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THE EFFECT OF DIFFERENT CASTING PARAMETERS ON THE RELATIONSHIP BETWEEN FLOWABILITY, MOULD FILLING CAPACITY AND COOLING CONDITIONS OF Al-Si ALLOYS

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ABSTRACT

Fluidity and mould filing capacity play a key role in the production of thin-section and geometrically complex cast parts. Fluidity in the casting industry is related to the maximal distance which a molten metal can reach flowing in a mould of constant cross section area before it solidify. Mould filling capacity is an ability of melt to fill the mould cavity and after solidification produce sharp edges of intricate cast product. In this paper those process parameters have been systematically investigated and the effect of different casting parameters on the relationship between flowability, mould filling capacity and cooling conditions of Al-Si alloys has been determined. In order to achieved better reproducibility of measurements new equipments for both tests have been developed.

Key words: AlSi alloy, fluidity, mould filling capacity

1. INTRODUCTION

The trend of the automotive industry goes toward the construction of high-powered, comfortable, economical, ecological and safe vehicles. However, production delivers the heavier and heavier vehicles. In 1974 the first VW Golf weighed 800 kg with an achievement of approx. 35 kW. Nowadays the Golf IV of double or triple achievement weights around 1200 Kg. The weight of modern luxury cars is almost two tons. Future automobiles should be lighter, more economical and ecological. This is possible to achieve through engine and car design development and supplementary under the use of lighter materials. Materials such as aluminium and magnesium alloys or aluminium-composites successfully substitute heavier conventional materials and constructions. They allow a lower automobile weight.

Aluminium alloys make in average approx. 60 kg of an automobile [1]. They are successfully used in such engine components as cylinder heads, crank cases, pistons, gear cases and oil pans. Nowadays engines must provide at least 300 000 km [2]. Therefore, materials have to endure different friction, thermal and mechanical tensions.

The severe requirements on cast parts can be met only under the choice of an appropriate alloy and the definition of production procedures. The first criterion for the alloy choice is the characteristic of mechanical properties. Requirements on mechanical qualities are worldwide standardised and every company proceeds under the particular norms. The production of test parts is regulated through the DIN Norm 10 002. This norm guarantees a uniform application of the test procedure and correct interpretation of the obtained results. In addition, the Quality Index (Q), developed in the 1980th also could be used to quantitatively describe the mechanical properties of cast parts using a *Q*-number [3, 4, and 5].

Nowadays foundry plants are forced to reduce the wall thickness of cast pieces, to keep the narrow tolerance extent (combustion chamber, canal position) and to minimise the surface roughness (suction canal). The higher requirements on cast pieces make the construction more extensive and more complicated.

Comparing to mechanical properties, determination of cast properties is not yet standardized. Each foundry uses its own test facilities according to its own experience and possibilities. Used test facilities have different informative ability and reproducibility [6]. Even the use of castability parameters such as flowability and mould filling capacity was differently understood by many authors. Both casting parameters are first time in 1953 differentiated and clearly described [19]. Flowability and mould filing capacity play a key role in the production of thin-section and geometrically complex casts. In this paper those process parameters have been systematically investigated and the effect of different casting parameters on the relationship between flowability, mould filling capacity and cooling conditions of Al-Si alloys has been determinated.

2. TEST METHODS FOR THE EVALUATION OF FLOWABILITY AND MOULD FILLING CAPACITY

Traditionally, the flowability is measured using spiral test that has been shown on Figure 1. The apparatus has two parts: (i) spiral contour that is milled in the lower half mould and (ii) upper part of the mould that is divided into two parts. The whole equipment has two thermocouples. The first thermocouple was built in the middle of the mould, while the second thermocouple was also built in the middle of the upper part. The total length of the spiral is 1150 mm. Flowability is determined through the flow length of an alloy in the milled spiral contour.

Figure 1. Spiral test

Mould filling capacity is measured using the ball test developed by Spaskij [7]. Figure 2, shows the mould which consists of three parts: (i) the left half mould, (ii) the right half mould with the half ball and (iii) the trig. Thermocouples were inserted in every mould part. A ceramic plate has been inserted between the test mould and the pouring cap. Mould filling capacity is quantified by measuring the non-poured surface area between the ball and the trig, expressed in mm^2. The smaller the intersection surface of the test piece denotes the better mould filling capacity of the alloy.

