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Umerjanje numeričnega izračuna za optimizacijo procesa litja grelne plošče

Numerical Calculation Calibration for Optimization of Foundry Technology of a Heat Plate

Povzetek

Numerični izračuni pri načrtovanju ali optimizaciji livarske tehnologije lahko bistveno pomagajo pri razumevanju problematike, ki na prvi pogled ni najbolj očitna. Numerični izračuni livarskih procesov nam danes nudijo vpogled v posamezno sekvenco litja na način, ki nam pomaga odkriti in razumeti vzroke za nastale napake. Z razumevanjem vzrokov napak se lahko učinkovito lotimo optimizacije procesa in novo tehnologijo preizkusimo najprej v virtualnem okolju, z izračunom z optimiziranimi robnimi pogoji. Na ta način lahko pri razvoju in/ali optimizaciji posamezne tehnologije učinkoviteje porabimo čas in sredstva.

Stopnja zaupanja v pravilnost rezultatov numeričnega izračuna je v veliki meri odvisna od samokritičnosti inženirja, ki rezultate analizira in jih vrednoti. Natančnost izračuna je lahko samo toliko dobra, kolikor so dobri začetni in robni pogoji problema. Sem spadajo tudi zbirke podatkov o lastnostih uporabljenih materialov – zlitin in ostalih pomožnih livarskih materialov. Za določene vhodne parametri pa obstajajo priporočene vrednosti, ki pa jih je treba potem izkustveno kalibrirati in umeriti za določeno tehnologijo litja in glede na specifičnost posameznega proizvodnega procesa v posamezni livarni.

V predstavitvi je predstavljeno umerjanje prestopnostnega koeficienta na meji med peščeno formo in ulitkom. Umerjanje koeficienta je bilo izvedeno tako, da smo na več natančno določenih mestih v peščeni formi izmerili temperaturo med litjem in ohlajanjem ulitka. Izmerjene rezultate smo nato primerjali z numerično izračunanimi. Glede na primerjavo izmerjenih temperatur smo ustrezno kalibrirali prestopnostni koeficient, tako da so se izračunane temperature ujemale z izmerjenimi. Proces umerjanja prestopnostnega koeficienta smo izvedli skupaj z optimizacijo dovodnega kanala na primeru litja grelnih plošč za odpravo poroznosti na mestu pripetja.

Ključne besede: gravitacijsko litje, siva litina, umerjanje prestopnostnega koeficienta, optimizacija livarskega procesa

Abstract

Numerical calculations in the designing and optimization of foundry technologies can contribute significantly to help understand a problem that is not apparent at first glance. Numerical calculation of the foundry process is now able to show us in detail every sequence of the process so that we can discover and understand the root cause of the problem. With an understanding of the root cause of the failure, we can effectively optimize the process. The new technology can then be virtually tested by numerical calculation using new optimized boundary conditions. In this way, we can significantly reduce the time and cost of developing a new process or optimizing an existing technology.

Confidence in the accuracy of the results of the numerical calculation depends on the self-criticism of the user who analyses the results. The accuracy of the numerical calculation can be as good as the initial and boundary conditions are accurate. The accuracy of the results also depends on the material properties in the database – the alloys used and the properties of other foundry materials. For some of the input parameters, there are only recommended values that need to be calibrated for a particular technology and a particular technology in a particular foundry.

In this presentation, the calibration of the heat transfer coefficient at the boundary between sand mold and casting is presented. The calibration was performed by measuring the temperatures in the sand mold at several points during casting, solidification, and cooling of the casting. The measured temperatures were then compared to the calculated temperatures. The heat transfer coefficient was calibrated so that the calculated temperatures matched the measured temperatures. The process of calibrating the heat transfer coefficient was performed together with the optimization of the gating system of a heat plate to eliminate porosity in the casting.

Keywords: gravity casting, gray iron, heat transfer coefficient calibration, casting technology optimization

1 Uvod

Livarne si pri načrtovanju livarske tehnologije za posamezni ulitek pomagajo z numeričnimi izračuni že v fazi izdelave ponudbe. Na ta način lahko zelo hitro ugotovijo, kje se bodo lahko pojavila kritična mesta, ki bi lahko povzročala težave pri proizvodnji. Livarne, ki začnejo z uporabo numeričnih izračunov, hitro ugotovijo, da prednosti, ki jih prinašajo rezultati numeričnih izračunov, niso samo prednost pred konkurenco, ampak obvezen tehnološki korak za zgodnje odkrivanje morebitnih težav pri izdelavi ulitkov. Razvoj programskih paketov v zadnjem desetletju sledi potrebam livarn, da zagotovijo podporo in računanje vseh livarskih tehnologij. Večina programskih paketov pokriva več ali manj vse livarske tehnologije, posamezni paketi pa lahko omogočajo samo natančno določeno livarsko tehnologijo. Programski paketi za reševanje temeljijo na različnih numeričnih metodah; metodi končnih

