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Application of Modular Die for Fluidity Test and Monitoring of the Pressing Force Flow by Semi-solid Squeeze Casting of AlSi7Mg0.3

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Abstract

The fluidity is the term to determine the materials ability to fill the mold cavity properly. Fluidity is complex property with many variables. Up to this date, there is no methodology for defining the fluidity in a semisolid material state. Submitted paper deals with the proposal of a new method designed for aluminium alloy fluidity evaluation in semi-solid state trough the design of the layered construction die. Die will be primary used for fluidity tests of semi-solid squeeze casted aluminium alloy and to observe the pressing force flow by mentioned casting technology. The modularity consists of possibility to change each die segment. In the experiment the die design was evaluated by simulation in ProCAST 11.5 and by production of experimental castings. The die was made by laser cutting technology from construction steel S355JR. Experimental material was aluminium alloy AlSi7Mg0.3. The temperature of the semisolid state was chosen to achieve 35% of solid phase. The result of next study should be a selected parameters observation and their effect on the fluidity of aluminium alloy in semi-solid state. This will be very important step to determine the optimal conditions to achieve a castings with certain wall thickness produced by the method of semi-solid squeeze casting.

Keywords: Innovative Foundry Technologies and Materials, Solidification Process, Semi-solid Squeeze Casting, Aluminium alloy AlSi7Mg0.3 (A356), Fluidity test, Pressing force flow

1. Introduction

Processing of semi-solid metal (SSM) is technology, which combines casting and forging methods. This technology can be considered as near-net-shape producing method. By this method can be achieved a final product with high integrity in one forming step. The methods of SSM processing can be divided into two major principles: thixocasting and rheocasting. The thixocasting method of aluminium and magnesium alloys is commonly used in the automotive industry due to its ease of automatization [1-3].

For some decades the SSM processing of nondendritic structures has been studied and commercially practiced. The progress in this method of metal processing has been summarized in various articles [4-6].

In recent years, the commercial growth of thixocasting decreased because of high cost associated with specially produced raw materials. This technology also does not allow recirculation of the scrap material during the manufacturing process. Rheocasting method tries to remove these disadvantages by using low cost common foundry alloys which can be easily recycled. The research in last years has been directed to the development of new rheo-based processes that are cost-effective and usable for commercialisation [7-9].

Small amount of works have been focusing on understanding the fundamentals of the important initial solidification of the semisolid structure. Experiments of Martinez and Flemings are focused to study structure evolution during initial stages (less than 5 seconds) [10].

There are some works that investigate and consider the behaviour of aluminium alloys in semisolid metal processing. Simlandi et al. present the behaviour of A356 alloy during extrusion process in the semisolid state. Sheykh-Jaberi et al. quantified the semisolid constitutive behaviour of A356 using a Gleeble thermo-mechanical physical simulation system [11-12].

Nowadays there is no methodology for defining the fluidity of the material in a semisolid state. The study of Kishore et al. comprises of evaluating a parameter known as mold filling ability – a measure for fluidity [13].

The aim of this paper is to purpose a new fluidity evaluation method for aluminium alloy in semisolid state. Technology of semisolid metal processing does not use the gravity force to fill the mold cavity but the metal is forced into the cavity by the increased external forces. Therefore, traditional fluidity tests using gravity to fill the test form cannot be used to test metal in the semi-solid state.

2. Experiment methodology

For the experiment was to design a die for fluidity test. The primary requirement for the die was modularity of cavity shape. The modularity was achieved by the layered construction as shown in figure 1. Die consists of upper and lower plate between which can be placed segments that form the shape of final cavity.