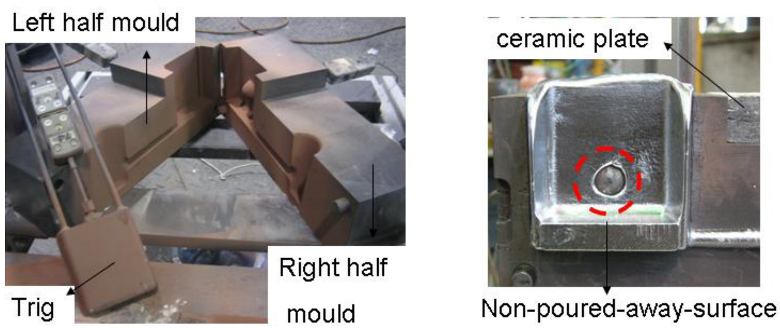

Figure 2. Mould filling capacity test

The investigations of the castability are limited due to the low reproducibility of test methods. Several statistical analysis revealed that the reproducibility of this conventional methods (spiral test or spiral test with stopper) is very low and lies in the range of approx. 5% to 30%. It was found that the reproducibility of these methods depends on worker's skills and process parameters that have been not until now entirely controlled. Such inaccurate measurement apparatus could not be used to identify the effect of some process parameters on the flowability. In order to overcome this problem an optimised system, shown in Figure 4 was developed and used in these experiments. This equipment is independent on operator and can keep constant process parameters such as melt temperature, mould temperature, amount of melt, casting speed and some others important factors (for details please see Figure 5).

The reproducibility of the new system has been tested using AlSi12MnNi piston alloy. Figures, 3a and 3b, show the flow lengths and non-poured-away-surfaces for nine measurements conducted by constant process parameters (during those experiments the form temperature was held at 150 +/- 5°C and the melt temperature, measured in the pouring cup was kept constant at 750 +/- 2°C).

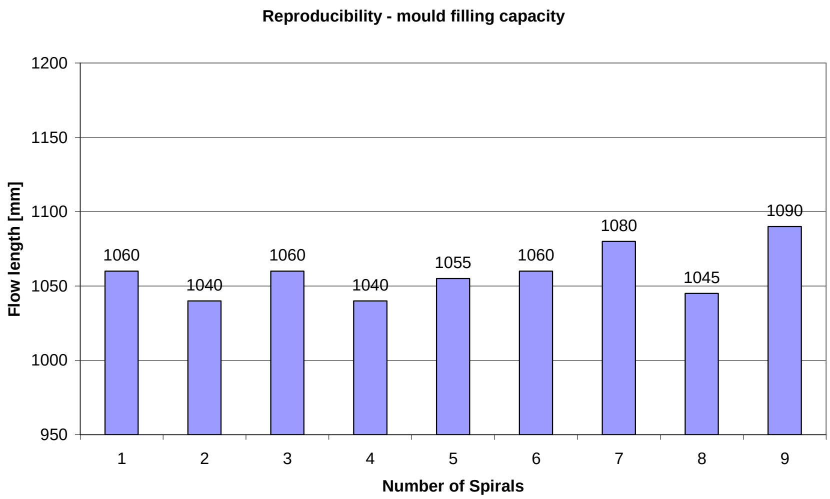

Figure 3a. Length of fluidity measurements by constant process parameters

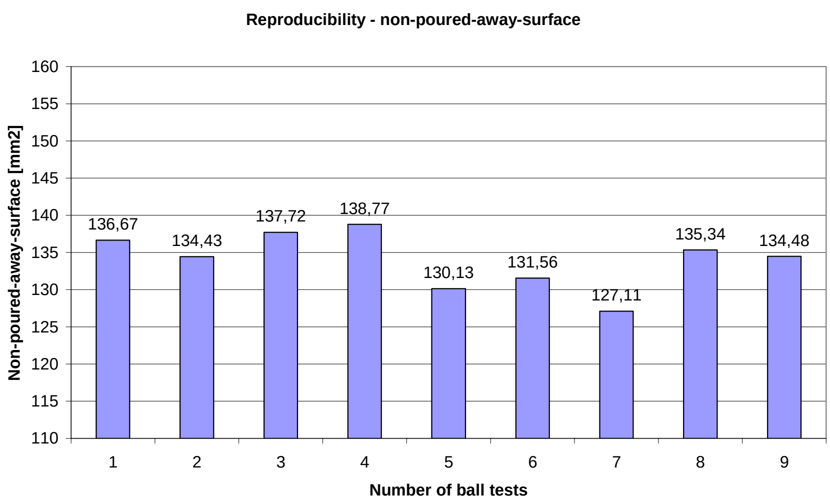

Figure 3b. Non-poured-away-surface of mould filing capacity measurements by constant process parameters

From the nine experiments the average flow length was 1058.8mm (standard deviation for all measurements was σ = 18,27mm), and the average non-poured-away-surface was 134,02 mm^2 (standard deviation for all measurements was σ = 3,78 mm^2).

Figure 4 shows the assembly of the experimental equipments. The equipment configuration provides the use of different test moulds under the constant parameters.