1 Introduction

When designing foundry technology, foundries rely on numerical calculations from the early stages of offer preparation. With this approach, they can very quickly discover the critical areas where challenges might arise in the production process. Foundries using numerical analysis are discovering that the benefits of numerical analysis are not only an advantage over the competition but also a must for early detection of the potential challenges in casting production. Software development in the last decade follows the foundries' need to support the analysis of all foundry technologies. Most foundry software can calculate the basic foundry technologies, and some are also able to calculate the special foundry technologies. The software is based on the solution of differential equations using various methods; finite difference method, finite element method, finite volume method, etc. [1, 2]. Basic diferenc, metodi končnih elementov, metodi končnih volumnov in podobno [1, 2]. Poleg osnovnega izračuna livarskih napak, kot so plinska in krčilna poroznost, analiza toka taline, prikaz temperaturnega polja v ulitku in/ali v kokili oz. formi, lahko izračunamo deformacijo ulitka in izračunamo nastale napetosti. Iz rezultatov lahko predvidimo lokacijo napake, zaostale napetosti, velikost in amplitude deformacije ter napovemo mikrostrukturo in mehanske lastnosti.

Za najbolj optimalne rezultate uporabe numeričnega izračuna je treba numerične simulacije vključiti že na začetku izdelave ali celo že pri samem dizajniranju ulitka [3]. V prvi simulaciji se izračuna samo strjevanje samega ulitka, da bi ugotovili najbolj kritična mesta. Nato sledi izdelava ulivno-napajalnega sistema. Uporaba numeričnega izračuna je zelo uporabna tudi pri reševanju problemov pri obstoječi proizvodnji ulitkov, saj lahko z analizo rezultatov numeričnega izračuna vidimo procese in pojave, na katere brez simulacije na prvi pogled ne bi nikoli pomislili. Analiza simulacije obstoječega stanja proizvodnje ulitka nam lahko zelo hitro in enostavno da odgovore, zakaj je prišlo do določene napake. Še več, zelo hitro lahko opredelimo potrebne spremembe, ki bodo nastalo napako minimizirale ali celo odpravile.

Zanesljivost in točnost numeričnih izračunov je seveda v veliki meri odvisna od uporabljenih robnih in začetnih pogojev kot tudi od izkušenj in znanja inženirja, ki izračun pripravi in analizira. Uporabljene materialne lastnosti za standardne zlitine in pomožne livarske materiale so iz baze podatkov, ki so del simulacijskega programa [4]. Za opredelitev določenih robnih in začetnih pogojev pa so določene priporočene vrednosti, ki pa jih mora nato fino nastaviti sam uporabnik, za kar pa potrebuje precej izkušenj. Primer takih robnih oz. začetnih pogojev je prestopnostni koeficient na

results of numerical calculation include gas and shrinkage porosity, melt flow analysis, temperature distribution in the melt, solid casting, and mold or die. Advanced results also include stress calculation, which allows us to analyze casting deformation and stresses in the casting and mold. From the analysis of numerical results, we can predict the location of defects, residual stresses, magnitude and direction of deformation, microstructure, and mechanical properties.

To obtain optimal results from numerical calculations, it is necessary to include the calculations in the early stage of foundry technology preparation or even at the casting design [3]. In the first calculation, only the solidification of the casting without a gating system is calculated to define the critical areas on which we should focus when defining the gating system. Numerical analysis is also very useful to solve problems in existing casting production, because with numerical results we can see the processes and things from a different perspective, and without numerical results, the problem would be more difficult to solve. Analyzing the current production process can give us very quick and easy answers to why some problems occur. Even more, with the right knowledge we can quickly define the right changes that will minimize the error or even eliminate the error.

The accuracy of numerical results depends entirely on the boundary and initial conditions used and, on experience and knowledge of the engineer performing the calculations and analyzing the results. Most of the required material properties for standard casting alloys and foundry auxiliaries are included in the casting simulation software in the standard database [4]. There are some general recommendations for defining some boundaries and initial conditions, which the user must fine-tune based on his technical kontaktni meji med dvema snovema – konkretno na kontaktni meji med formo iz peščene mešanice in ulitkom iz sive litine. Fina nastavitev prestopnostnega koeficienta za posamezno tehnologijo v livarni se izvede z referenčno meritvijo temperature v formi in ulitku ter primerjavo numerično izračunanih vrednosti na istih mestih. Z ustreznim spreminjanem prestopnostnega koeficienta je lahko razlika med izmerjenimi in izračunanimi temperaturami minimalna.

