ARCHIVES
of
FOUNDRY ENGINEERING

10.24425/afe.2024.149258

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 2024
Issue 1/2024

115 – 120

14/1

Evaluation of High Pressure Die Casting Mold Temperature Relations Depending on the Location of the Tempering Channels

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Received 11.12.2023; accepted in revised form 9.02.2024; available online 18.03.2024

Abstract

During the casting cycle, the relatively cold material of the mold comes into contact with the significantly higher temperature melt, which causes high temperature fluctuations on the face of the mold and in its volume, which cause cyclic temperature stress. The submitted article is based on conclusions of the article "Evaluation of the temperature distribution of a die casting mold of X38CrMoV5_1 steel", in which the modification of temperature relations of the mold in the direction from the mold face to its volume was investigated. In current article, the influence of the tempering channel distance on the temperature modification in the volume of high pressure die casting mold is investigated. Three variants of the tempering channels placements with different location respecting the mold cavity were investigated. The temperature was monitored in two selected locations, with distribution of 1mm, 2mm, 5mm, 10mm and 20mm in the direction from the mold cavity surface to the volume of fixed and movable part of the mold. As a comparative parameter, the temperature of the melt in the center of the runner above the measuring point and the temperature of the melt close to the face of the mold were monitored. The measurement was performed using Magmasoft simulation software. It was discovered that up to a distance of 5mm from the face of the mold, a zone with complete heat transit without its accumulation occurs. Above this limit, the mold begins to accumulate heat, and from distance of 20mm from the face of the mold, the heat gradually passes into the entire mass of the mold without significant temperature fluctuations. The propositions derived from the results of the experiments presented at the end of the article will subsequently be experimentally verified in further research works.

Keywords: Product development, Application of information Technology to the foundry industry, Thermal stress, Mold material, Tempering.

1. Introduction

High pressure die casting (HPDC) is a process that is commonly used to produce large series of complex metal parts for multiple industries [1,2]. In this casting method, molten metal is forced into the cavity at high speed and pressure. In periodic cycles, the processes of filling the chamber, solidifying the casting, opening and closing the mold, removing the casts and treating the mold with spraying and blowing. During these periodically alternating cycles, the high pressure die undergoes significant temperature changes, which causes thermal imbalance [3,4]. When a molten HPDC alloy is injected into a relatively cold mold cavity, the solidification rate is highly dependent on the interfacial heat transfer behavior of both the mold and the molten alloy, and subsequently affects the macrostructure and mechanical properties of the final product[5-7]. It is the thermal balance of the mold that has a significant influence on the quality of casts produced by high pressure die casting, on the general reduction of defects and on the extension of the lifespan of the mold. The distribution of temperature in different places of the inner surface of the mold and in the depth of the mold material is difficult to control. This has an adverse effect on the lifespan of the mold. Unequal temperature change in different places of the cavity has a significant impact on the technological process during casting, which results in increased production of defects. The constantly repeating temperature cycles induce thermal stresses which, in connection with the high specific pressure during mold being in work, lead to operating conditions similar to high dynamic stress. These conditions occur in the cavity of the mold and partially also on its dividing plane [8].

The thermal slope depends on the thermal conductivity of the material from which the mold is made, on the mass of the mold itself to the mass of the cast ratio, and on the mold temperature before casting. A larger ration of the mold material mass to the mass of the cast facilitates the heat transfer from the upper layers of the mold to its entire volume, which contributes to increasing of its lifespan. For example, when high pressure die casting the aluminum alloys at a higher ratio of the mold mass to mass of the cast, the lifespan of the mold is longer compared to the same casts being produced by ingot molds in which very thin walls prevail. At the same time, the high pressure die casting mold works in significantly more difficult conditions [9-11].

To ensure the quality of the casts, it is important to ensure the stability of the casting process, that means, the cast must be produced under the constant conditions. A tempering system is used to ensure the stability of the casting process in the high pressure die casting molds [12,13].

From the conclusions presented in the publication[8], it arises that the distribution and the design of the tempering channels has a significant influence on the temperature field changes in the volume of the mold and related heat dissipation. By monitoring the thermal progress of the mold in the process, it was found that at different depths of the mold material from the cavity wall coming into contact with the molten metal, the temperature changes significantly during the one work cycle. As it was demonstrated in the article [8], the smaller the distance between the mold cavity wall and the tempering channel, the smaller the temperature difference in the mold volume. Therefore, it is advisable to dimension the tempering channels as close as possible to the mold cavity.

