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Research Article

Modeling the Effect of Pour Height, Casting and Mold Heating Conditions for the Analysis of Fluidity of Different Section Thicknesses in Die Mold Casting of Al12Si Alloys

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Abstract

It is very important for the casting method that the metal could completely fill the mold cavity with a proper fluidity. Therefore, there is a need to improve the fluidity properties of aluminum alloys, which is an important engineering material. The aim of the study is to evaluate the parameters affecting the fluidity in the casting of Al12Si alloy, which is widely used industrially, by modeling techniques. The effects of varying pouring height, casting temperature and mold preheating temperature on fluidity in different section thicknesses were investigated in permanent mold casting. A specially designed mold with cross-sectional thickness varying from 2 mm to 8 mm was used in the study. Modeling studies were made with the FlowCast filling module, which is integrated into the SolidCast Casting simulation program. When the results are examined; It has been determined that all parameters play an active role on fluidity and different filling levels in different section thicknesses.

Keywords: Al12Si casting, Fluidity, FlowCast, Casting simulation

Al12Si Alaşımlarının Kalıcı Kalıp Dökümünde Döküş Yüksekliği, Döküm Sıcaklığı ve Kalıp Ön Isıtma Sıcaklığının Farklı Kesit Kalınlıklarının Akışkanlığa Etkisinin Modellenmesi

Öz

Döküm yönteminin ilk ve en önemli adımı sıvı metalin kalıp boşluğunu tamamen doldurmasıdır. Bu nedenle birçok avantajlı özelliği sayesinde kullanım alanı genişleyen alüminyum alaşımlarının akışkanlık özelliklerinin iyileştirilmesine ihtiyaç duyulmaktadır. Bu çalışmanın amacı, Al12Si alaşımının dökümünde akışkanlığı etkileyen parametreleri modelleme teknikleri ile incelemektir. Kokil kalıp dökümde, değişen döküm yüksekliği, döküm sıcaklığı ve kalıp ön ısıtma sıcaklığının farklı kesit kalınlıklarında akışkanlık üzerindeki etkileri araştırılmıştır. Çalışmada 2 mm'den 8 mm'ye değişen kesit kalınlıklarında özel olarak tasarlanmış kalıp kullanılmıştır. SolidCast Döküm simülasyon programına entegre edilen FlowCast dolum modülü ile modelleme çalışmaları yapılmıştır. Sonuçlar incelendiğinde; Farklı kesit kalınlıklarında akışkanlık ve farklı dolum seviyeleri üzerinde tüm parametrelerin aktif rol oynadığı tespit edilmiştir.

Anahtar Kelimeler: Al12Si döküm, akıcılık, FlowCast, döküm simülasyonu

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1 Introduction

Casting is known as a manufacturing process performed by melting metals into the mold cavity. With this method, even complex shaped parts can be easily produced from any material that can be melted [1]. The casting production requires two crucial steps. The first of these is filling the melt into a mold. The second stage is the solidification and cooling process [2]. One of the important mistakes in casting is that the liquid is not completely filled in the mold cavity. This is usually due to the thermal properties of the liquid metal and mold material, heat conduction and solidification. In addition, the oxide layer on the liquid metal surface also prevents the flow. Therefore, the fluidity analysis of the Aluminum is crucial to do in casting manufacturing [3,4].

It is called fluidity when metals and alloys pass through the gating system and fill the mold completely. Fluidity; it is not a property of the liquid, such as viscosity and density, but its complex behavior under certain conditions inside the casting mold. The fluidity of alloys is adversely affected by the coexistence of liquid and solid phases. Many factors affect the fluidity of the liquid metal. Some of these can be listed as alloy properties, mold properties, casting temperature and additional alloying elements added to the casting alloy [5-7]. It is also affected by alloy properties such as composition, latent heat, oxide film, specific gravity, melt surface tension, melting point and solidification mode. It is also affected by alloy properties such as composition, latent heat, oxide film, specific gravity, melt surface tension, melting point and solidification. In addition, factors such as mold interface heat transfer coefficient, mold temperature and mold conductivity are also important [8]. Fluidity is used to indicate how far a molten metal can flow before it solidifies. Fluidity represents an important property for casting alloys [9]. Fluidity is a length usually measured in millimeters or meters. There are test methods using molds such as spiral mold, u-shaped sample, rod-shaped sample for fluidity measurement [10,11].