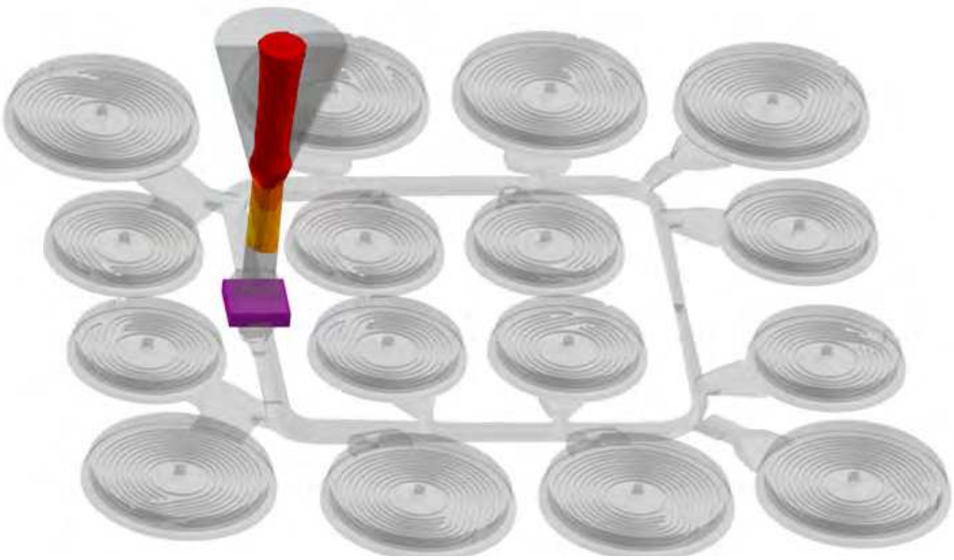
2 Eksperimentalno delo

Umerjanje prestopnostnega koeficienta je bilo izvedeno na primeru optimizacije litja grelne plošče iz sive litine z lamelnim grafitom. Forma je narejena na avtomatski formarski napravi s horizontalno delilno ravnino. Pojavlja se napaka krčilne poroznosti v ulitku, kar prispeva k večjemu izmetu v sami livarni. Napaka je posledica krčilne poroznosti, ki nastane na mestu

experience. An example of such a boundary condition is the heat transfer coefficient at the boundary between two different volumes that are in contact, e.g., at the boundary between sand mold and gray iron casting. Accurate fine-tuning of the heat transfer coefficient for a particular foundry can be done by measuring the temperature during pouring and solidification in the mold and then comparing it to the numerically calculated results at the same location where the measurement was made. The change in the heat transfer coefficient must be made so that the calculated temperature curve matches the measured one.

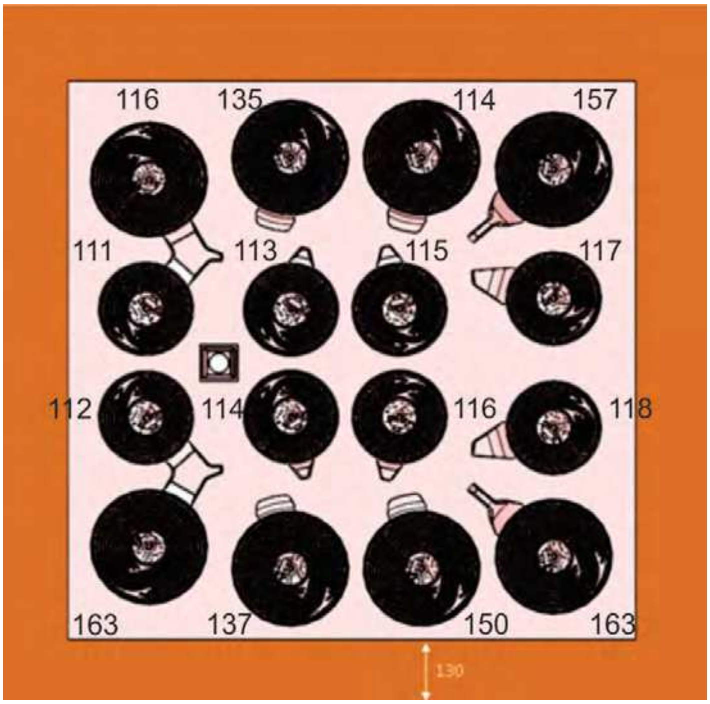
2 Experimental

The calibration of the heat transfer coefficient was carried out using the casting of a heat plate made of lamellar gray iron as an example. The mold was made on an automatic molding machine with a