The main objective of the submitted article is to assess the temperature relation of the high pressure die casting mold depending on the tempering channels distribution in relation to the mold cavity. During the assessment of the thermal stress of the mold, an experimental distribution of tempering channels was proposed, approximating the real mold, with the objective to ensure different conditions of heat dissipation. In this layout, the variable distance of tempering channels from the mold face was selected in three variants. The measurements were carried out using the Magmasoft simulation program.

2. Description of experimental procedure

The measurements were realized on the cast of the electric motor flange. In the Magmasoft simulation program, the experimental layout of the tempering channels was designed according to Figure 1. Measuring points were selected in the location of the main runner branching point and in the secondary runner opposite of the location from the ingates (Figure 1). Chromium molybdenum steel X38CrMoV5_1 was selected as the material of functional mold parts, which is commonly chosen material for the production of molds intended for aluminum alloys casting.

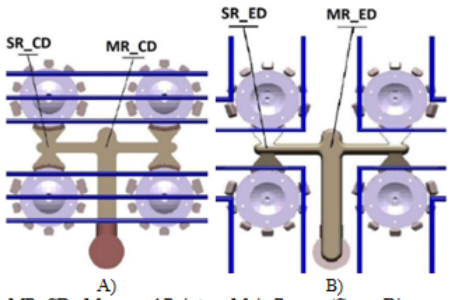

Fig. 1. Gate system of casting and experimental tempering system (A) - distribution of tempering channels in the Cover Die, B) - distribution of tempering channels in the Ejector Die)

Measuring points were distributed in a straight line perpendicular to the dividing plane of the mold. The temperature change in the fixed and moving half of the mold was monitored. The spacing of the measuring points in the mold volume was as follows 1mm, 2mm, 5mm, 10mm and 20mm from the mold cavity face. The cross-section of the tempering channels is 9mm.

The influence of the tempering channels distance on the temperature relations of the mold was investigated on three variants of the design solution for the distribution of the tempering channels according to Figure 2.

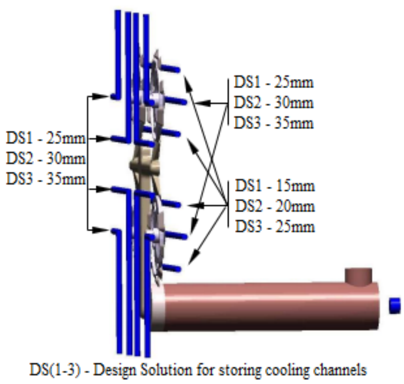

Fig. 2. Variants of tempering channels distribution from the mold face

The setting of input technological parameters is presented in Table 1.

Table 1.
Technological parameters of casting cycle

Parameter	Value
Alloy	EN AC 47100
Molten alloy temperature [°C]	705
Mold material	X38CrMoV5_1
Mold temperature [°C]	200
Tempering medium	Oil
Tempering medium temperature [°C]	190
Pressing piston velocity [$m.s^{-1}$]	2.6
Holding pressure [MPa]	25
Mold cavity filling time [s]	0.016

To ensure the relating temperature stability of the mold material, five pre-production heating cycles were defined in the Magmasoft simulation program. Monitoring of temperature changes was realized in the sixth production cycle. The mold cavity before closing was treated with spraying with a duration of 3s and blowing with duration of 3s. The opening and ejection of the cast from mold was conditioned by the temperature of the cast. The opening of the mold will only happen as soon as the maximal temperature in the Cast Alloy Materials falls below 400 °C.

3. Description of achieved results of own researches

Based on monitoring the temperature at the measuring points according to Figure 1, for individual variants of the tempering channels distribution, according to Figure 2, the temperature change for individual variants was evaluated and presented in Table 2.

As can be seen from Table 2, the material of the mold near the face of the mold cavity is stressed by the temperature fluctuation ΔT over 200°C. The results presented in Table 2 are presented as absolute values of temperature at individual measuring points.

In order to understand and visualize the progress of temperature changes in individual measuring points, graphic representations of the temperature changes progress as a function of time were created. To compare the course of temperatures in the fixed half in the area of SR_CD measuring points, the following dependencies are presented for the design variant DS1 – Figure 3 and DS3 – Figure 4.

