EVALUATION OF THERMAL CONDITIONS AT CAST-DIE CASTING MOLD INTERFACE

JAN MAJERNIK[1], STEFAN GASPAR[2], MARTIN PODARIL[1], TOMAS CORANIC[2]

[1]Institute of Technology and Business in Ceske Budejovice

[2]Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov

DOI: 10.17973/MMSJ.2020_11_2020041

majernik@mail.vstecb.cz

The internal structure of the castings depends on the super-cooling level of the melt upon contact with the face of the mold. In die casting technology, the relatively cold mold material comes into the contact with substantially higher temperature melt in short successive cycles. This causes high thermal fluctuations that cause cyclic thermal stress of the mold. The contribution evaluates the heat balance of the mold during casting of a particular type of the cast and describes the distribution of the temperatures in the mold volume during one casting cycle. The contribution presents a comprehensive picture of thermal processes occurring between the cast, the mold and the surroundings.

KEYWORDS

HPDC, temperature distribution, mold material, tempering

1 INTRODUCTION

The internal structure of the castings depends on the super-cooling level of the melt upon contact with the face of the mold [Turtelli 2006]. In die casting technology, the relatively cold mold material comes into the contact with substantially higher temperature melt in short successive cycles. This causes high thermal fluctuations that cause cyclic thermal stress of the mold. The contribution evaluates the heat balance of the mold during casting of a particular type of the cast and describes the distribution of the temperatures in the mold volume during one casting cycle. The contribution presents a comprehensive picture of thermal processes occurring between the cast, the mold and the surroundings.

2 HEAT BALANCE OF THE HIGH PRESSURE DIE CASTING MOLD

To ensure the quality of the casts, it is important to ensure the stability of the casting process, i.e. the cast must be cast under the stable conditions. A tempering system serves to ensure the stability of the casting process in the high-pressure casting molds. For its correct construction, it is necessary to determine the heat balance of the mold for one casting cycle. The solution of heat balance calculation considers the following assumptions:

- the die casting mold and the cast constitute a closed system that is in thermal equilibrium,
- the heat fluxes and mold pats temperatures are constant during the casting cycle,
- the temperature variation in the mold cavity surface during the casting cycle is neglected,
- the face temperature of the mold is considered to be the arithmetic mean of the temperatures on the face of the fixed and movable part of the mold,
- the temperature of tempering medium at the inlet/outlet to/from the mold is considered to be the arithmetic mean of the temperatures of the medium at inlet/outlet to/from the fixed and movable part of the mold.

From the general perspective, no thermal processes can occur between the cast and the mold by condution, convection and radiation. Based on the processes described above, it is possible to determine the heat balance of the mold for heat transfer from the solidifying cast based on the formula:

$$Q = Q_{rad} + Q_{fl} + Q_t + Q_{fr} + Q_{pist} + Q_{spr} \qquad (1)$$

where:

Q – total heat dissipated by the cast (J),
Q_{rad} – heat dissipated by radiation (J),
Q_{fl} – heat dissipated to the ambient area by flow (J),
Q_t – heat dissipated by the tempering system (J),
Q_{fr} – heat dissipated by conduction into the machine frame (J),
Q_{pist} – heat dissipated by machine piston (J),
Q_{spr} – heat dissipated by protective mold face coating spray (J).
[Novakova 2006, Pasko 2014, Mascenik 2019].

2.1 DETERMINATION OF THE AMOUNT OF HEAT DISSIPATED BY THE CAST

The total heat dissipated by the cast is given by the sum of the individual thermal energy components that the melt dissipates during the solidification and cooling process of the cast. In general, the amount of heat dissipated by the cast can be determined by the formula:

$$Q = Q_{overheat} + Q_{solid} + Q_{cooling} + Q_{frict} \qquad (2)$$

where:

$Q_{overheat}$ – heat dissipated from the overheated melt (J),
Q_{solid} – heat dissipated during solidification of the melt (J),
$Q_{cooling}$ – heat dissipated during cooling of the cast (J),
Q_{frict} – heat generated by the kinetic energy of the piston (J).