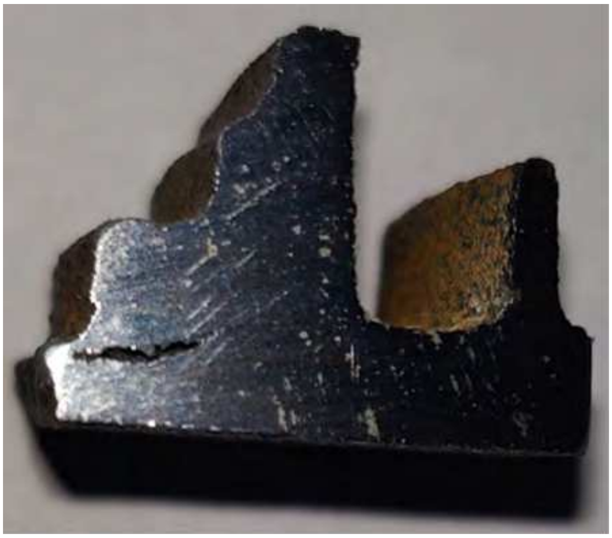
Slika 1. 3-D model z ulitki grelnih plošč in elementi ulivno-napajalnega sistema.

Figure 1. 3D model with heat plates and gating system.



Slika 2. Postavitev in oznaka grelnih plošč v formi.

Figure 2. Position and heating plate marking.



Slika 3. Slika prereza skozi grelno ploščo št. 157 (180 mm), na kateri je vidna krčilna poroznost v bližini dovodnega kanala.

Figure 3. Heating plate no. 157 (180 mm) cross-section where shrinkage porosity at the casting inlet can be seen.

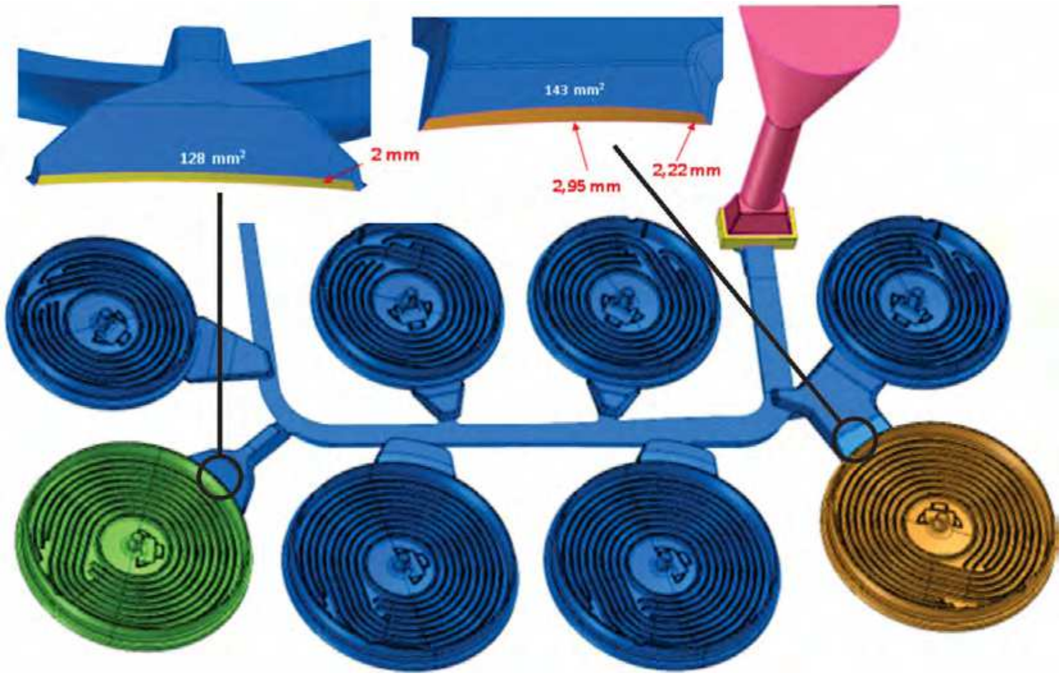
med dovodnim kanalom in ulitkom. V formo se hkrati ulije osem grelnih plošč premera 180 mm in osem grelnih plošč premera 145 mm. Velikost forme je 900 x 900 mm. Na

horizontal dividing plane. The defect in the casting is shrinkage porosity, which is the main cause of rejects in the foundry. The defect in the hotplate occurs when the sliki 1 je 3-D model z ulitki grelnih plošč ter elementi ulivno napajalnega sistema.