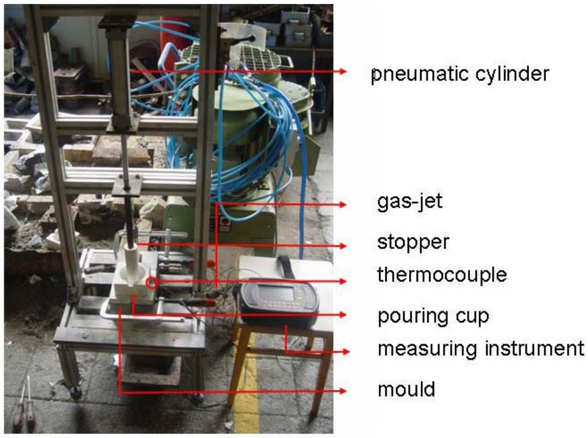

Figure 4. Experimental equipment

3. DEFINITION OF PROCESS PARAMETERS

Figure 5 shows Ishikawa diagram with process parameters that have significant effect on the castability of aluminium alloys. Among all of them in theses experiments the effect of the following parameters have been analysed:

- The effect of the mould and pouring temperatures,
- The effect of modifier (AlSr10 master alloy has been used in all experiments)
- The effect of various content of copper.

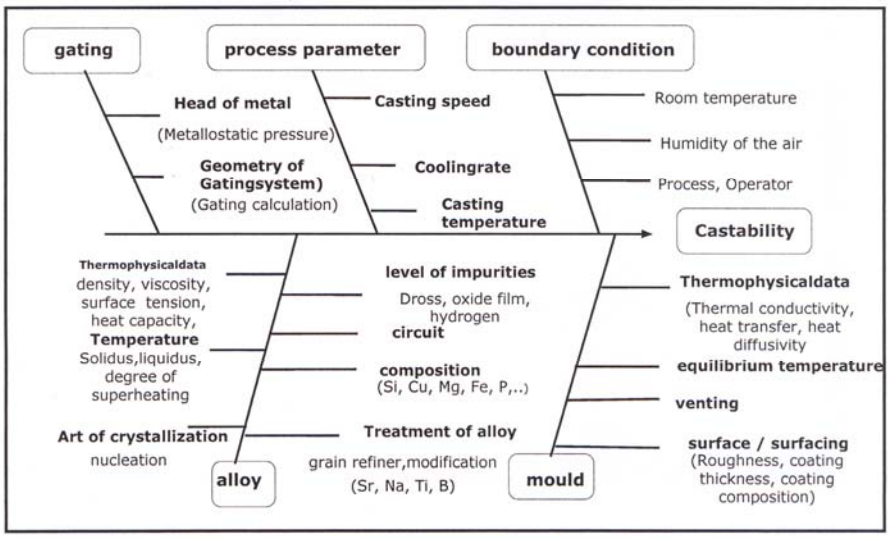

Figure 5. Process relevant parameters

4. RESULTS

4.1. Influence of mould and pouring temperature

It is well known, that the mould temperature at the beginning of casting process or after any longer break is not homogenous. Based on the own casting experience at least after seven castings the necessary homogenous mould temperature can be achieved. Therefore, the first cast parts usually get defects such as cold shuts or incompleteness.

The AlSi7Mg0.3 alloy without addition of grain refiner and/or modifier was used in the experimental work. The amount of impurities in the melt was kept as low as possible. The melt surface has been protected using the argon atmosphere. The coating of the form was made by hand with the air-driven spray gun using the Simonides coat. The characteristic temperatures of this alloy has been recorded using thermal analysis technique.

In the first set of experiments the melt temperature as a variable has been gradually changed starting from 610°C up to 730°C. During theses experiments, the mould temperature has been kept constant at 120°C.

The second set of experiments have been run with the constant melt temperature at 670°C, while the mould temperatures have been varied between 100 and 300°C. Figures 6 and 7 show the effect of those two process parameters on the flow length. Based on this results , it is obvious that the melt temperature has a more significant impact on the flow length than the mould temperature. The increase in the melt temperature from 610°C to 730°C increase the flow length from approximately 300 mm to 730 mm respectively. The linear relationship between melt temperature and flow length is in agreement with previously published results for this alloy [9]. The mould temperature has not so significant effect on the flow length as Figure 7 illustrated. An increase in the mould temperature for 200°C increase the flow length for roughly 100 mm.