The amount of the heat generated by the friction of the piston and due to the kinetic energy is quite small and can be neglected. The amount of the heat dissipated from the overheated melt $Q_{overheat}$ can be determined by:

$$Q_{overheat} = m \cdot c_L \cdot \left(T_{cast} - T_{liq}\right) \qquad (3)$$

where:

m – weight of the melt (kg),
c_L – specific heat capacity of the melt (J.kg^{-1}.K^{-1}),
T_{cast} – casting temperature (K),
T_{liq} – liquidus temperature of the melt (K).

The amount of the heat dissipated during the solidification of the melt Q_{solid} is dependent on its volume and its latent crystallization heat:

$$Q_{solid} = m \cdot L_{SOL} \qquad (4)$$

where:

L_{SOL} – latent crystallization heat of the melt (J.kg^{-1}).

The amount of heat that will be dissipated by the cast during cooling Qcooling can be determined as follows:

$$Q_{cooling} = \Sigma Q_{cooling\_i} = \Sigma m_i \cdot c_S \cdot \left(T_{liq} - T_{per\_i}\right) \qquad (5)$$

where:

m_i – unit weight of the gating system (kg),
c_S – specific heat capacity of the melt in solid state, J.kg^{-1}.K^{-1},
T_{liq} – liquidus temperature of the melt (K),
T_{per_i} – unit temperature of the ambient (K).

2.2 DETERMINATION OF THE AMOUNT OF HEAT DISSIPATED FROM THE MOLD INTO THE AMBIENT

The amount of the heat dissipated from the mold o the ambient by radiation can be determined according to the following formula:

$$Q_{rad} = \sigma \cdot \varepsilon \cdot \left(T_o^4 - T_{per}^4\right) \cdot S \cdot t_{cycle} \tag{6}$$

where:

σ – Stefan-Boltzmann constant ($W.m^2.K^{-4}$),

ε – relative radiation (0,7 – 0,99),

T_o – object temperature (K),

T_{per} – ambient temperature (K),

S – object surface (m^2),

t_{cycle} – working cycle time (s).

The heat dissipation from the mold to the ambient by flow occurs under the influence of ambient air flow and is dependent on the thermal gradient. The amount of dissipated heat by flow can be determined as follows:

$$Q_{fl} = \alpha_P \cdot \left(T_o - T_{per}\right) \cdot S \cdot t_{cycle} \tag{7}$$

where :

α_P – flow heat transfer coefficient ($W.m^{-2}.K^{-1}$).

The flow heat transfer coefficient is determined on the basis of empirical relation:

$$\alpha_P = 1{,}77 \cdot \left(T_o - T_{per}\right)^{1/4} \tag{8}$$

The amount of heat passing through the body is directly proportional to the temperature gradient, time and to the flow area perpendicular to the direction of the temperature flow. The amount of heat dissipated from the mold to the machine frame is determined from:

$$Q_{fr} = \alpha_v \cdot \left(T_{sd-m} - T_{sm-d}\right) \cdot S_{d-fr} \cdot t_{cycle} \tag{9}$$

where:

α_v – the heat transfer coefficient from the mold surface to the machine frame ($W.m^{-2}.K^{-1}$),

Sd-fr – the area of mold and machine frame contact, m2

$S_{d\text{-}fr} = S_{sdp}$

$T_{sd\text{-}m}$ – the mold external surface temperature in contact with the machine (K),

$T_{sd\text{-}m} = T_{o\_exd}$

$T_{sm\text{-}d}$ – the machine surface temperature in contact with the mold (K),

$T_{sm\text{-}d} = T_{per}$

The amount of heat dissipated by the tempering system via the circulating medium can be determined based on the relation:

$$Q_t = m_t \cdot c_t \cdot \left(T_{out} - T_{in}\right) \tag{10}$$

where :

m_t – the weight of tempering medium (kg),

c_t – specific heat capacity of the tempering medium ($J.kg^{-1}.K^{-1}$),

T_{in} – inlet medium temperature of the tempering system (K),

T_{out} – outlet medium temperature of the tempering system (K).