Kritična mesta so se pojavljala praktično na vseh modelih plošč obeh premerov, največ napak pa je bilo na mestih, najbolj oddaljenih od ulivne čaše (slika 2 – skrajno desno), t.j. na ulitkih št. 163 ter št. 157. Krčilno poroznost lahko vidimo na Sliki 3. Slika 3 predstavlja prerez ulitka na mestu dovodnega kanala, kjer vidimo, da je krčilna poroznost v ulitku ter se nadaljuje do dovodnega kanala. Dovodni kanal se v nadaljnji obdelavi mehansko obdela s

casting is connected to the gating system. In the mold, there are a total of eight heating plates with a diameter of 180 mm and eight heating plates with a diameter of 145 mm. The size of the mold is 900 x 900 mm. Figure 1 shows a 3D model with castings and a gating system.

Critical areas for defects are found on all castings of both diameters, but the greatest porosity was on a casting farthest from the spur (Figure 2 – right), labeled 163 and 157. Shrinkage porosity can be seen in Figure 3. Figure 3 shows the cross-



Slika 4. Geometrija in dimenzije dovodnega kanala.

Figure 4. Geometry and dimensions of the inlet.

Preglednica 1. Kemijska sestava uporabljene sive litine.

Table 1. Chemical composition of used gray iron.

C	Si	Cr	Mn	S	P
3,4	2,15	0,41	0,75	0,1	0,3

struženjem, kar odpre krčilno poroznost in se jo lahko opazi s prostim očesom na površini grelne plošče. Taka plošča je kakovostno neustrezna in predstavlja izmetni ulitek.

Na Sliki 4 je prikazana geometrija obstoječega stanja litja skupaj z ustreznimi geometrijami in dimenzijami dovodnega kanala, ki je bila uporabljena tudi za numerični izračun in umerjanje prestopnostnega koeficienta.

Za numerično analizo litja smo uporabili progam ProCAST. Materialne lastnosti za obravnavno kemijske sestave sive litine iz Preglednice 1 in bentonitno peščeno mešanico smo izbrali iz standardne zbirke programa. Začetna temperatura za simulacijo je bila opredeljena pri 1400 °C. V realnosti zaradi neogrevanega livnega avtomata temperatura litja variira med 1380 °C in 1470 °C. Vse ostale začetne temperature so bile v simulaciji nastavljene na 30 °C.

2.1 Merjenje temperature v formi

Za natančno opredelitev prestopnostnega koeficienta, ki pomembno vpliva na natančnost numeričnega izračuna, smo v

section of the casting at the gate where the shrinkage porosity begins in the casting and ends in the inlet. The casting is machined and after machining the porosity can be seen at the inlet. This defect is not suitable and the casting is rejected.

Figure 4 shows the geometry of the inlet for the original casting technique with the corresponding geometry and dimensions. This geometry was used to calibrate the heat transfer coefficient and temperature measurements.

The numerical calculations were performed using ProCAST software. The material properties for the gray iron used with the chemical composition in Table 1 and the bentonite sand were used from the standard database of the program. The pouring temperature for the simulation was set at 1400 °C. In practice, the pouring temperature varies between 1380 °C and 1470 °C because the ladle is not heated. All other initial temperatures were set to 30 °C.

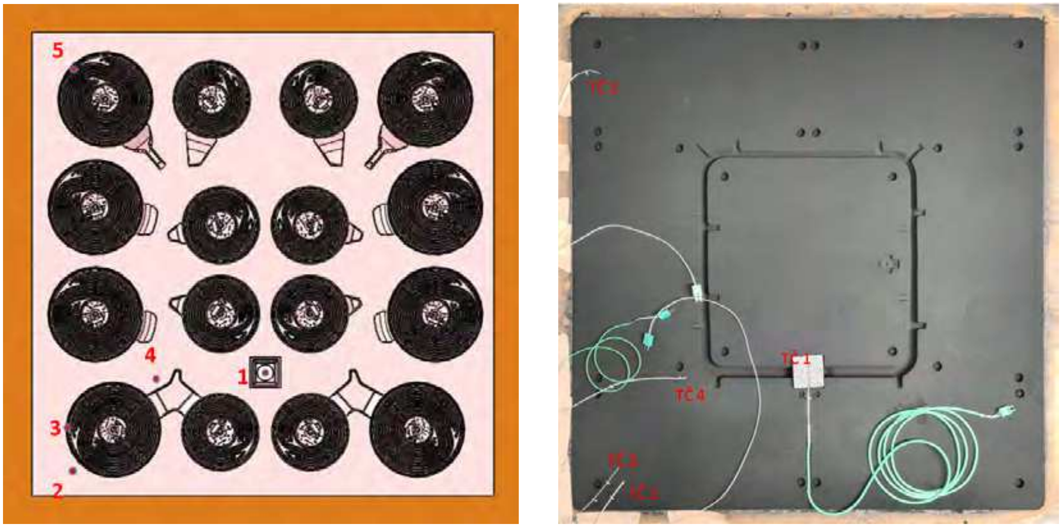
2.1 Measurements in the Mold

To accurately determine and calibrate the heat transfer coefficient, which is an important factor for accurate numerical

Preglednica 2. Položaj termoelementa v formi.