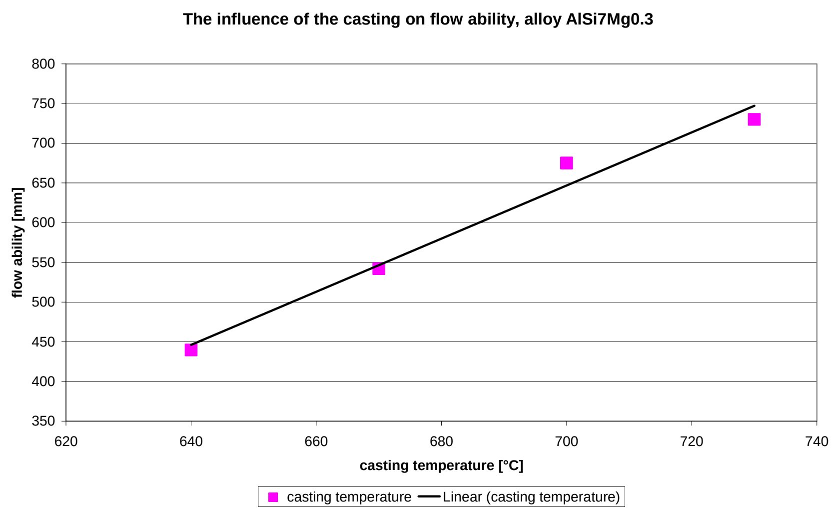

Figure 6. The influence of the casting temperature on flow ability

The effect of melt temperatures on the mould filling capacity has been estimated through the measured values of the non-poured-away surface. The Figures 8, 9 and Figure 10 show that the impact of the melt temperatures on the mould filling capacity is not so significant. The increase in the melt temperature from 630°C to approximately 700°C, caused the minimal change in the non-poured-away surface, from 125 mm^2 to 123 mm^2. In additions, the Figures 9 and 11 show that the effect of the mould temperature on the same process variable is negligible.