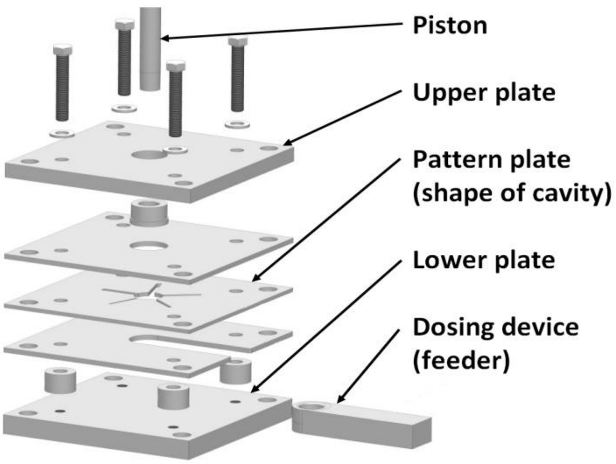

Fig. 1 Parts of the mold

For the experiment were selected two designs of cavity shape. At figure 2 can be seen two types of pattern plate with their shapes of casts.

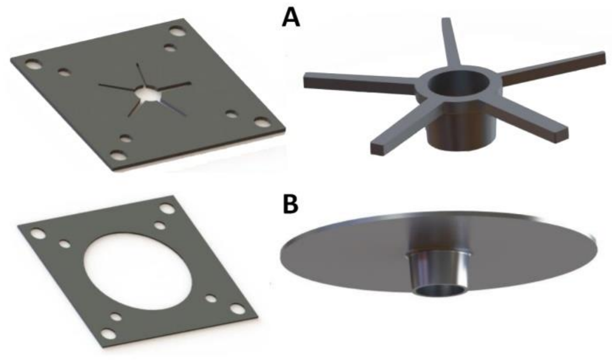

Fig. 2 Types of pattern plates and shapes of casts

Type “A” has a shape of the five-point star with different length and thickness of arms. Height of each cross-section dependents on the thickness of used layer (plate). During experiment, the thickness of the plate was 4 mm. Widths of the cross-sections were from 2 to 6 mm. Type “B” has a simple shape of the disc. By using type “B” it is possibility to change the height of cavity cross-section by using a laser-cut part with different thickness or by combination of more various laser-cut layers.

The purpose of the proposed mold cavity shapes is to assess the fluidity of the semi-solid metal for different cross-sections in order to observe the effect of pressure, solid and liquid phase fractions, filling rate, etc.

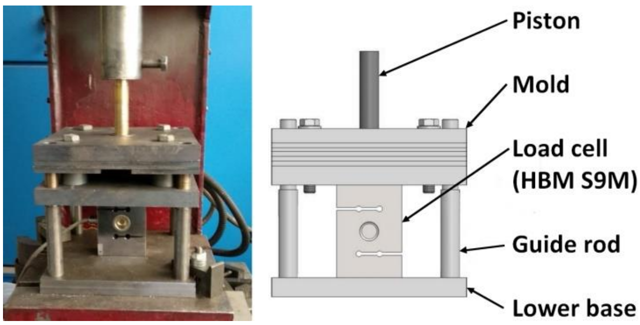

Fig. 3 Option for pressing force monitoring

Observation of the pressing force is possible by fitting the die on guidance rods (figure 3) that allows a free movement of the die at the direction of pressing force. A value of the pressing force is recorded by a dynamometer HBM S9M.

As experimental material was used aluminium alloy AlSi7Mg0.3. Chemical composition of this alloy is described in table 1.

Table 1.
Chemical composition of used AlSi7Mg0.3 (A356) alloy [wt. %]

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
8.835	0.135	0.007	0.006	0.303	0.004	0.002	Bal.

For the selected alloy was performed thermal analysis (figure 4).