Aluminum alloys are very important engineering materials due to their light weight, high corrosion resistance, high strength and ductility. Therefore; It is widely used in different applications in the automotive, aerospace, defense, aerospace industry, machinery manufacturing and food industry [12]. It is preferred for many applications in the automotive and aerospace sectors, especially due to the low density of aluminum compared to iron [13-16]. With the addition of silicon to aluminum alloys, fluidity, corrosion resistance, weldability increase and hot cracking tendency decreases [17,18]. Al-Si alloys, which have these properties and the highest fluidity among aluminum alloys, constitute a large part of all aluminum casting alloys [19-21].

In a study on fluidity, it was stated that the heat transfer and solidification properties of the alloy affect the fluidity of the melt [22]. While the excessive increase in the casting temperature of the alloy increases the fluidity, it can create many negative effects. Effects such as removal of the alloying elements from the liquid with different reactions, deformation of the mold, and grain growth can be observed. For this, an optimum temperature must be determined. Casting should be done approximately 125 °C above the melting temperature [23]. In the casting process, non-metallic impurities can adversely affect the fluidity and hinder the flow of melt in the cavity [24]. One of the most important defects are the bifilms that impede fluidity [25-27]. Timelli [28] looked into the effect of superheating and oxide content over the fluidity of A356. It was concluded that as bifilm index [26] was decreased from 31 mm to 18 mm, fluidity was increased from792 mm to 909 mm. Sanchez [29] worked with A319 and A356. The addition of Ti and Sr had decreased the formation of cold shut defects which had resulted in increased fluidity. Dahle examined the effect of grain refinement on the fluidity of the A356 alloy and concluded that the fluidity increased with Ti grain refinement and further increased due to dendrite consistency in B grain refinement [6]. However, by applying grain refinement and/or silicon modification, strength values can be increased with further increase in fluidity. Strontium is added to alter silicon to finer fibrous structure while Ti-B master alloys are also widely used as grain refiners. Yet, fluidity can be significantly affected by presence of defects such as oxides [30-31]. Han conducted tests with the High-Pressure Casting method to test the fluidity of the Al-Si alloy and reached the conclusion that the fluidity increased with the effect of pressure [32].

Sin found that the fluidity increased with the increase of casting and mold temperature. It has also been determined that increasing the pouring height has better filling ability depending on the increase of the filling speed [33]. Hua found similar results in his study, and also determined that the decrease in liquidus temperature with the addition of alloying elements increased the fluidity [34]. Yang, Li, Du, Wang and Tang investigated the effect of Ni and Si contents on the fluidity of Al-Ni-Si alloys with a spiral permanent pattern. It has been observed that the fluidity of Al-Ni-Si alloys increases with Si and Ni content [35]. Han and Xu stated in their study that as an alloy's solidification temperature range increases, its fluidity length decreases. As a result of experiments, they determined that the fluidity length of an alloy increases with the decrease of the solidification temperature range. On the other hand, they reported that this phenomenon cannot be observed under high pressure casting conditions [32].

In a study conducted by Şensoy et al., gravity casting method was used in order to optimize the fluidity efficiency of A356 Aluminum alloy. In the study, casting temperature, preheating temperature and section thickness were taken into consideration as test parameters; As a result of the sensitivity analysis, it was concluded that the parameter that affects the fluency the most is the thickness [36]. In their study, Çolak and Arslan investigated the effects of mold preheating temperature on pouring into the mold. It has been determined that there are positive effects of feeding due to the increase of different mold preheat temperatures (200°C, 300°C, 400°C) of aluminum alloys [37,38].