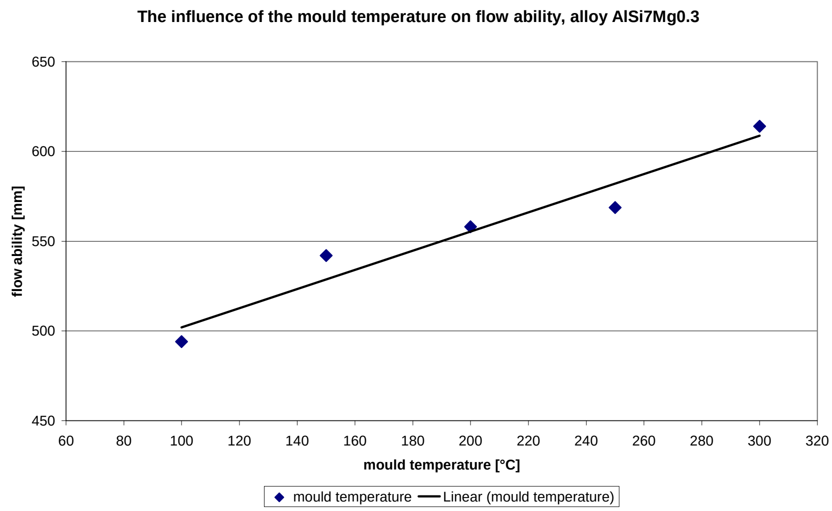

Figure 7. The influence of the mould temperature on flow ability

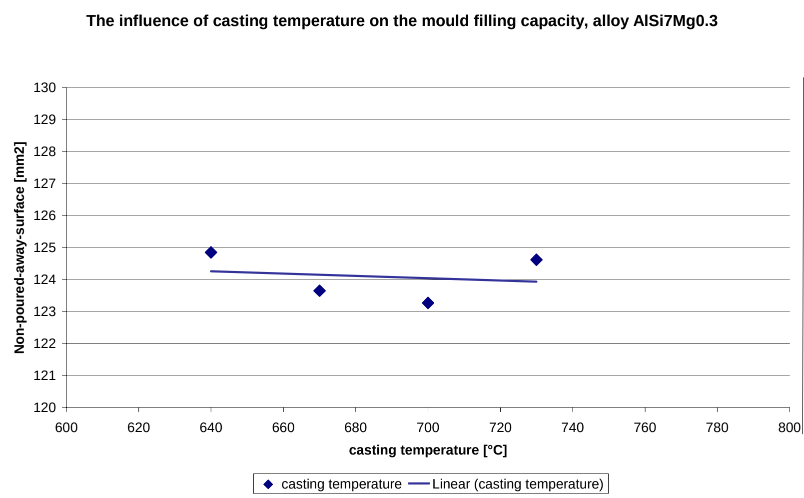

Figure 8. The influence of casting temperature on the mould filling capacity

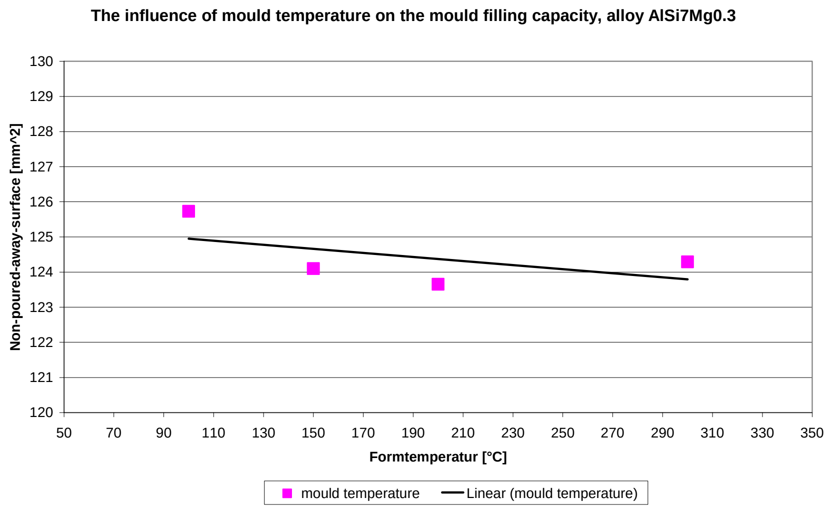

Figure 9. Influence of mould temperature on the mould filling capacity

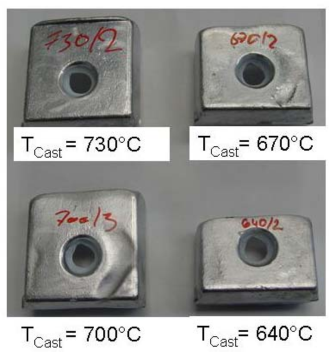

Figure 10. Cast samples - the influence of the cast temperature

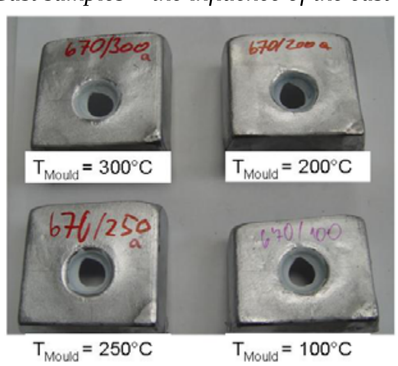

Figure 11. Cast samples - the influence of the mould temperature

The investigations showed that both process parameters do not influence the contour precision of the cast products. For the practise it means that superheating and higher mould temperature can not influence significantly the contours such as casting clocks, engravings etc.

4.2. Influence of modification - Sr

In order to improve the mechanical properties many Al-Si alloys are modified using different modifiers. Thanks to the low effect of fading in comparison to other refining elements, strontium is commonly used by this type of hypo-aluminium alloys as a modifying element. By adding of strontium the eutectic structures change getting finer, which influence the mechanical properties of Al-Si alloys.

Literature survey [12, 13] has shown, that the addition of Sr decrease the flowability of aluminium alloys. Seshadri has revealed in his work [14] that the modification in sand form reduce flowability of AlSi alloy from 5 to 7%, while in the steel mould that reduce is a little bit smaller varied between 2% or 3%. Mollard [15] has found that the flow property of aluminium alloys can be reduced up to 8% due to Sr addition. Kotte and Serak [16, 17] have shown that the lowering of the flowability through Sr addition is not so high as that cause by modification with sodium. According to them, the reason for the strong decreasing of the flowability of AlSi alloys through the sodium addition might be due to its effect on the surface tension of AlSi alloys [18]. Di Sabatino [9] in her theses find out that Sr has a positive effect on fluidity by superheat up to 70°C and a negative effect on the fluidity by superheat around 130°C.

In this work it has been also investigated the effect of strontium addition on the flowability of AlSi7Mg0.3 alloy. The amount of strontium was varied from 5 ppm up to 200 ppm. Process parameters such as mould temperature 150°C, casting temperature 700°C and pouring temperature 760°C were held constant during theses experiments.

The impact of the Sr addition on the solidification characteristics of this alloy has been studied using thermal analysis technique. At the same time the spiral test and ball test have been conducted. After each test the sample for chemical analysis has been collected and its composition has been determined by optical emission spectroscope analysis.

The strontium has short incubation time and work immediately after addition into the melt, by depressing the Al-Si eutectic nucleation temperature. Figure 12 shows two cooling curves of AlSi7Mg0.3 alloy with different content of Sr. The depression of the AlSi eutectic temperature is quite significant after addition of 248 ppm Sr into the melt. The AlSi7Mg0.3 alloy with residual amount of Sr had AlSi eutectic temperature of 571°C. The addition of Sr (approximately 240 ppm) decreased this temperature for 6°C. Beside that, it has not been recognized any significant impact on the other characteristic solidification temperatures caused by increased content of Sr, (for more details please see Figure 13). Although the strontium fading should be relatively slow the lost of strontium in this experiments was very fast. Less than three hours after addition of master alloy (AlSr10) the amount of Sr reached its residual level of 5ppm. This fast Sr fading can be only explained through the fact that the melt temperature in this experiments was very high (760°C). In additions, the furnace orifice was not covered during experiments that additionally aid removal of strontium from the melt.