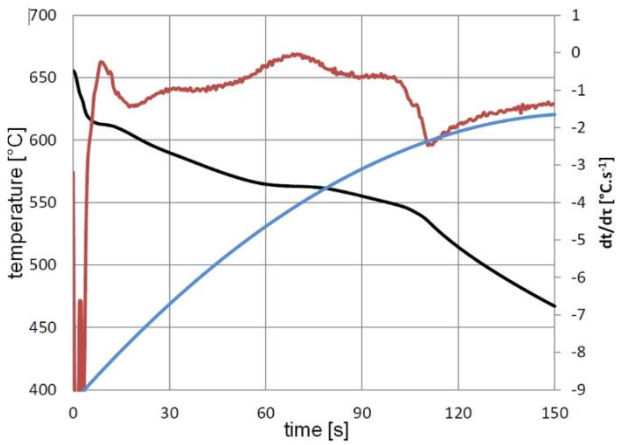

Fig. 4 Thermal analysis of AlSi7Mg0.3

The curve of solid phase fraction and temperature was obtained by the thermal analysis. Initial semi-solid state of the material was achieved by heating the material to temperature 590°C. On the basis of the graph of solid phase fraction against the temperature can be predicted, that the solid phase fraction is approximately 35% (figure 5).

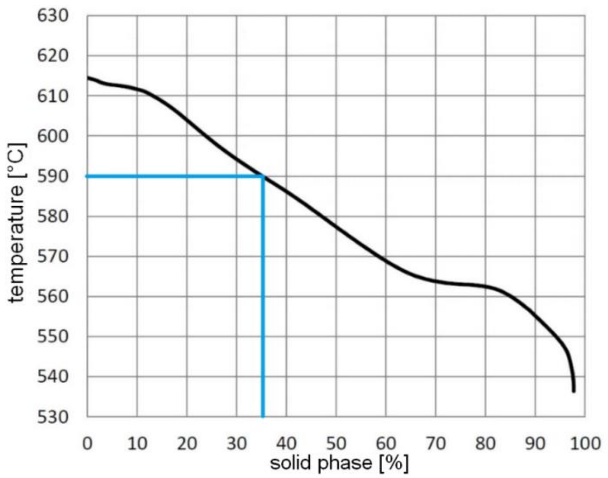

Fig. 5 Curve of solid phase fraction and temperature of AlSi7Mg0.3

3. Results

A part of the experiment was to perform the numerical simulation in casting software ProCAST 11.5. Simulation were focused to analyse filling and solidification. From the results of simulation, it is possible to observe the temperature curve during the processing of aluminium alloy by technology of semisolid squeeze casting. Also fraction of solid phase can be observed, which largely influences the ability of material to fill the mold cavity.

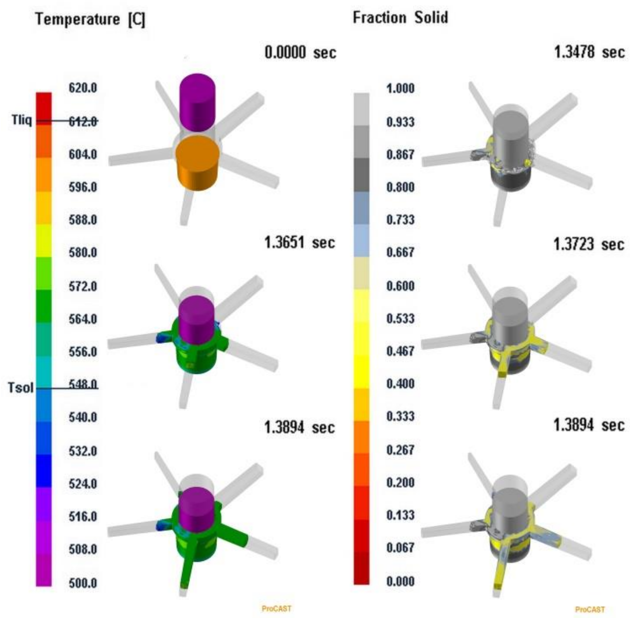

Fig. 4 The results of simulation for cavity of shape A

In figure 6 are shown simulations of the cavity filling in semi-solid state and solidification of the cast type A. On the basis of used boundary conditions for simulation a test cast were produced in foundry.

Table 2.
Parameters of casting

Pressure [MPa]	Temperature of die [°C]	Temperature of alloy [°C]	Piston velocity [m/s]
85	250	590	0,1

Figure 7 shows the final cast of shape type "A", that was made by parameters described in table 2.