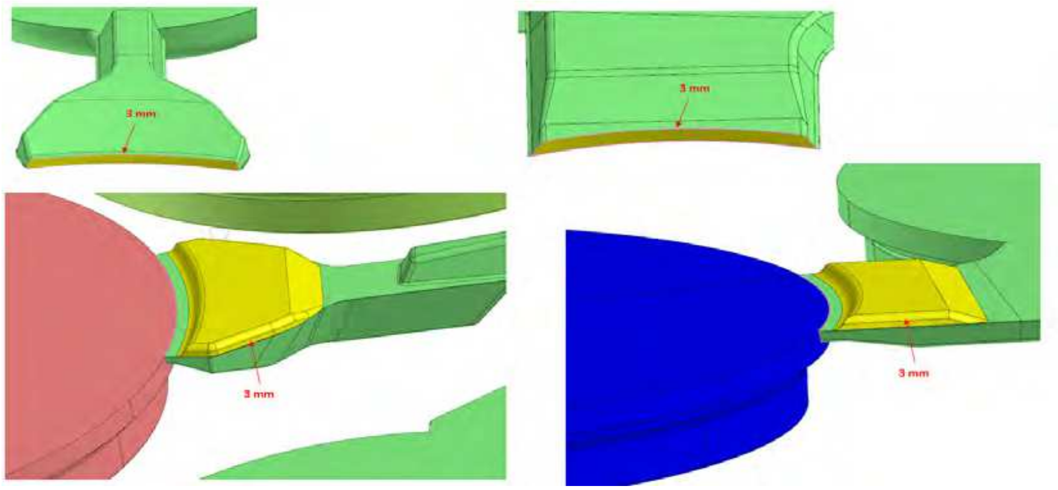
Table 2. Position of thermocouples in the mold.

Št. / No.	Opis položaja termoelementa / Position description
1	Temperatura pod livno čašo, kjer smo izmerili livno temperaturo / The temperature under the spur where the pouring temperature was measured
2	Temperatura v formi, kjer smo določili prestop toplote z ulitka na formo / The temperature in the mold, for heat transfer calibration
3	Temperatura v ulitku / The temperature in the casting
4	Temperatura v formi, kjer smo določili prestop toplote z ulitka na formo / The temperature in the mold, for heat transfer calibration
5	Temperatura v ulitku, da smo izmerili padec temperature / The temperature in the casting, to determine the temperature drop



Slika 5. Postavitev termočlenov v formo: skica (levo), eksperiment (desno).

Figure 5. Thermocouple position in the mold: sketch (left), experiment (right).



Slika 6. Optimiziran dovodni kanal različice 1 za ulitka 157 in 116 (oznake s Slike 2).

Figure 6. Gate optimization version 1 for casting no. 157 and 116 (marked in Figure 2).

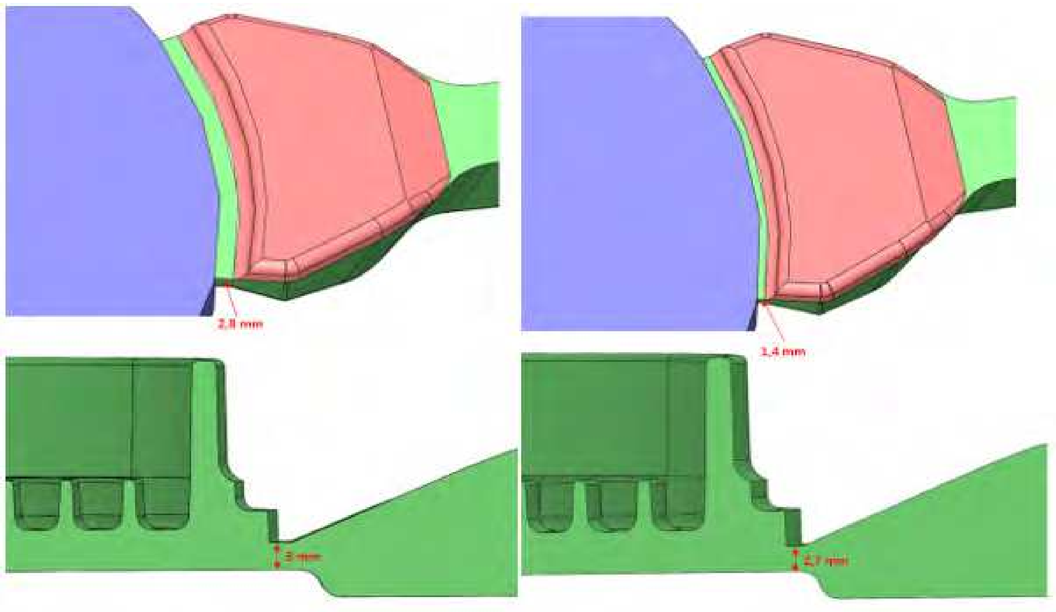
formi med rednim proizvodnim procesom namestili termočlene in merili temperature od litja do konca strjevanja. Meritev smo s tremi različnimi termočleni izvedli na petih različnih mestih v formi. Na mestu ena smo