The amount of heat dissipated from the mold by protective mold face coating spray can be determined as follows:

$$Q_{spr} = m_{spr} \cdot c_{spr} \cdot \left(T_{ev} - T_{spr}\right) + m_{spr\_ev} \cdot L_{ev\_spr} \tag{11}$$

where:

m_{spr} – applied coating spray weight (kg),

c_{spr} – protective coating spray specific heat capacity ($J.kg^{-1}K^{-1}$)

T_{ev} – evaporation temperature of the protective coating spray (K),

T_{spr} – initial temperature of coating (K),

s_{prt} – protective coating spray initial temperature (K),

m_{spr_ev} – evaporated protective coating spray weight (kg),

L_{ev_spr} – evaporation specific latent heat of coating ($J.kg^{-1}$).

2.3. DETERMINATION OF THE MOLD HEAT BALANCE FOR FLANGE CAST

The heat balance was determined for the mold for production of an electric motor flange cast. The alloy EN AC 47100 was used for production of the cast in high pressure die casting machine with designation Müller Weingarten 600 (Figure 1). The machine has semi-automatic operation with electronic control. It is designed for the high pressure die casting of non-ferrous metals and it is equipped with three-phase injection system with multiplier and button control. The main technological parameters are stated in Table 1.

Figure 1. High pressure die casting machine Müller Weingarten 600

Table 1. Parameters of the high pressure die casting machine

Dimensions (w/h/l)	2/3.2/8.7 m
Weight	27 t
Engine power	37 kW
Closing force	600 t
Pressing force	65 t
Ejection force	35 t
Min./max mold height	0.4/0.9 m
Max weight of cast	12 kg

The setting of the technological parameters of the casting cycle was constant during the casting process of individual groups of casts. Individual parameters and their values are listed in Table 2.

Table 2. Basic technological parameters of the casting cycle

Melt temperature in the feeding chamber	890.3 K
Mold temperature	473.2K
Pressing piston velocity	2.9 $m.s^{-1}$
Holding pressure	25 MPa
Filling time of mold cavity	0.016 s

To determine the heat dissipated by the cast according to the relation [Klobčar 2008, Majernik 2019, Wladysiak 2017, Yu 2016 and 2017]. To determine the amount of the heat dissipated by cooling of the cast according to it should be noted that each part of the cast will cool under different conditions. As an ambient temperature T_{per} was considered the average temperature of the individual parts of the inlet system just after the opening of the mold. The measured points of temperature eject after opening the mold are depicted on *Figure 2.*

The determination of heat dissipated from the mold into the ambient was realized according to the relations [Gaspar 2012, Pasko 2014, Zhi Peng 2008]. The amount of heat that is transferred from the mold to the ambient by radiation is composed of two components:

- heat transferred by radiation from the external surface of the mold during the entire cycle, Q_{rad1},
- heat transferred by radiation from the mold dividing plane during the time the mold is opened, Q_{rad2}.

To determine the total heat dissipated through radiation by mold into ambient, the modified relations has been used:

$$Q_{rad1} = \sigma \cdot \varepsilon \cdot \left(T_{o\_exd}^4 - T_{per}^4\right) \cdot S_{exd} \cdot t_{cycle} \qquad (12)$$

$$Q_{rad2} = \sigma \cdot \varepsilon \cdot \left(T_{o\_sdp}^4 - T_{is}^4\right) \cdot S_{sdp} \cdot t_{od} \qquad (13)$$

where:
T_{o_exd} – external surface temperature of the mold (K),
T_{per} – ambient temperature (K),
S_{exd} – contact area of the mold with ambient (m^2),
T_{o_sdp} – mold temperature in dividing plane (K),
T_{is} – mold cavity temperature during the opening (K),
S_{sdp} – dividing plane area of the mold (m^2),
t_{od} – time, during which the mold is open (s).