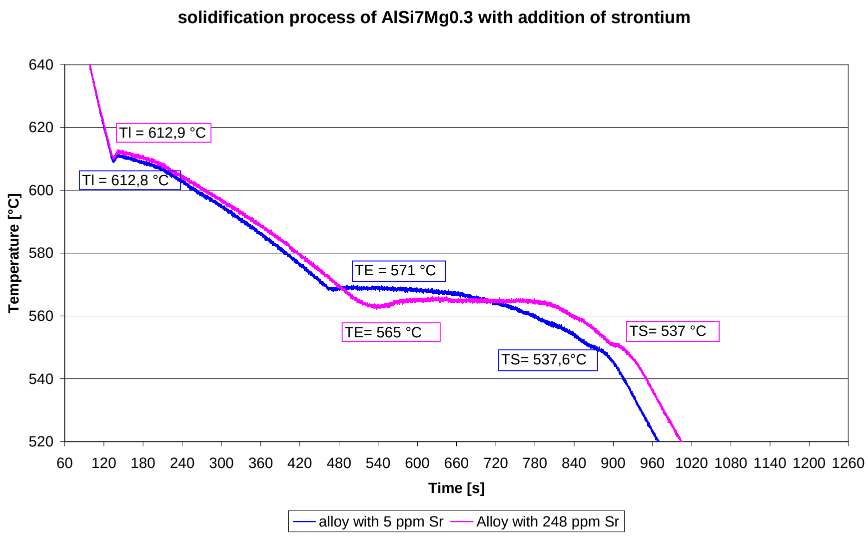

Figure 12. Solidification process

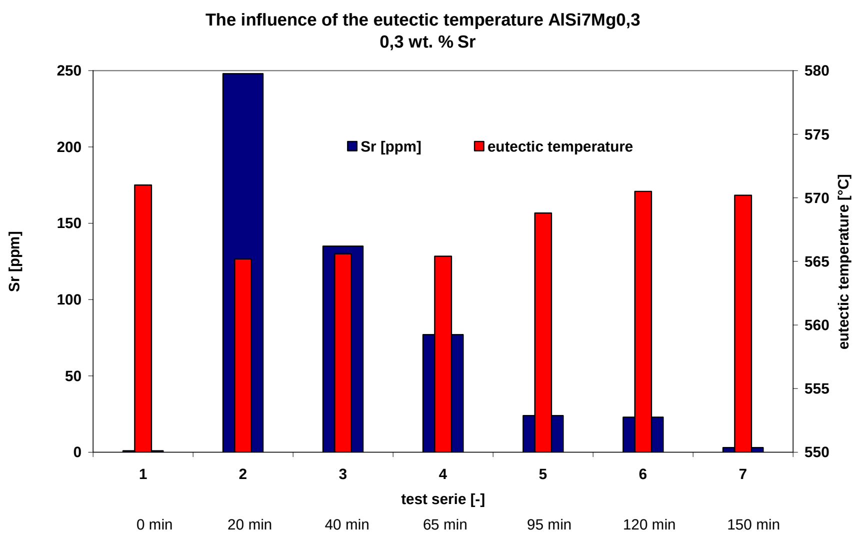

Figure 13. The influence of the eutectic temperature

The Figure 14 shows the relationship between content of Sr dissolved into the aluminium melt and flowability. The obtained results support assumption that the strontium has significant impact on the castability of aluminium alloys. The higher content of Sr reduced the flow distance for approx. 40% in respect to the whole length of spiral cavity. The Sr has also positive influence on the mould filling capacity, as Figure 15 shows. The higher amount of dissolved Sr reduced the measured surface of non-poured area, improving the contour accuracy of alloy. In the series of experiments without Sr additions a quite big area with non-poured-away surface has been recognized (approx. 138 mm^2). It means that the contour accuracy of the alloy is quite weak. The Figure 16 qualitatively illustrate the effect of Sr content on the mould filling capacity.