calculation results, temperatures in the mold were measured with thermocouples during the pouring and solidification on the production line. The temperature was measured at five locations in the mold uporabili termoelement tip K, oplaščen z inoksom premera 3 mm. Na mestu dva in štiri smo uporabili termoelement tip K, oplaščen s steklenimi vlakni premera 1 mm, na mestu tri in pet pa smo uporabili termoelement tip K, oplaščen z inoksom premera 1 mm. Položaji termočlenov so prikazani na Sliki 5. Podatke smo zajemali z analogno-digitalnim pretvornikom proizvajalca National Instruments tip NI9213 in programom Labview. Frekvenca meritev je bila 50 Hz. Položaj termočlenov je opisan v Preglednici 2 in shematsko prikazan na Sliki 5.

2.3 Optimizacija dovodnega sistema

Obstoječe stanje dovodnih kanalov s Slike 4 ni optimalno in ima za posledico krčilno

using three different thermocouple types. At the first location, a type K thermocouple with a 3 mm diameter stainless steel coat was used. At locations two and four, a fiberglass-coated type K thermocouple with a diameter of 1 mm was used. Type K thermocouples with 1 mm stainless steel coat were used at locations three and five. The location of the thermocouples is marked in Figure 5. The measurement data were recorded using a National Instruments analog-to-digital converter (type NI9210) and a Labview program. The measurement frequency was 50 Hz. The description of the thermocouples can be found in Table 2 and the position of the thermocouples is marked in Figure 5.



Slika 7. Geometrija dovodnega kanala optimizacije ena in dva.

Figure 7. Gate geometry used in optimization one and two.

poroznost. Za odpravo te krčilne poroznosti smo v prvi različici dovodni kanal optimizirali tako, da se je geometrijski in termalni modul povečal na način, da se je vsa krčilna poroznost premaknila v dovodni kanal. Geometrija novega dovodnega kanala je prikazana na Sliki 6.

Naknadno smo dovodni kanal optimizirali še za bolj optimalno lomljenje ulitka iz ulivnega sistema. Pri prvi optimizaciji se ulitki niso vedno sami odlomili na iztresalnih rešetkah, kjer pa so se odlomili, je ostal večji srh, ki je povzročal težave pri nadaljnji mehanski obdelavi. Za rešitev tega problema smo optimizacijo dva izvedli tako, da se je zmanjšala debelina pripetja, povečani del dovodnega kanala pa se je prestavil bližje ulitku. Primerjava geometrije med optimizacijo ena in dva je prikazana na Sliki 7.

3. Rezultati

S termoelementi izmerjene temperature so prikazane na Sliki 8. Na Sliki 9 je prikazana primerjava izmerjene temperature in temperature, izračunane z numeričnim izračunom na enakem mestu, kot so bili nameščeni termoelementi. Izmerjene in izračunane temperature se dokaj dobro ujemajo glede na opredeljene začetne in robne pogoje numeričnega izračuna. Upoštevati je treba, da pri numeričnem izračunu ne moremo upoštevati vseh spremenljivk, ki v realnosti vplivajo na proces ohlajanja. Največja neznanka pri vplivu na spreminjanje temperature ulitka in forme je lahko prestopnostni koeficient (HTC) med dvema snovema – v tem primeru med ulitkom iz sive litine in med peščeno formo iz bentonitne peščene mešanice. Ta koeficient lahko glede na specifičnost livarske tehnologije v posamezni livarni med posameznimi livarnami variira. V