As in the previous case, the total heat dissipation by flow has to be considered in two components:

- heat transferred by flow from external surface of the mold during the entire cycle Q_{fl1},
- heat transferred by flow from the mold dividing plane during the time the mold is open Q_{fl2}.

Following modified relations are used to determine the total heat dissipated by flow into the ambient:

$$Q_{fl1} = \alpha_P \cdot \left(T_{o\_exd} - T_{per}\right) \cdot S_{exd} \cdot t_{cycle} \qquad (14)$$

$$\alpha_{P1} = 1{,}77 \cdot \left(T_{o\_exd} - T_{per}\right)^{1/4} \qquad (15)$$

$$Q_{fl2} = \alpha_P \cdot \left(T_{o\_sdp} - T_{is}\right) \cdot S_{sdp} \cdot t_{od} \qquad (16)$$

$$\alpha_{P2} = 1{,}77 \cdot \left(T_{o\_sdp} - T_{is}\right)^{1/4} \qquad (17)$$

where:
T_{o_exd} – external surface temperature (K),
T_{o_sdp} – mold face temperature (K),
T_{is} – cavity temperature during the time the mold is open (K).

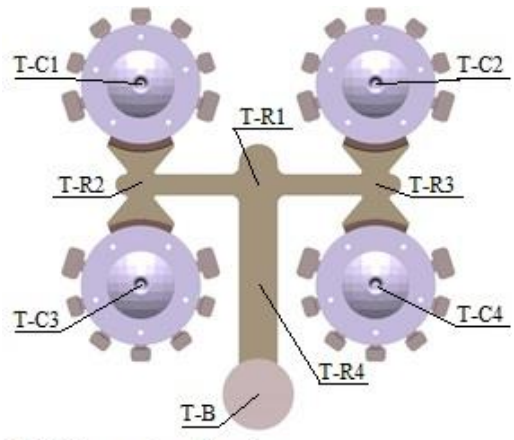

Figure 2. Temperature measurement points after mold opening

Table 3 contains the values used to calculate the heat balance of the high pressure die casting mold.

Table 3. Values used to calculate the heat balance of high pressure die casting mold

m	1,18 kg
$m_{casting}$	0,424 kg
m_{runner}	0,544 kg
$m_{biscuit}$	0,212 kg
T_{melt}	890.3 K
T_{liq}	858.15 K
T_{cast}	513.85 K
T_{runner}	586.85 K
$T_{biscuit}$	617.45 K
L_{SOL}	497000 J.kg^{-1}
c_L	1131 J.kg^{-1}.K^{-1}
c_S	1080 J.kg^{-1}.K^{-1}
σ	5,67.10^{-8} W.m^2.K^{-4}
ε	volená hodnota 0.85
T_{o_exd}	433.15 K
T_{per}	302.15 K
T_{o_sdp}	473.2K
T_{is}	253.15 K
t_{cycle}	39.134 s
t_{od}	16.012 s
S_{exd}	0.75 m^2
S_{sdp}	0.72 m^2
α_v	15 W.m^{-2}.K^{-1}
m_{spr}	0.43 kg
c_{spr}	4186 J.kg^{-1}.K^{-1}
L_{ev_spr}	2253000 J.kg^{-1}
T_{spr}	298.15 K
T_{ev}	373.15 K
c_t	2501 J.kg^{-1}.K^{-1}
m_t	5 kg
T_{in}	463.15 K
T_{out}	447.15 K

Based on above mentioned relations, the individual heat components in heat balance of the mold were determined according to the relation (1) as presented in Table 4.

Table 4. Overview of heat components heat balance values of the high pressure die casting mold

Q	Total heat dissipated by casting	1001555.86 J
Q_{rad}	Total heat dissipated into ambient by radiation	57209.8 J
Q_{fl}	Total heat dissipated ito ambient by flow	31127.52 J
Q_t	Total heat dissipated by tempering system	- 200080 J
Q_{fr}	Total heat dissipated by conduction into the machine frame	55366.78 J
Q_{spr}	Total heat dissipated by protective mold face coating spray	1055300 J
Q_{ALL}	**Total heat dissipated into ambient by individual components**	**998924.1 J**

The difference in results between Q and Q_{ALL} is due to a disregard of the heat value that is dissipated by the machine piston and at the same time due to possible inaccuracies in the experimental temperature determination. As can be seen from the calculation of the heat dissipation by the tempering system, the value of the heat Q_t = - 200080 J. Based on the calculation, it can be stated that the tempering system does not dissipate the heat from mold, but on the contrary, it supplies it to the mold.