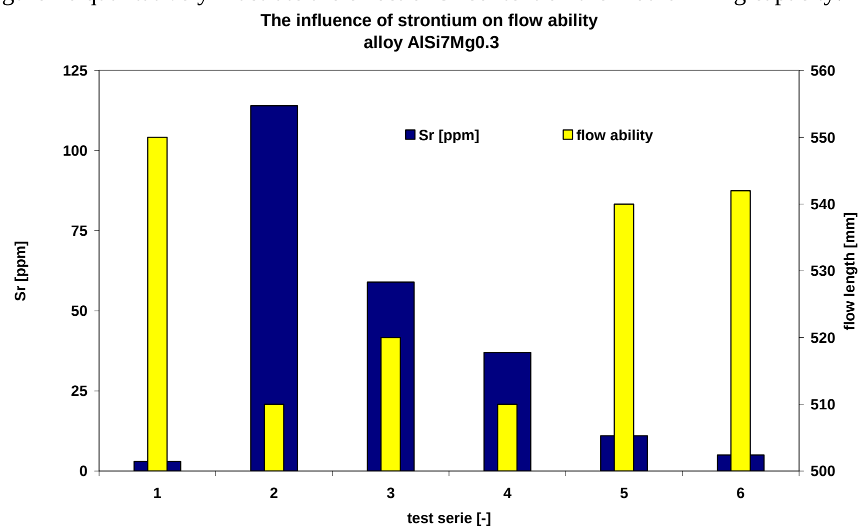

Figure 14. The influence of strontium on flow ability

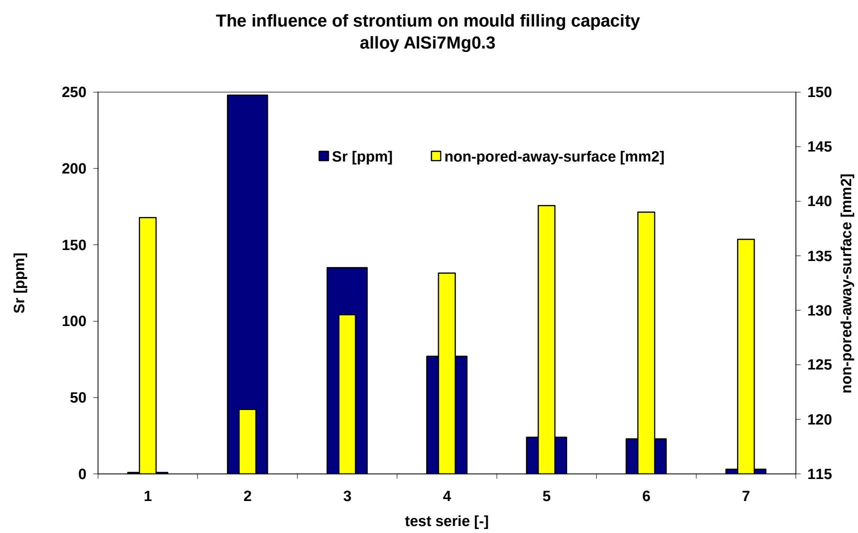

Figure 15. The influence of strontium on mould filling capacity

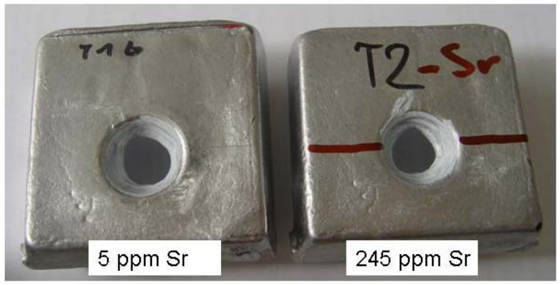

Figure 16. Cast samples, the influence of strontium on the mould filling capacity

4.3. Influence of copper on fluidity

The solidification path of any aluminium alloy is dependent on the cooling rate, melt temperature and chemical composition. The changes of solidifications kinetics could influence flowability, viscosity and surface tension of aluminium alloys. In this part of work the effect of various content of copper on the solidification path of AlSi alloys will be studied as well as their impact on the casting properties, specially fluidity will be analysed.

Copper is major alloying element by AlSi alloys, usually present by this family of aluminium alloy in the amount up to 5 wt. %. Copper is added to increase the strength of these alloys by precipitating the copper reach phases during solidification [20]. Also, additions of Copper in the AlSi melt increase the solidification interval of those alloys, making then more prone to the porosity formation.

The main target of this investigation was to analyse the effect of Cu on cast properties of AlSi alloys. The copper purity of 99.9% has been added into the melt. Every 60 minutes after the copper addition spiral test and mould filling capacity test were carried out. Parallel the sample for chemical analysis has been collected while the solidification process has been observed using thermo analyses technique. The copper level was varied from 0 up to 5 wt %. The casting temperature was kept constant at 700°C as well as the mould temperature at 150°C. As Figure 17 shows the increase in the amount of copper has positive effect on the flowability of aluminium alloys, while its impact on the mould filling capacity is almost insignificant. It looks that increased copper content postpone the creation of dendrite coherency network towards lower temperatures allowing longer flow length of the melt. This assumption has to be prove in the next experiments.

The positive change of the flowability is shown in the Figure 17. The alloy without Cu additions achieved the flow length of about 54 % (670 mm) of the total spiral cavity. By the 5 wt.% addition of Cu the flow length increased up to approx. 58 % (720 mm) of the total spiral cavity. On another hand, the mould filling capacity of the alloy with 5 wt. % of copper didn’t show any significant changes.

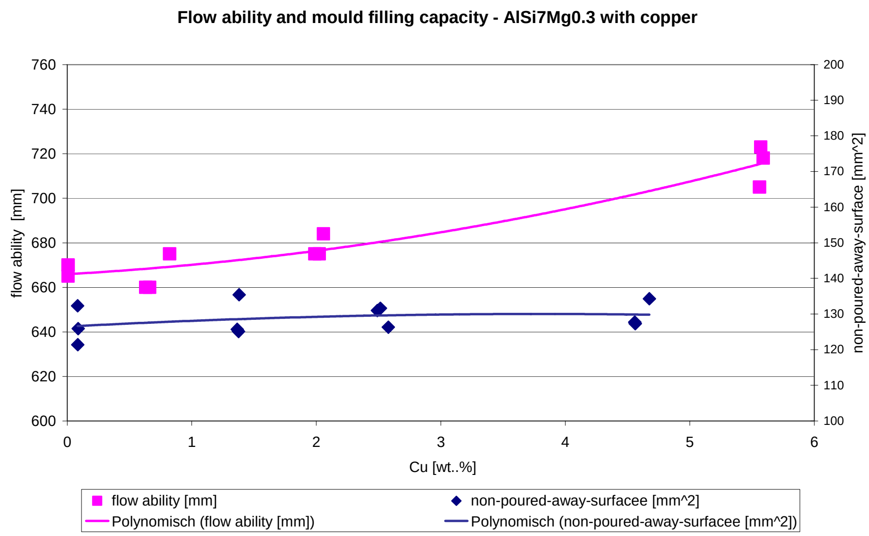

Figure 17. The influence of copper on flow ability and mould filling capacity

5. CONCLUSION

Flow ability and mould filling capacity play a significant role in the production of thin-section and geometrically complex casts parts. In this work the most important process parameters were systematically investigated and the effect of different casting parameters on the relationship between flow ability, mould filling capacity and cooling conditions of Al-Si alloys were determined.