With the fluidity tests that can be done practically in foundries, casting conditions can be determined depending on temperature and composition. In these experiments, liquid metal is flowed into a long channel of small cross-section. In fluidity tests known as spiral mold or vacuum test, the distance the liquid metal moves before solidifying is considered as a measure of fluidity [39,40]. Many studies on fluidity and casting simulation are available in the literature [41-43]. However, due to the fact that the section thickness is constant in these models, alternative fluidity test models are developed due to the differences observed in the results. Kwon used an eight-channel die design to check the reproducibility of the test results. In the experiments, he explained that it was concluded that the fluidity increased even at low temperatures with grain refinement [44]. Qudong used a star-shaped mold consisting of 8 channels of various thicknesses and found that increasing both the casting and mold temperatures will increase the fluidity length in thin sections [45]. Di Sabatino has prepared a standardized test equipment where parameters are perfectly controlled and produce repeatable results with spiral test patterns [46].

In this study, the effects of varying pouring height, pouring temperature and mold preheating temperature values on the flowability in different sections in permanent mold casting of Al12Si alloy were investigated by modeling techniques. In the study, a 4-channel mold was designed in which castings between 2 mm and 8 mm section thickness could be evaluated. The module from the FlowCast casting software was utilized in modeling simulations. By evaluating the modeling results, the determination of the liquid metal filling distance under changing conditions and the effects of changing factors on the fluidity were determined.

2 Material and Method

Here, the subject of the study is to investigate the properties of the eutectic Al12Si alloy fluidity according to the different casting preparations. Therefore, a specially designed fluidity test model with increasing region thicknesses was used under varying casting conditions. In the study in which permanent mold casting models were made, the experimental procedures were detected as casting temperature, casting height, mold preheating temperature and section thickness. Experimental parameters were selected using the literature information, and the parameters that have the most effect on the fluidity properties of the alloy and that the foundry can intervene during manufacturing. In Table 1, the experimental parameters in which the fluidity properties of the alloy were investigated are given.

Table 1. Experiment Parameters

Casting Temperature (°C)	**Pouring height (mm)**	**Mold Preheat Temperature (°C)**
690	100	200
720	150	300
750	200	400

Within the scope of the study, temperatures were determined as 3 temperature parameters, low and high, based on the normal casting temperature for the alloy. The pouring height was determined as 100, 150 and 200 mm since it creates static liquid pressure and affects the filling speed. It is known that the mold preheating temperature is determined by the company depending on the section thickness in foundries. For this reason, 200, 300 and 400 °C were determined to examine the effect of mold heating temperature in the model with thickness varying from 2 mm to 8 mm.

2.1. Model Design

In order to determine the fluidity properties of the alloys, a model was designed with different section thicknesses. Modeling studies were performed for the design whose solid model image and dimensions are given in Figure 1. The length of the liquid Aluminum allow path is deliberately kept so long that it is not completely filled, so that the distance of the liquid metal can be measured. In addition, thanks to the different section thicknesses, it will be possible to detect what thickness castings can be performed under what conditions