Table 2.
Temperature change in measuring points

Die Temperature, [°C]									
	DS1			DS2			DS3		
Measuring Point	Tmax	Tmin	ΔT	Tmax	Tmin	ΔT	Tmax	Tmin	ΔT
MR_CD – 1mm	456.8	229.7	227.1	457.6	230.9	226.7	459.0	231.2	227.8
MR_CD – 2mm	442.2	229.9	212.3	438.8	231.2	207.6	439.8	231.5	208.3
MR_CD – 5mm	396.0	231.5	164.5	397.9	232.7	165.2	400.3	232.9	167.4
MR_CD – 10mm	339.6	235.8	103.8	343.2	236.8	106.4	342.0	237.2	104.8
MR_CD – 20mm	284.1	238.5	45.6	284.8	239.6	45.2	283.6	239.7	43.9
MR_ED – 1mm	462.9	236.2	226.7	467.8	237.3	230.5	464.1	234.4	229.7
MR_ED – 2mm	443.5	236.4	207.1	453.2	237.4	215.8	447.4	234.6	212.8
MR_ED – 5mm	401.1	237.8	163.3	407.8	238.5	169.3	403.4	236.2	167.2
MR_ED – 10mm	347.1	241.3	105.8	351.9	241.7	110.2	352.1	240.4	111.7
MR_ED – 20mm	295.7	241.6	54.1	298.0	242.3	55.7	290.5	244.2	46.3
SR_CD – 1mm	419.1	196.9	222.2	416.1	197.3	218.8	416.2	197.5	218.7
SR_CD – 2mm	396.0	197.0	199.0	391.7	197.5	194.2	392.0	197.7	194.3
SR_CD – 5mm	350.1	197.9	152.2	347.7	198.3	149.4	348.2	198.5	149.7
SR_CD – 10mm	295.2	201.9	93.3	291.1	202.9	88.2	293.2	202.8	90.4
SR_CD – 20mm	209.7	209.7	35.3	243.7	210.3	33.4	243.2	210.4	32.8
SR_ED – 1mm	399.3	198.0	201.3	398.5	198.8	199.7	405.7	197.6	208.1
SR_ED – 2mm	383.5	198.3	185.2	376.3	199.1	177.2	384.6	197.9	186.7
SR_ED – 5mm	343.0	200.0	143.0	338.8	201.1	137.7	349.5	199.8	149.7
SR_ED – 10mm	273.8	205.1	68.7	268.1	206.1	62.0	282.3	205.6	76.7
SR_ED – 20mm	237.0	207.3	29.7	236.2	207.5	28.7	233.8	208.6	25.2
Aloy Temperature, [°C]									
Center of M.R.	638.6	350.2	288.4	638.4	351.3	287.1	638.1	350.6	287.5
Surface of CD	637.7	350.2	287.5	636.2	351.2	285.0	635.4	350.6	284.8

Surface of ED	635.6	350.5	285.1	636.1	351.4	284.7	636.8	350.6	286.2
Center of S.R.	631.8	271.6	360.2	631.6	272.0	359.6	631.0	272.0	359.0
Surface of CD	628.4	271.2	357.2	629.3	272.2	357.1	629.4	272.2	357.2
Surface of ED	627.9	270.4	357.5	627.3	271.6	355.7	628.9	271.4	357.5