3 TEMPERATURE DISTRIBUTION EVALUATION INTO THE MOLD VOLUME

The knowledge of the mold heat balance provides an indication of how much heat is transferred in the casting – high pressure die casting mold assembly and how it is dissipated from the system. In order to optimize the design of runners, it is preferable to know the temperature influence of the individual mold zones. Temperature measurement is the most difficult task in determining the interfacial heat transfer in HPDC [Majernik 2019, Yu 2016, Krenicky 2011]. A group of authors led by ZHI-PENG designed a special temperature sensor unit (TSU) to obtain a sufficiently fast response to the HPDC process and accurate temperature measurement inside the mold. Using the TSU the temperature at 1, 3 and 6 mm from the surface to the mold volume were measured [Zhi Peng 2008]. Our examination of distribution and temperature change in individual mold zones was inspired by this kind of measurement. The temperature was monitored at two selected locations (*Figure 3*), with a distribution of 1mm, 2mm, 5mm, 10mm a 20mm in the direction from the surface of the die cavity to the volume of the fixed and movable mold parts.

Measurement points were distributed in a line perpendicular to the dividing plane of the mold. Adjusting of the technological parameters is presented in *Table 2 and Table 3*. The cross-section of the tempering channels in the fixed part of the mold is 10mm, in the movable part is 9mm. As comparative parameters, the temperature of the melt in the center of the main runner above measurement point and the temperature of the melt close to the mold face were monitored. In total, the temperature was monitored at 26 measurements points and evaluated. The measurement was performed using the Magmasoft MAGMA5 – HPDC module.

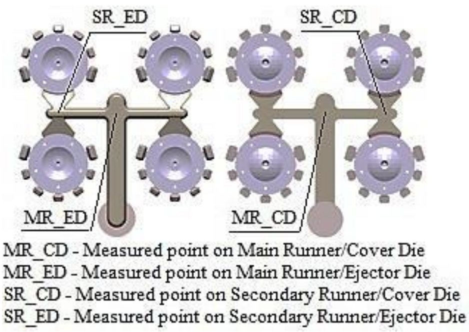

Figure 3. Temperature distribution measurement points

3.1. MEASUREMENT RESULTS

Based on measurements performed on the selected system, the course of temperature at individual measurement points was evaluated. Table 5 depicts the measured temperature change in values.

As arises from Table 5, the surface layers of the mold near the work cavity of the mold are stressed by the temperature fluctuation ΔT above 200 °C. The results in Table 5 are presented as absolute temperature values for each measurement point. To understand the development of temperature change, a graphical dependence of the temperature change over time has been created for each measurement point, Figure *4*. From *Figure 4* arises that the mold temperature is at a constant level during the filling phase, more precisely that the layer just below the surface heats up only minimally.

Table 5. Temperature change at measurement points

Measurement Point	Tmax, °C	Tmin, °C	ΔT, °C
MR_CD – 1mm	460.2	219.3	240.9
MR_CD – 2mm	441.3	220.4	220.9
MR_CD – 5mm	393.2	226.9	166.3
MR_CD – 10mm	339.0	241.3	97.7
MR_CD – 20mm	279.9	249.2	30.7
MR_ED – 1mm	461.7	219.1	242.6
MR_ED – 2mm	442.8	220.1	222.7
MR_ED – 5mm	393.9	226.5	167.4
MR_ED – 10mm	336.3	241.9	94.4
MR_ED – 20mm	279.4	249.6	29.8
SR_CD – 1mm	417.5	178.6	238.9
SR_CD – 2mm	389.0	179.5	209.5
SR_CD – 5mm	329.3	184.3	145.0
SR_CD – 10mm	272.8	194.4	78.4
SR_CD – 20mm	217.7	196.6	21.1
SR_ED – 1mm	395.5	191.5	204.4
SR_ED – 2mm	370.7	192.4	178.3
SR_ED – 5mm	317.3	197.7	119.6

