0.51	127	2.656	3.938
OCH15	V	2.107	24.8	344	0.71	128	2.659	3.825
OCH10	VII	2.440	21.4	401	0.78	139	2.717	1.717
OCH10	VI	3.785	14.9	401	0.78	137	2.713	1.865
OCH10	V	3.785	19.6	426	1.29	142	2.707	2.068

The image of the chill influence on the density of the tested alloy casting, of dimensions 240x160x15mm, is shown in Figure 7. When the casting is performed without the chill, the mould wall of the tested casting significantly influences the obtained density values in individual places of the casting. The cooling rate is significant at the casting edges, the so-called edge effect.

In case when the chill influences the density of the solidyfying plate casting, the highest influence occurs directly under the chill. For both cast plates the maximum density is obtained there, while in the determined influencing zone (Fig. 8) being approximately 20÷30 mm from the chill wall the average density obtains 2.694 g/cm^3 for the plate of the wall thickness being 10 mm oraz 2.633 g/cm^3 for the plate of the wall thickness of 15 mm.

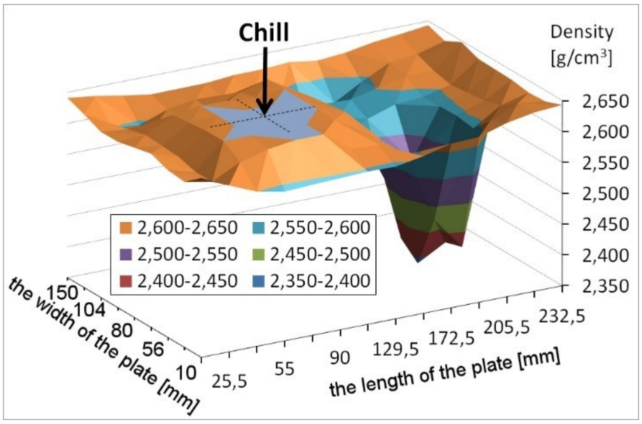

Fig. 7. The image of the chill influence on the density of the tested casting alloy 240x160x15mm

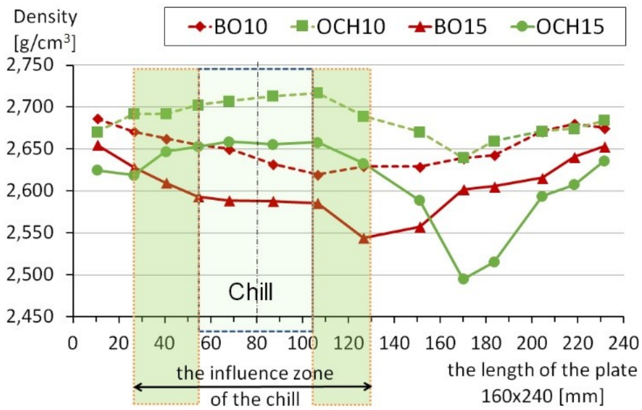

Fig. 8. The density ρ change of the AlSi7Mg alloy in the middle part of the casting

The accurate determination of the spacing between secondary dendrite arms of α phase – structural *SDAS* parameter, allows to notice explicitly the influence zone of the increased solidification rate, caused by the chill application. The images of microstructures of the tested alloy for the maximal and minimal solidification rates (P_k - G) are presented in Figures 9 - 11, together with the selected parameters, such as: alloy density ρ and the *SDAS* parameter. The plates cast without the chill are characterised by the lattice parameter *SDAS* values from 38.8 µm to 56.5 µm. The intensive influence of the chill surface on the fragment of the solidifying plate casting caused decreasing of distances between secondary dendrite arms of α phase to 15 µm (when the wall thickness was equal 10 mm) and to 25 µm (when the wall thickness was equal 15 mm). The chill influence zone becomes visible in places where the *SDAS* parameter obtains values not higher than approximately 35 µm at the casting wall thickness of 10 mm and approximately 40 µm, when the casting wall thickness equals 15 mm.