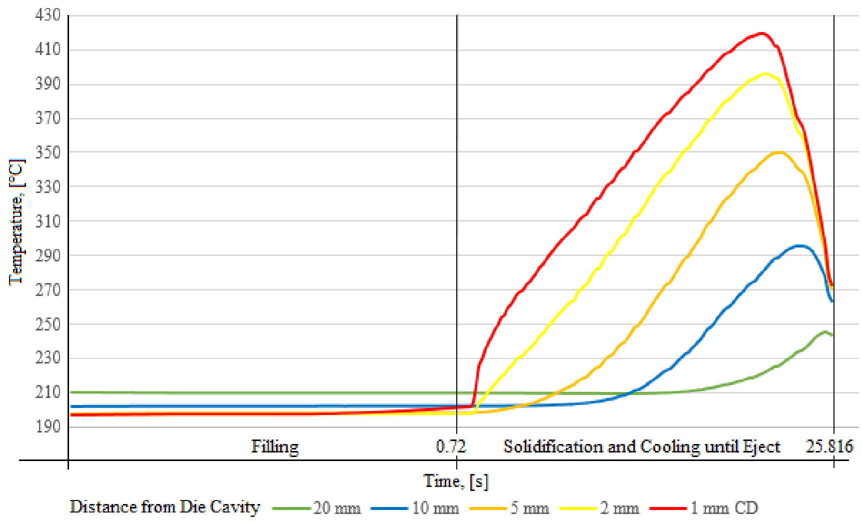

Fig. 3. Temperature progress Secondary runner/Cover Die – variant DS1

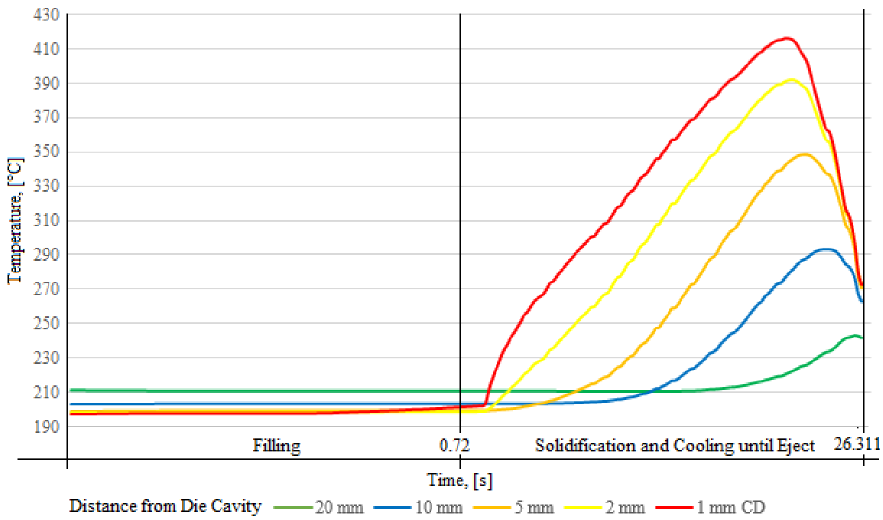

Fig. 4. Temperature progress Secondary runner/Cover Die – variant DS3

As emerges from Figure 3 and Figure 4, the temperature of the mold is, regardless of the distribution of tempering channels, during Filling phase at a constant level, respectively, the layer just below the surface is heated only minimally. This also confirms the conclusions presented in the article according to [8]. Intensive temperature increase in the mold volume occurs only during the Solidification phase. The temperature progress into the mold volume depicting the heat transfer from the surface of the mold cavity into the mold volume can be determined at the points where the individual temperature curves intersect. The temperature difference between the end of the Cooling phase and the beginning of the Filling phase of the new cycle is caused by the surface treatment of the mold cavity between individual cycles, when the mold is sprayed and blown, while its surface is also cooled by the flow of ambient air.

From Table 2 and at the same time from Figure 4, it is evident that the temperature maximum and minimum do not show extreme deviations. When examining the temperature progress at the measuring points for individual variants, it was found that while the duration of the Filling phase is identical for all design variants of the tempering channels distribution, the duration of Solidification and Cooling until Eject is slightly affected by the tempering channels distribution. The total duration of mold closure for individual variants is presented in Table 3.

Table 3.
Die closure duration

	Design Solution		
	DS1	DS2	DS3
Die closure duration, [s]	25.618	26.018	26.311

With regard to the conclusions of the article [8], the statement is confirmed that with increasing distance from the die face, the temperature also increases slightly. This fact can be explained by the fact that the die behaves not only as a thermal conductor, but also as an accumulator. This heat in the die mass therefore comes from previous cycles and is accumulated in it. From this, it can be concluded, that the tempering channels do not remove the heat from die perfectly. Despite this, during the regular work cycles, the temperature in die volume in the vicinity of the tempering channels fluctuates at the relatively constant level. The most affected by fluctuations are the areas near the die cavity face, as evidenced by the average temperature changes at the measuring points for individual design solutions for distribution of tempering channels presented in Table 4. The absolute temperature change in the individual layers of the die can be understood as a die temperature stress.

Table 4.
Average temperature changes in the die volume during the work cycle

Distance from Die Face	DS1	DS2	DS3
	Average temperature change		
	ΔT, [°C]	ΔT, [°C]	ΔT, [°C]
1 mm	218.1	218.9	321.4
2 mm	200.9	198.7	221.1
5 mm	155.8	155.4	158.5
10 mm	92.9	91.7	95.9
20 mm	41.2	40.7	37.1

The values presented in Table 4 were obtained as an arithmetic averages of temperature changes at measuring points equidistant from the die face, which makes it possible to assess the temperature stress of the high pressure die in the investigated layer across the surface and to better evaluate the appropriateness of the selected tempering channels distribution. We can see that the die is exposed to considerable thermal stress exclusively in the vicinity of its cavity.