Intensive temperature increase is the mold volume occurs only during the solidification phase. In places where the temperature courses at each measurement point intersect, it is possible to determine the temperature progression into the mold volume, reflecting the heat transfer from the surface of the die cavity of the mold into the mold mass. The temperature drop between the end of the solidification phase and the start of the filling phase occurs in time during which the mold is open. The casting is ejected from the mold and the mold is being treated by spraying and blasting. The face of the mold is thus cooled in this phase due to the ambient air temperature, due to the temperature of the medium during spraying and due to the air pressure during blasting.

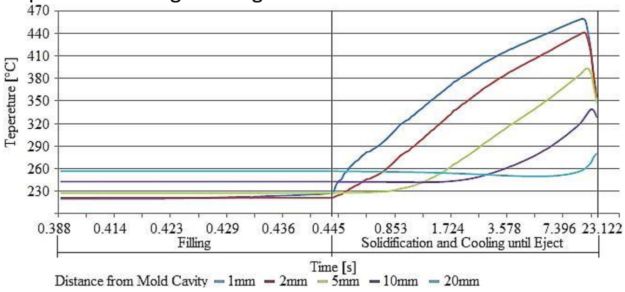

Figure 4. Temperature development Main Runner/Cover Die

The highest temperature gradient between the melt temperature and the mold face is at the beginning of solidification phase. *Figure 5* depicts the temperature gradient between the main runner and cover die.

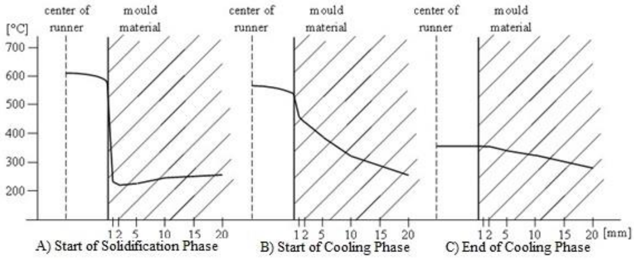

Figure 5. Temperature gradient Main Runner / Cover Die

As arises from Figure 5, at the beginning of solidification, as the distance from the mold face increases, so does the temperature. Explanation can be found in the heat balance evaluation of the mold. As presented in the Section 2.3, Table 4. The tempering system supplies the heat to the mold (see Q_t). The measurement point located 20mm from the mold face is located near the tempering channel, and thus the influence of Q_t is more pronounced. Also, the mold itself, by cyclically repeated heating under the influence of heat transferred from the melt, behaves as an accumulator. Therefore, the temperature at the start of the solidification in the mold volume is higher than the temperature at the surface of its cavity. Thus, by regular working cycles, the temperature in the mold volume is at relatively constant level, with an average temperature fluctuation in the range of 15 – 30°C, which is depicted by graphical representation of the temperature gradient in the various phases of the casting cycle in *Figure 5*.

4 ANALYSIS OF ACHIEVED RESULTS

Based on the experiment conducted with the intention of determination of the thermal balance of the mold, it can be stated that the high pressure die casting is a thermal process very difficult to observe by the measurement technique. The metal mold must be considered both as a conductor and as a heat accumulator. The melt transfers large amount of heat to the mold cavity during one casting cycle because the conditions are created to transfer the heat from the melt as quickly as possible. The complexity of the heat balance calculation lies in a very fast, cyclical and non-stationary thermal processes between the melt and the mold face, making the mathematical solution very problematic. A simplified calculation methodology is presented in Chapter 2. The individual components of the heat transferred from the mold are shown in *Table 4*. A graphical representation of the individual components percentage of transferred heat from the mold is depicted in *Figure 6*. The highest proportion of heat is dissipated by the mold protective coating spray followed by the radiation from the mold surface, conduction of heat through the machine frame and the smallest heat component is the heat dissipated from the mold by flow. As shown by the calculation, the tempering system supplies the heat to the mold.