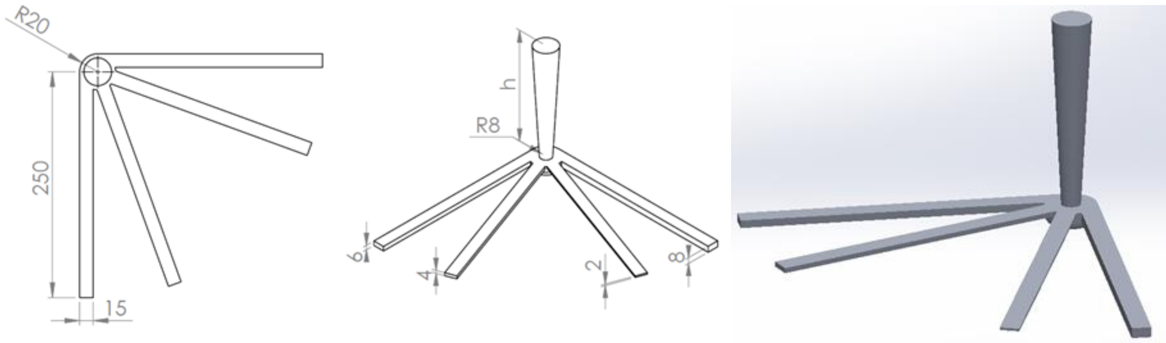

Figure 1. Fluidity test sample solid model image and dimensions.

As seen in Figure 1, the width of all channels was determined as 15 mm. The channel length was determined as 250 mm and the vertical runner was designed with a conical 3° taper for the pouring height.

2.2. Modeling Studies

Modeling of casting processes is required for mathematical method for the computer to make predictions about what happens inside the mold as the mold is filled and after filling. These programs are generally capable of modeling the given casting geometry by calculating with finite difference or finite element techniques, with thermal and material properties and boundary conditions of the material for different casting and mold materials. The casting geometry of the part was designed in the SolidWorks CAD platform. The model was transferred to the casting simulation software with a STL file format. After importing the model geometry, the thermal and material properties of the casting alloy and mold were defined. Thermo physical values of A413 (Al12Si) casting alloy used in simulation are shown in Table 2.

Table 2. Thermal and material properties of the A413 alloy used in the modelling.

Alloy	**Thermal Conductivity (W/m.K)**	**Specific Heat (J/kg.K)**	**Density (kg/m^3)**	**Casting Temperature (ºC)**	**Solidification Temparature (ºC)**	**Freezing Range (ºC)**	**Latent Heat of Fusion (J/kg.)**
A413	121,24	962,3	2657,3	690-720-750	557	17	388175,1

The material properties of the part are defined in the software. Afterwards, the solid model geometry was analyzed by meshing in the simulation program. Filling models were performed with the FlowCast program. FlowCast computes some factors such as underfilling, cold junction, turbulence, and pressure while filling the liquid metal into the mold cavity according to fluid dynamics criteria. Modeling was carried out with a filling time of 5 seconds., images of the samples are given In Figure 2.