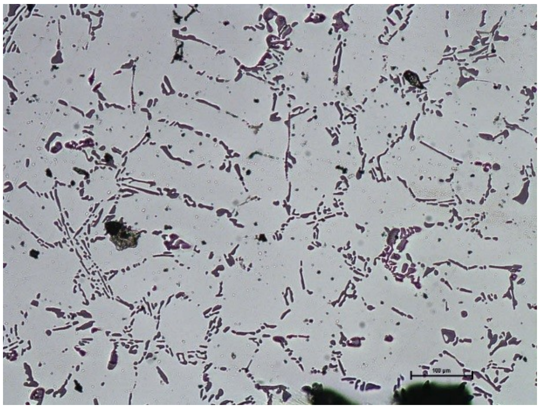

Fig. 9 Microstructure of the tested alloy – sample BO15 VII. Minimal solidification rate: P_k-G = 0,426[°C/s]; ρ = 2,586 [g/cm^3]; *SDAS*= 49,0 [µm], 100x

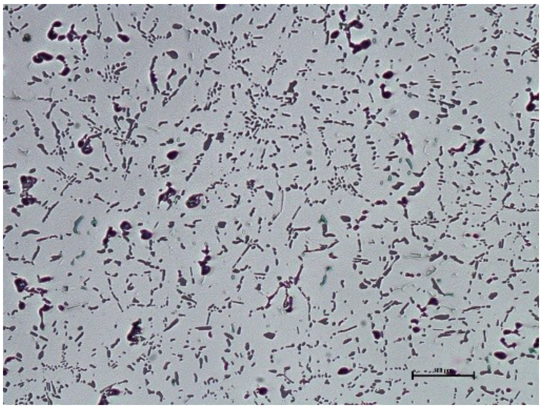

Fig. 10. Microstructure of the tested alloy – sample OCH15 V. Solidification rate P_k-G = 2,107[°C/s]; ρ = 2,659 [g/cm^3]; *SDAS*= 24,8 [µm], 100x

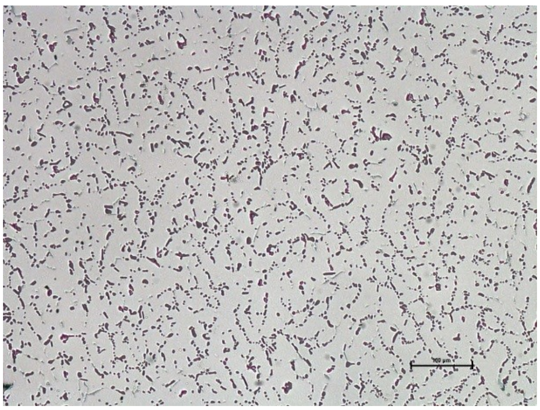

Fig. 11. Microstructure of the tested alloy – sample OCH10 V. Maximal solidification rate P_k-G = 3,785[°C/s]; ρ = 2,707 [g/cm^3]; *SDAS*= 19,6 [µm], 100x

4. Conclusions

The research cycle aimed at the determination of the chill influence zone was performed in the hereby work. The presented investigations of castings of two plates, cast of the AlSi7Mg alloy of a modified composition and dimensions 160x240 mm and two different thicknesses of the wall (10 and 15 mm), the first one solidyfying under normal conditions and the second one solidyfying with the influence of the copper chill (50x50mm), allow to notice several effects influencing obtaining healthy castings (without casting defects).

The solidification process analysis, determination of the cooling rate, as well as the determination of the tested casting properties such as: tensile strength UTS, elongation %E, hardness BHN, alloy density ρ, casting porosity P, microstructure refinement (*SDAS* parameter) in individual points of the casting, reveals wide spectrum of the chill influence on the tested casting. Utilizing of several parameters describing the quality of the alloy solidifying under conditions of the chill influence allows to define conclusions concerning the quantitative determination of the zone and range of the chill influence on the casting [11-13].

Taking into consideration the results obtained for castings of various wall thicknesses it is possible to present several influencies of the cristallisation rate P_k-G or the distances between secondary dendrite arms of α phase on such properties as e.g. tensile strength UTS, hardness BHN, elongation %E , the alloy density ρ and casting porosity P. The selected lists are shown in Figures 13 and 14.