4. Discussion of the achieved results

The main objective of the submitted article is to assess the temperature relations of the high pressure die casting mold depending on the distribution of tempering channels regarding the die cavity. From Table 2 arises, that the size of temperature change ΔT decreases with increasing distance from the die cavity surface. That is, the amount of thermal stress on the die material is inversely proportional to the distance from the die face.

After summarizing the results in Table 4, it can be concluded that due to the alternating heating and cooling of the die during individual work cycles, significant temperature fluctuations occur, especially to a depth of 5 mm from the die cavity surface, where at a certain moment the temperature of surface layers approximates to the temperature of the melt. The layer between 5 mm and 10 mm deep is then stressed less by the temperature fluctuations. At the depth approximating 20 mm and beyond, the thermal stress is negligible, because this layer is located closer to the tempering channels then others investigated.

The material is not the only aspect that greatly affects the thermal stress of the die. The layout and cross-section of the tempering channels, as well as the flow rate and temperature of the tempering medium cannot be neglected in this regard. As Figure 1 and Figure 2 shown, the geometry and distribution of the tempering channels was selected for the needs of the simulations in this work in order to avoid excessive influence of the temperature at the measuring points and thus distortion of the results. Therefore, there was no tempering channel in the vicinity of the measuring points in the main and secondary runners in either the fixed or the movable half of the die. For this reason, there is no extreme jump in the temperature values in Table 2. It is also clearly visible in Table 2 that the heat released from the melt penetrates the mass of the fixed and movable halves of the die very similarly up to a depth of 10 mm. The next measuring point is located at the depth of 20 mm, and at this depth, the influence of heat transfer by tempering channels, which are distributed deeper in the moveable half of the die then in the fixed half, is already noticeable. This difference can be understood as distribution of tempering channels closer to the die face may be more advantageous in terms of better heat dissipation.

Figure 3 and Figure 4 show the progress of the temperature in the area of the secondary runners at individual measuring points of the fixed half of the die. As stated in the previous paragraph, the experimental layout of the tempering system allows one half of the die to be examined for simplicity, because the heat transfer manifests itself similarly in the other half. It should be noted that the temperature was recorded only when the die was closed. The filling phase lasted exactly 0,72 s for all 3 cycles, and during the filling phase no significant temperature change was recorded in any of the measuring points. A significant increase in temperature occurs during the ”Solidification and cooling phase”, when the melt is intensively cooled and the cast solidifies, while the melts heat is dissipated towards the die volume. The cooling phase ends when the die is opened. In each simulation, this happens at a different moment, as shown in Table 4.

From Figure 3 and Figure 4, as well as from the examination of the temperature change progress in individual variants of the tempering channels distribution, it follows that the material of the die up to depth of 5 mm forms a transit zone for the heat transfer without its accumulation. Above this limit, the die begins to accumulate heat, and from a distance of 20 mm from the die face, the heat gradually passes into the entire mass of the die without significant temperature fluctuations.

After opening the die, when the cast is ejected from die, die cavity treatment and its closure, a period of 15 seconds elapses. Due to the influence of ambient air, spraying and blowing, the temperature of both die halves is additionally reduced to the temperature at which the first contact with the cast melt takes place.

The amount of subcooling of the melt in contact with the die face determines the structure of the cast. Thus, the amount of temperature between the melt and die cavity surface affects the size of grains in the cast walls. The higher the undercooling of the melt, the finer-grained the structure of the cast is achieved, which is reflected in an increase in their surface hardness [14]. In practice, it is preferred to set the die temperature to 1/3 of the melt temperature [15]. In our experiment, this condition was maintained.

5. Conclusions

By monitoring the thermal progress of the die, it was found that at different depths of the die material from the wall of the cavity coming into contact with molten metal, the temperature changes significantly during one work cycle. At the same time, the conclusions resulting from previous work, presented in [8], were verified and confirmed.

An important finding, expanding the knowledge presented in [8], is the determination of a zone with complete heat transit without its accumulation. This zone is limited to values of 5 mm from the cavity face to the die volume.

At the same time, it was proven that the distribution of tempering channels, or the distance of the tempering channel from the die face affects the length of solidification and cooling of the cast, which translates into the total duration of the casting cycle.

The results presented in this article serve as a platform for further research. The following research will be directed to the area of evaluation of the total thermal field of the die depending on the change in the die material, as well as on the weight of the cast, and thus the different thermal capacity of the metal cast into the die on the values of the temperature stress of the die and the heat transfer intensity.

Acknowledgements

Acknowledgements should be placed before references.

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