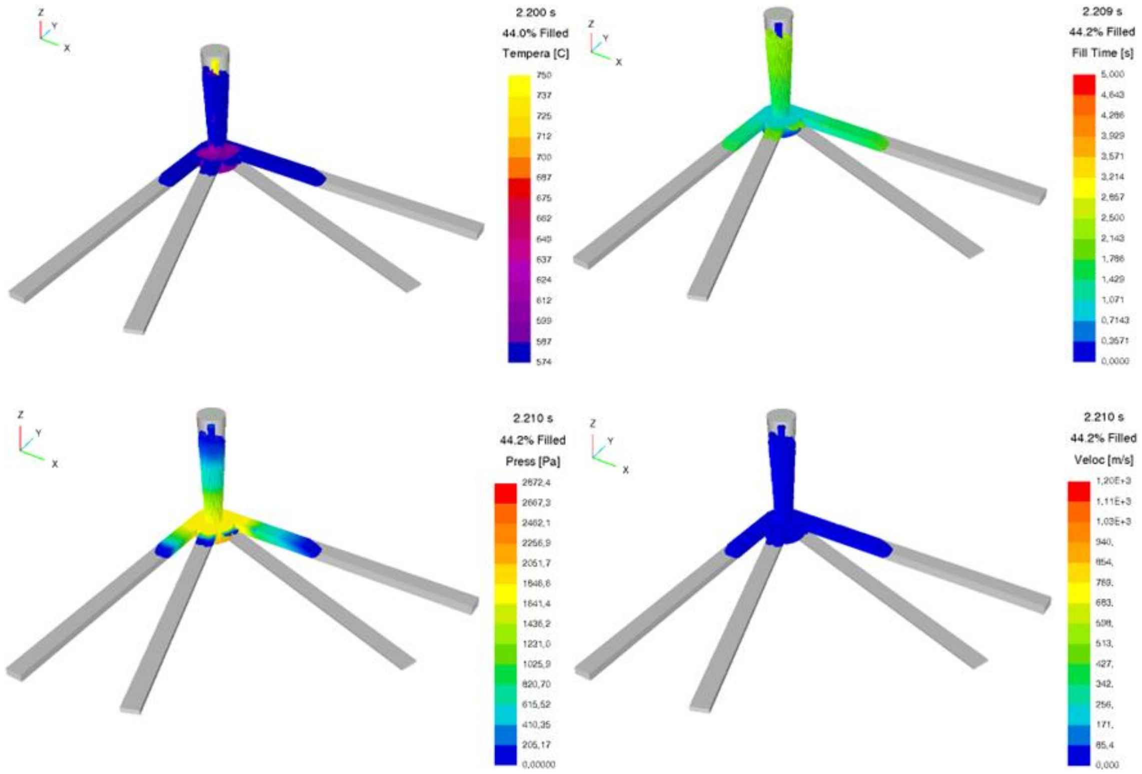

Figure 2. Images from the FlowCast modeling software

In order to determine the liquid metal filling distances from the casting modeling results, the examinations were carried out using the image analysis program. Images were loaded into the program and the channel length was defined as 250 mm. Then, the liquid metal filling distance was measured. The sample image taken from the program is given in Figure 3.

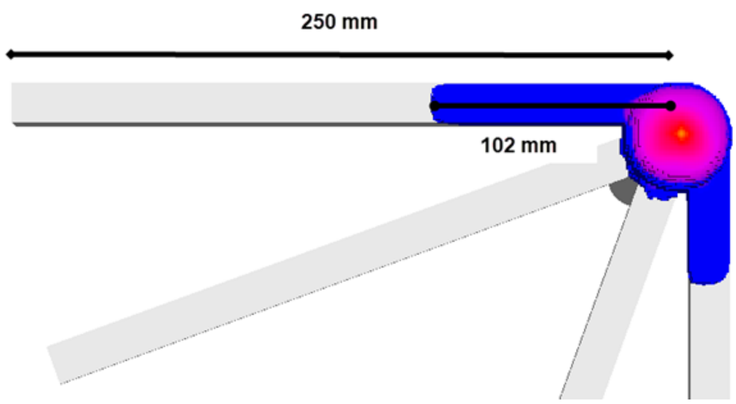

Figure 3. Determining the liquid metal filling distance with the İmage Analysis program

3 Results and Discussion

3.1 Modeling Results and Evaluation

The results of the liquid metal filling distance and percent filling amount obtained from the FlowCast filling modeling software at different thicknesses depending on the test parameters are given in Table 3.

Table 3. Modeling Results

	Pouring height (mm)	Casting Temperature (°C)	Mold Preheat Temperature (°C)	Channel Section Thickness (mm)				Fill Rate (%)
				2	4	6	8	
1	100	690	200	4	7	35	86	21,11
2	100	690	300	5	8	38	92	26,04
3	100	690	400	5	11	41	95	37,93
4	100	720	200	7	14	46	93	22,03
5	100	720	300	7	14	49	98	35,41
6	100	720	400	8	16	55	107	39,13
7	100	750	200	11	19	73	105	25,53
8	100	750	300	12	21	77	112	36,21
9	100	750	400	14	22	84	118	40,15
10	150	690	200	5	12	54	95	22,34
11	150	690	300	6	14	58	98	28,54
12	150	690	400	8	19	64	109	39,12
13	150	720	200	10	16	61	105	24,23
14	150	720	300	12	21	67	111	38,14
15	150	720	400	15	29	72	118	41,84
16	150	750	200	14	23	71	114	28,37
17	150	750	300	17	28	73	125	39,95
18	150	750	400	21	32	84	136	42,73
19	200	690	200	14	21	74	103	23,32
20	200	690	300	18	25	79	106	29,63
21	200	690	400	25	29	86	118	40,08
22	200	720	200	21	31	84	114	25,72
23	200	720	300	27	38	93	125	39,04
24	200	720	400	32	42	99	129	42,18
25	200	750	200	31	41	96	128	29,63
26	200	750	300	38	49	107	138	40,16
27	200	750	400	45	56	115	147	44,41