The superheating of the alloy influenced significantly its flowability. This increases of the flow length is linear. It was also found that form temperature has a limited influence on the flow length. The influence of casting and mould temperature on the mould filling capacity was valued by means of non-poured-away surface. The non-poured-away surface changed minimally and appeared only in the reproducibility area. The same result has been obtained by analysing the mould temperature. The investigations showed that both process parameters do not influence significantly the contour precision of the cast products.

The spiral test experiments have shown that the amount of strontium in the aluminium melt has an effect on the flow length. Increase in the amount of strontium decrease significantly the flow length of the aluminium melt. Fading of the strontium has positive effect on the flow ability. The effect of the higher amount of strontium is quite opposite regarding to the mould filling. The addition of strontium into the melt improved significantly the contour accuracy of the aluminium alloys.

The effect of various content of copper on the flow length and the mould filling capacity has been also analysed. The addition of copper has positive impact on the flow length of investigated aluminium alloys. The alloy without Cu additions achieved the flow length of about 54 % (670 mm) of the total spiral length. By addition of 5 wt.% of Cu the flow length increased up to approx. 58 % (720 mm) of the total spiral length. On the other hand, the mould filling capacity of the alloy with 5 wt. % of copper didn't show any significant changes.

LITERATURE

[1] Aluminium 82, Jahrgang 2006, ½, Seite 25

[2] R. Viets, A. Pflug, L. Kis, L. Toth.: Berechenbarer Guss im Motorenbau AHM, VDI-Berichte Nr. 1949, Gießtechnik im Motorenbau 2007, Seite 59 – 70

[3] Cáceres C. H.; A phenomenological approach to the Quality index of Al-Si-Mg casting alloy, Int. J. Cast Metals Res. 2000, 12, 367-375

[4] Jacob S.; The quality index in the prediction of properties of aluminium castings: a review, Hommes&Fonderie, December 2001, Nr. 319

[5] Cáceres, C.H., Wang. L., Makhlouf. M., Apelian, D.; Auswahl von Druckgusslegierungen mit Hilfe des Qualitätsindex, Druckguss-praxis 1/2002

[6] Bouska O., Flowability and Mould filling capacity, 43 Foundry days Brno

[7] Spaskij A G.; Übersetzung aus der Russ. Sprache Makosch, W.: Grundlagen des Gießereibetriebes, Leipzig Fachbuchverlag 1955

[8] Kim, J.C., Loper, C.R.; Einfluss des Erstarrungsverhaltens auf das Fließverhalten von AlSi-Gußlegierungen, Gießerei-Praxis Nr.4/1998, S. 151-159

[9] Sabatino M. Di, Shanka S.r, Apelian D., Arnberg L., Influence of temperature and alloying elements on fluidity of Al-Si alloys. Doctoral Thesis Fluidity of aluminium foundry alloys. Trondheim, September 2005

[10] Vankateswaran S, Mallya R.M., Seshadri M.R.; Effect of trace elements on the fluidity of eutectic Al-Si alloy using the vacuum suction technique, AFS Transaction 67, 1986

[11] Taylor, J.A, Couper. M.J., Smith, C.L., Singh, D.P. K, Dissolution, recovery and fade of Sr master alloys in AlSi7Mg0.5 casting alloy, Light Metals 2005,

[12] Ramachandran M.R., Modern Casting 48 (1965)1, S 110/122

[13] Kondic, V. Kozlowski, H.J.; J.Inst. Met. 75 (1948,49) S.665

[14] Seshadri,M.R., Ramachandran: Modern Casting 48 (1965)1, S 110/122

[15] Mollard, F:R, Flemmings M.C., and Nyama E.F.; Understanding aluminium fluidity: the key to advanced cast products, AFS Trans (1987), vol. 95, p. 647-652

[16] Kotte, Strontium modification gievs critical melt control, Modern Casting, (1985), pp. 33-35

[17] Serak, V. Modifikace slitiny AlSi10Mg sodikem a stronciem, Sbornik Konference Aluminium 2001 Decin

[18] G. Lang Ranshofen, Gießeigenschaften und Oberflächenspannung von Aluminum und binären Aluminiumlegierungen, Aluminium 48 (1972) S.664 – 672

[19] Bachtik, Chaloupecky, Pripevek k otazce definice zabihavosti kovu a slitin, Slevarenstvi c.10, 1976