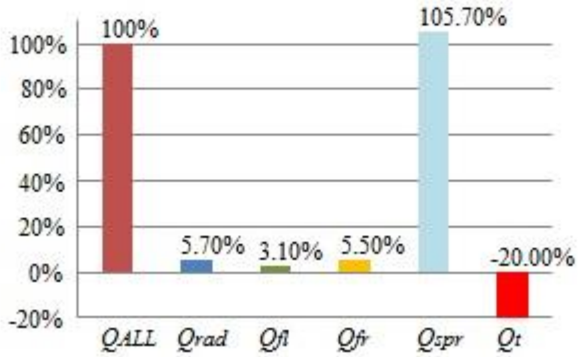

Figure 6. Transferred heat from the mold

The determination of the mold heat balance is giving the quantitative picture about the heat transfer between the casting, mold and the ambient, but does not give us information about the heat transfer and temperature changes in the individual mold volume zones. The magnitude of the temperature change in each zone according to the selected location of measurement points is presented in *Table 5*. It is possible to state that alternating heating and cooling during one work cycle causes a considerable temperature variation at the depth of up to 5mm and at depth less than 10mm. Of course, this alternating thermal stress is mostly pronounced at the mold face, where the temperature of the mold surface layers is close to the temperature of the melt. At a distance of 20mm from the die cavity, the heat supplied by the mel tis gradually transferred to the entire mold mass without significant thermal fluctuations. *Figure 4* depicts the temperature course at each of the measurement points during the work cycle. It should be noted that the temperature was only recorded at the time when mold was closed. A significant change in temperature of the mold material is ongoing during the solidification and cooling phase, where the heat transfer from the casting to the mold volume is the most intense.

The magnitude of the melt supercooling upon a contact with the mold face determines the casting structure. Thus, the magnitude of the temperature gradient between the melt and the die cavity surface affects the grain size in the casting walls. The higher the supercooling of the melt, the finer the grain structure of the castings, which results in an increase in their surface hardness. In practice, it is preferred to set the mold temperature to 1/3 of the melt temperature [Gaspar 2012, Majernik 2019]. In our experiment, this condition was maintained. By comparing the temperature gradient according to *Figure 5/A)* and the results obtained during the experiment, it was found that the temperature difference between the melt and the subsurface mold face layer at the end of the filling phase is an average of 420°C at the location of secondary runner and 380°C at the location of main runner.

5 CONCLUSIONS

This contribution is devoted to the evaluation of thermal conditions at the casting – die casting mold interface. It is conceptually divided into two parts, namely to assess the heat balance of the mold and visualize the temperature distribution in the mold volume. Based on the performed calculations and measurements with the support of the simulation program Magmasoft it is possible to state conclusions into following points:

1.) Simplified methodology of heat balance calculation is verified and refined. The correctness of the calculation methodology is confirmed by the match between the heat transferred to the mold Q and the total dissipated heat from the mold Q_{ALL}.

2.) It is advantageous to visualize the temperature distribution into the mold volume using the CAE support in the foundry industry.

3.) When evaluating the temperature distribution into the mold volume, it is not appropriate to focus solely on the absolute temperature values at the selected measurement points, but the overall temperature course during the casting cycle as well as the temperature gradient should be taken into the account to help us predict the internal structure of the casting.

4.) The distribution and design of the tempering channels have significant influence on the temperature field change in the mold volume and the associated heat dissipation. As has been proven, the smaller the distance between the die cavity wall and the tempering channel, the smaller the temperature difference in the mold volume. It is therefore appropriate to dimension the tempering channels as close to the die cavity as possible. This gives us more temperature-balanced mold, which will produce the same quality castings in individual castings cycles without high internal stresses.