When the results given in Table 3 are examined, it is understood that different values of fluidity properties are obtained under varying conditions. It is understood that the critical factor on the fluidity is the temperature of the casting. With the increasing casting temperature, an increase in liquid metal filling distances of all thicknesses was determined. The increase in the mold preheating temperature also showed an easing action for fluidity. With the increase of the mold preheating temperature, the liquid metal filling distance increased due to the late solidification of the liquid metal. The increase in casting height has benefited fluency by contributing to the longer progression of liquid metal without solidification, as it directly affects the speed of liquid metal entry into the mold. In all casting conditions, the liquid metal filling distance increased with the increase of the section thickness. In Figure 4, a graph is given for the comparison of the effects of the experimental parameters for 100 mm pouring height.

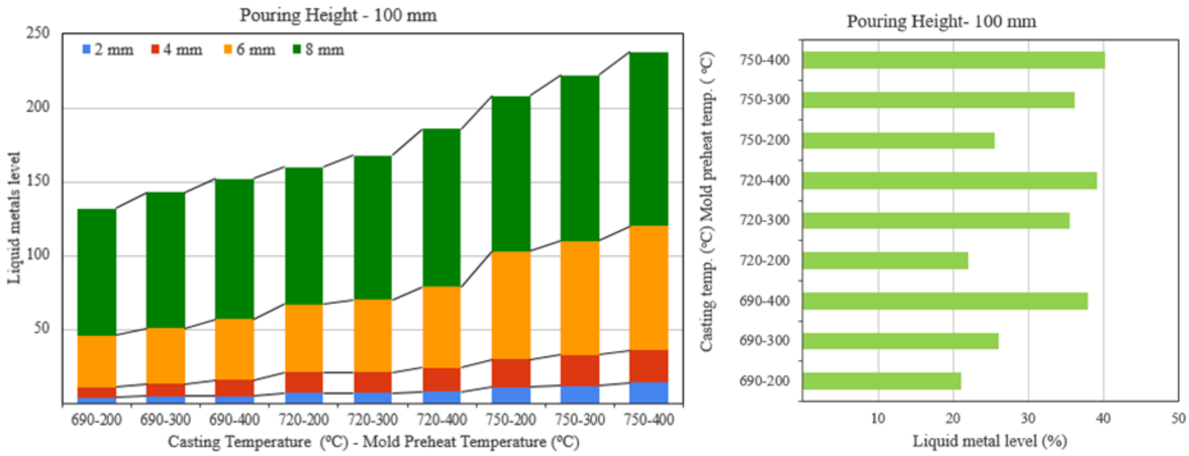

Figure 4. Comparison of parameters based on modeling results on fluidity

When the results given in Figure 4 are examined, it is understood that the pouring temperature has the greatest effect on the fluidity. In all casting experiments, very little filling was detected in the 2 mm thick channel. In the castings made at 680 °C casting temperature, the filling amount in the 2 mm channel was very low. As an example, the increase in the amount of advance with the increase of pouring temperature is given in the modeling results 1, 4 and 7 in Figure 5.