Fig. 5 Test cast type A

At an arm (width 2 mm) cooling effect of the mold became apparent, thereby rapidly stopping the melt flow. For arms (width 3 and 4 mm), the length increases proportionately with the width increasing. For the conditions used in experiment the cross-section with width of 4 mm appears to be optimal, because it was almost completely filled. At cross-sections with width of 5 and 6 mm, the arms were shorter due to the reduction of the specific cross-sectional pressure and the more difficult pressure distribution in semi-solid metal. This phenomenon was reflected by gradually reducing a wider cross-section.

By using the dynamometer HBM S9M the flow of pressing force was observed. In the figures below it is possible to see a difference in pressing force flow (during filling of the mold cavity) between technology of semisolid squeeze casting (SSSC) and technology of squeeze casting (SC). In figure 8 is described the flow of pressing force by production of the cast "A" made by technology of semi-solid squeeze casting (SSSC). Figure 9 shows the pressing force flow of squeeze casting technology (SC). At this technology the process parameters were identical to technology SSSC. The casting temperature was 630 ° C.

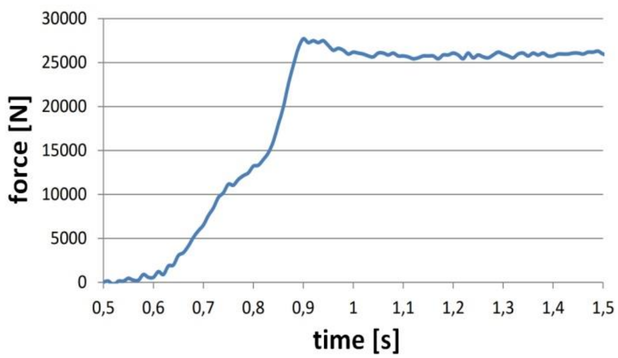

Fig. 6 Force-time graph of pressing force (SSSC)

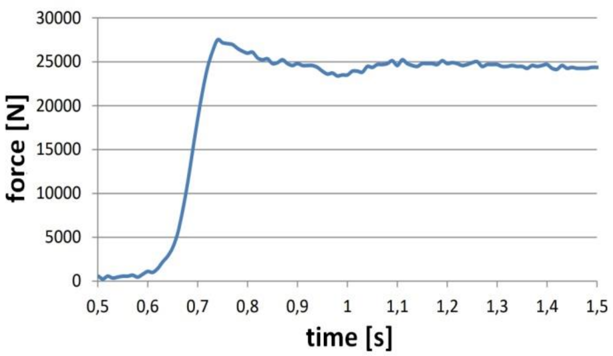

Fig. 7 Force-time graph of pressing force (SC)

It is apparent from the pressing force flow during the filling of the mold cavity that in SC technology with a material in the fully liquid state the resistance of the material is minimal. During filling of the mold cavity, there is no significant change in the course of applied force. After filling the cavity there is a direct pressure increase to the final value. The filling cycle time is approximately 0.15 s.

On the force-time graph of pressing force for SSSC technology we can observe a change in the course of the applied force. Higher viscosity of the material causes a higher flow resistance which is manifested by an increase in force during filling of the mold cavity. Gradual filling of the mold cavity can be observed by changing the slope of the curve. The filling cycle time is approximately 0.3 s.

4. Conclusions

The main objective of the paper was to design and produce a layered construction die that can be used for fluidity test of aluminium alloys casted by semi-solid squeeze casting method. The die design was verified by the simulation in the ProCAST software. Test castings were produced, which confirmed the usability of proposed die. In addition, design of the die allows the monitoring of the pressing force flow.

In the test cast, a different ratio between the individual dimensions of the mold cavity cross-section was observed. The individual arms were not filled according to the increasing width of their cross-section. This effect was due to the different fluidity of the melt around the solid particles in each sample region.

The difference in viscosity and pressure distributions in the fully liquid and semi-solid state is manifested in different conditions of filling individual elements and a significant extension of the filling cycle. In this case, the casting cycle time was doubled.

Based on the present results, it can be concluded that the fluidity of semisolid metal is strongly dependent on the shape of the mold cavity.

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