Results presented in this contribution serve as a platform for further research. A methodology for evaluating the thermal stress of the molds/temperature distribution into the mold volume is introduced to highlight important factors affecting the mold temperature equilibrium. The following research will be directed to the evaluation of the overall thermal field of the mold as a function of the mold material change, the design and distribution of tempering channels in the mold and their distance from the die cavity.

ACKNOWLEDGEMENT

This article has been prepared within the project VEGA 1/0116/20.

REFERENCES

[Gaspar 2012] Gaspar, S., et al. Dependence of pressure die casting quality on die casting plunger velocity inside a filling chamber of a pressure die casting machine. Journal of Computational and Theoretical Nanoscience, 2012, Vol. 14, No. 1, pp. 499-502. ISSN 1936-6612.

[Gaspar 2017] Gaspar, S., et al. Influence of structure adjustment of gating system of casting mould upon the quality of die cast. Lüdenscheid: RAM Verlag, 2017. ISBN 978-3-942303-47-7.

[Klobcar 2008] Klobcar, D., et al. Thermal stresses in aluminium alloy die casting dies. Computational Materials Science, 2008, Vol. 43, No. 4. ISSN 1147–1154.

[Krenicky 2011] Krenicky, T. Implementation of Virtual Instrumentation for Machinery Monitoring. In: Scientific Papers: Operation and Diagnostics of Machines and Production Systems Operational States: Vol. 4, RAM-Verlag, Lüdenscheid, 2011, pp. 5-8. ISBN 978-3-942303-10-1.

[Majernik 2019] Majernik, J., et al. Evaluation of the Temperature Distribution of a Die Casting Mold of X38CrMoV5_1 Steel. Archives of Foundry Engineering, 2019, Vol. 19, No. 1, pp. 107-112. ISSN 2299-2944.

[Mascenik 2019] Mascenik, J., Pavlenko, S. Innovative broad - Spectrum testing and monitoring of belt transmissions. MM Science Journal, 2018, Vol. 11, No. 5, pp. 2706-2709. ISSN 1803-1269.

[Novakova 2006] Novakova, I. The thermal and pressure conditions in the system casting - casting tool during the high pressure die casting of the alloys of alluminium with silicon: dissertation thesis. Liberec, Czech Republic: Technical University of Liberec, 2006.

[Pasko 2014] Pasko, J., Gaspar, S. Technological Factors of Die Casting. Lüdenscheid: RAM Verlag, 2014. ISBN 978-3-942303-25-5.

[Turtelli 2006] Turtelli et al. Magnetic and structural characterization of as-cast and annealed melt- spun Fe80-xSi20Crx. Journal of Magnetism and Magnetic Materials, 2006, Vol. 304, No. 2, pp. E687-E689.

[Wladysiak 2017] Wladysiak, R., Kozun, A., Pacyniak, T. The Effect of Water Mist Cooling of Casting Die on the Solidification, Microstructure and Properties of AlSi20 Alloy. Archives of Metallurgy and Materials, 2017, Vol. 62, No. 1, pp. 187-194. ISSN 1733-3490.

[Yu 2016] Yu, W.-B., et al. Development and application of inverse heat transfer model between liquid melt and shot sleeve in high pressure die casting process under non-shooting condition. China Foundry, 2016, Vol. 13, No. 4, pp. 269-275. ISSN 1672-6421.

[Yu 2017] Yu, W.-B., et al. Interfacial heat transfer behavior at metal/die in finger-plated casting during high pressure die casting process. China Foundry, 2017, Vol. 14, No. 4, pp. 258-264. ISSN 1672-6421.

[Zhi-Peng 2008] Zhi-Peng, G., et al. Determination of the heat transfer coefficient at metal–die interface of high pressure die casting process of AM50 alloy. International Journal of Heat and Mass Transfer, 2008, Vol. 51, No. 25-26., pp. 6032-6038. ISBN 978-3-942303-47-7.

CONTACT:

Ing. Jan Majernik, PhD.
Institute of Technology and Business in České Budějovice
Okružní 517/10, 37001 České Budějovice
majernik@mail.vstecb.cz