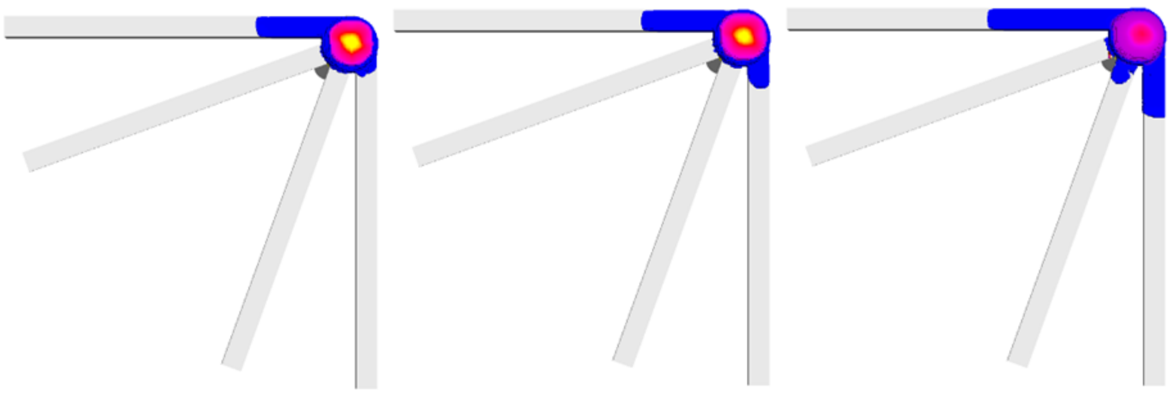

Figure 5. Results of the fluidity change according to casting temperature at modeling conditions 1, 4 and 7

In Figure 5, it is seen that the temperature increases and the liquid metal fluidity value in all section thicknesses increase in the modeling results at 200 °C mold preheating temperature and 690, 720 and 750 °C conditions at 100 mm pouring height. It has been determined that the liquid metal advance distance increases with the increase of casting temperature in castings made under the same conditions. Aslandoğan determined in his study that the most important effect increasing the fluidity in casting is temperature [23]. In a similar study, Kharkiv found that on one hand, high temperatures settings can help for the fluidity of all metals and alloys, on the other hand non-metallic impurities in the casting hinder their flow in the mold [24]. In Figure 6, the effect of pouring height on fluidity is given in modeling results 5, 14 and 23.

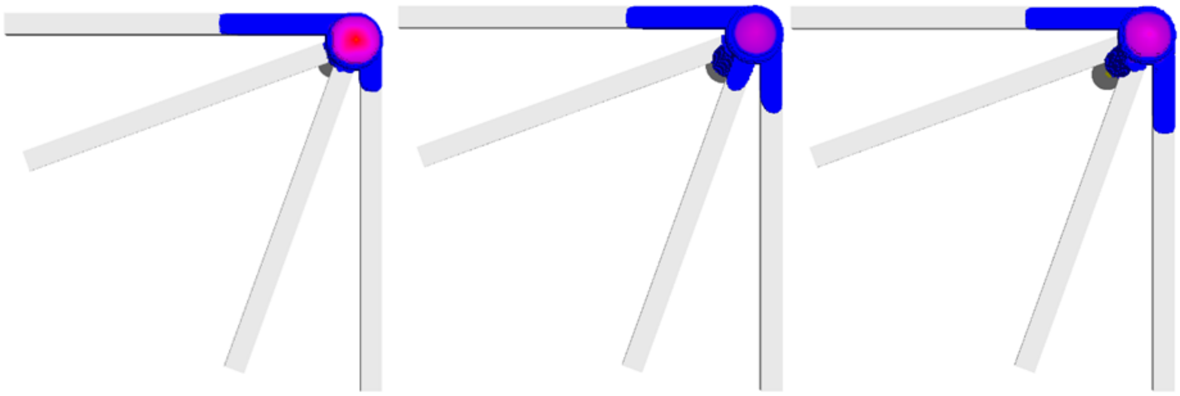

Figure 6. Results of the effect of pouring height on fluidity at test conditions 5, 14 and 23

It is understood from the modelling results in Figure 6 that the pouring height has a great influence on the fluidity properties in different sections at the conditions of 720 °C casting and 300 °C mold preheating temperature conditions at 100 mm, 150 mm and 200 mm pour height conditions. In studies on the subject, it is known that the pour height directly affects the liquid metal velocity. In Figure 7., the effect of mold preheating temperature on fluidity in varying sections is given in modelling results 13, 14 and 15.