Large differences in the obtained alloy properties, especially in case of low solidification rates (below 0.8 °C/s), are noticeable. This is the result of structural discontinuities related mainly to micro and macro porosities as well as to eventual lack of the proper supply of the casting with metal, during solidification.

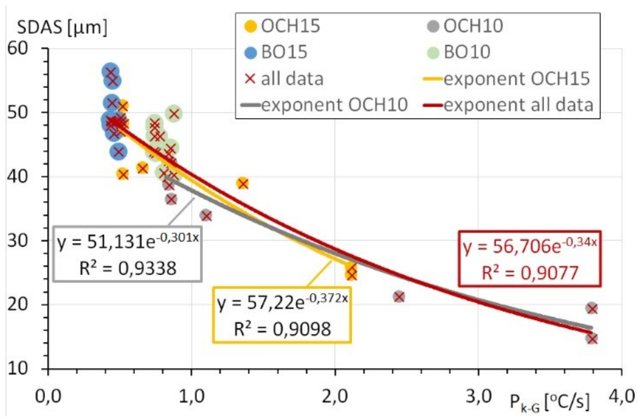

Fig. 13. Dependence between the casting solidification rate P_k-G and the spacing between secondary dendrite arms of α phase (*SDAS* parameter) of the tested alloy

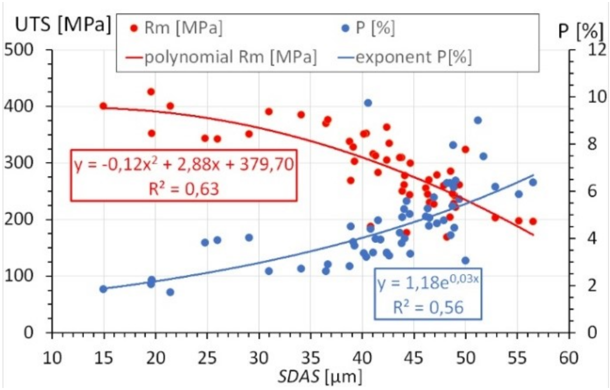

Fig. 14. Dependence of the tensile strength UTS [MPa] and casting porosity P [%] and the spacing between secondary dendrite arms of α phase (*SDAS* parameter) of the tested alloy

It is worth to notice, that the sand mould allows to obtain the solidification rate below 0.5°C/s, for the casting BO 15 mm without the chill and below 1°C/s for the casting BO 10mm. The obtained values of the *SDAS* parameter are relatively high (approximately and above 40 µm). The solidification rate above 1°C/s, recorded in the chill influence zone, allows to achieve the high refinement of the microstructure, and the *SDAS* parameters obtain values below 30 µm (Fig. 13).

High values of tensile strength Rm are guaranteed by the low value of the *SDAS* parameter and high density of the alloy, related to the porosity lack in the casting (Fig. 14). The presented combinations of investigations allow to infer that by increasing the solidification rate of the AlSi7Mg alloy to approximately 1.0 °C/s, we will be able to obtain the casting characterised by very good mechanical and functional properties.

The performed investigations as well as the analysis of the results allowed to determine the influence zone of the chill. For the casting of the plate of dimensions 160x240 and the wall thickness up to 15 mm, made of AlSi7Mg alloy, this zone reached from 35 mm from the chill wall. However it should be noticed, that efficient influencing of the chill, i.e. the place up to which the chill is still intensively influencing the solidifying plate casting was equal 30 mm (measured from the chill wall). It is easy to notice that there is a certain dependence between the thickness of the casting wall and the influence zone of the chill, being not less than 2g, where g is the casting wall thickness.

It should be also mentioned, that the application of the chill influences the whole casting. The intensive local influence in the chill zone causes a possibility of the occurrence of casting defects in other places of the casting, which should be also remembered.

The next aim of successive investigations will be finding the confirmation that there is the dependence between the casting wall thickness and the influence zone of the chill for other thicknesses of walls. We would like to prove that this principle is of a universal character.

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