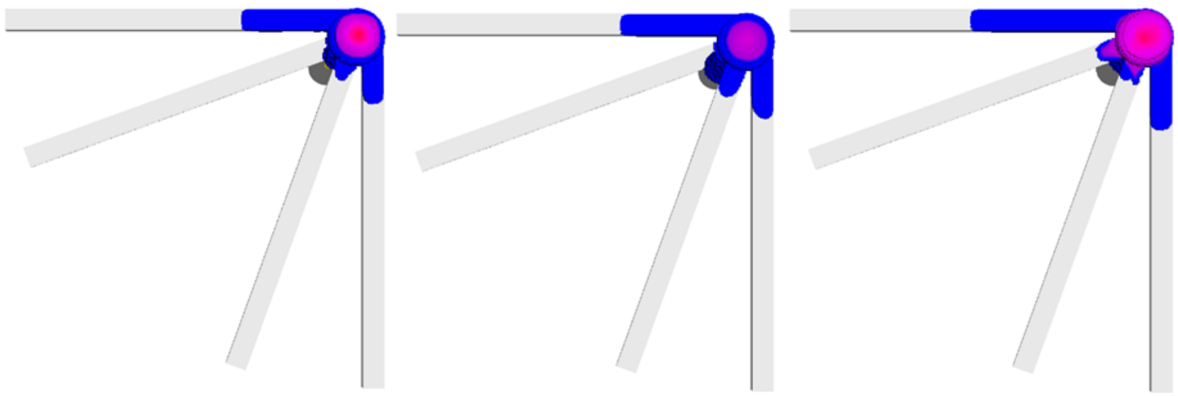

Figure 7. Results of the effect of mold preheating temperature on fluidity in test conditions 13, 14 and 15

In Figure 7, it is understood from the modelling results that the mold preheating temperature affects the fluidity at the conditions of 720 °C casting and 150 mm pouring height at 200 °C, 300 °C and 400 °C mold preheating temperatures. It is thought that with the increase of the mold temperature, the fluidity increases due to the long solidification time of the liquid metal.

4 Conclusion

The effect of changing conditions on the fluidity of A413 aluminum alloy in permanent mold casting was investigated by modeling techniques. The results obtained as a result of the studies are presented below:

- It has been determined that all parameters are effective on fluidity in modeling studies. It was understood that the most influence on the parameters was the casting temperature, followed by the pouring height and the mold preheating temperature, respectively.

- It has been determined that with the increase of the casting temperature, the liquid metal progress in the casting channels increases at all thicknesses in the mold. In the castings made under the same conditions, increasing the casting temperature had a positive effect on the fluidity, causing more liquid metal advance distance.

- It was determined that the liquid metal filling increased with the increase of the section thickness in all casting conditions. Very little liquid metal propagation was observed under all conditions in castings with 2 and 4 mm spacing. For this reason, it is thought that care should be taken to fill the casting completely in sections below 4 mm in permanent mold casting.

- With the increase of the pouring height, an increase was observed in the liquid metal filling distances depending on the speed in the free fall. However, with increasing casting height, attention should be paid to the rate of entry of the liquid metal into the mold. It should be noted that excessive liquid metal velocity will cause turbulence and bifilm in the mold.

- Since the mold preheating temperature increase will cause later solidification, therefore the fluidity can be enhanced by it.

Ethics in Publishing

There are no ethical issues regarding the publication of this study.

Author Contributions

Yunus Emre ASAN: Conceptualization, Methodology, Investigation, Writing-Original Draft, Visualization Murat ÇOLAK: Methodology, Writing-Review & Editing

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