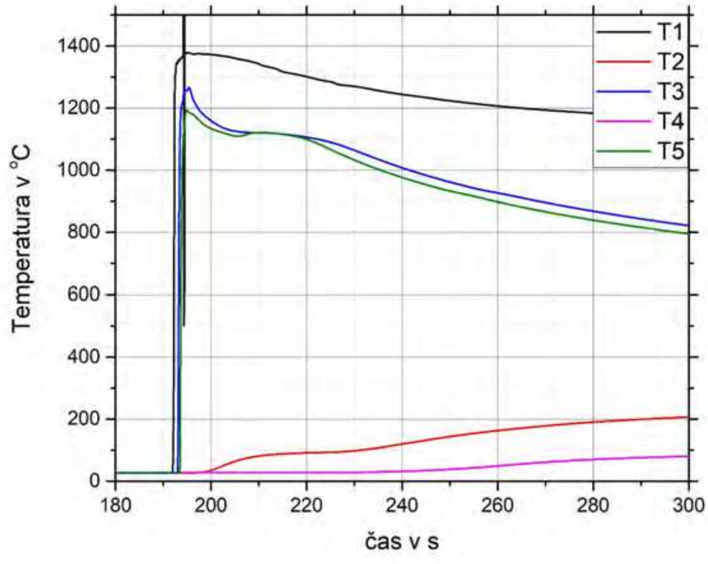
2.3 Gating System Optimization

The gating system shown in Figure 4 is not optimal and causes shrinkage porosity. To eliminate shrinkage porosity, the first optimization of gates was done. In the gates, the geometry and thermal modulus were increased so that the shrinkage porosity is moved to the gate. The geometry of the new gate is shown in Figure 6.

After the first version, the gate was additionally optimized to optimize the braking of the casting by the gating system. In the first optimization, the castings did not break out of the gating system by themselves, and even when the casting was finally broken out of the gating system with manual assistance, there was still extra material left for processing, which was not acceptable. To solve this problem in the second optimization, the thickness of the gate was reduced on one side and the added part on the gate was moved closer to the casting. The geometry of the second optimization is shown in Figure 7.

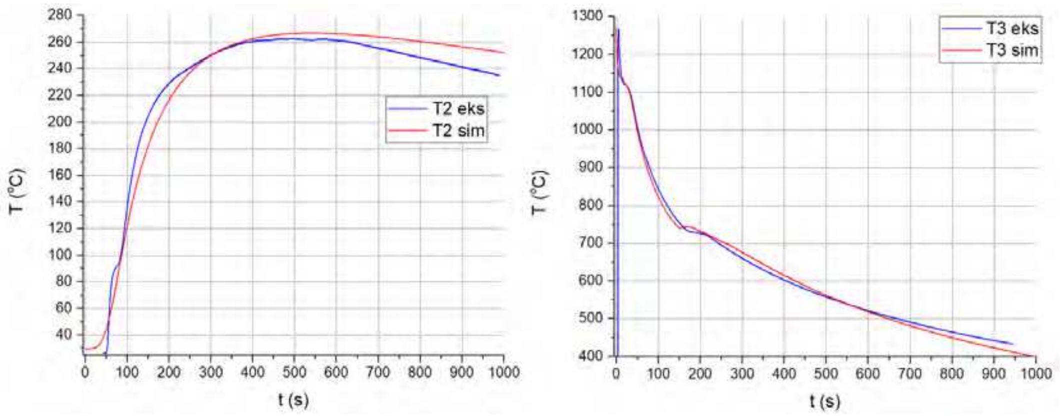
3 Results

The temperatures measured with thermocouples are shown in Figure 8. Figure 9 shows the comparison of the measured temperature with the numerically calculated temperature at the location where the thermocouple was placed. The measured and calculated temperatures are in good correlation with the initial and boundary conditions specified in the numerical calculation. It should be noted that not all variables can be taken into account in the numerical calculation, so the calculated and measured temperatures cannot match 100 %. One of the parameters that have a great influence on the numerical calculations of the casting is the heat transfer coefficient



Slika 8. Izmerjene temperature v formi na označenih mestih (Slika 5).

Figure 8. Measured temperatures in mold at marked locations (Figure 5).



Slika 9. Primerjava izmerjenih in numerično izračunanih temperatur.

Figure 9. Comparison of calculated and measured temperatures.

tem primeru smo glede na priporočila in izkušnje uporabnikov programske opreme HTC opredelili kot funkcijo temperature. Dokler je talina še tekoča, je HTC 550 W/m^{2}K, potem pa 400 W/m^{2}K. Tak način opredeljevanja HTC se izkaže za boljšega,

(HTC), which can be difficult to set. The heat transfer coefficient at the boundary between the casting and the mold is a boundary condition variable that varies from foundry to foundry due to specific foundry technology. The HTC was defined as a temperature-kot pa če bi bil opredeljen konstantno. Na ta način upoštevamo spremembo HTC zaradi temperaturne odvisnosti ter zaradi nastanka dodatne reže med ulitkom in formo, ko se ulitek strdi. Izbrane vrednosti HTC glede na minimalno odstopanje izmerjenih in izračunanih temperatur so ustrezne.

Pri prvi optimizaciji dovodnega kanala smo uspešno odpravili krčilno poroznost na samem mestu pripetja. Problem pri prvi optimizaciji se je pojavil v sami proizvodni praksi, in sicer zaradi ulitkov, ki se iz ulivnega sistema na vibracijski mizi niso odlomili. Napaka je nastala zaradi povečanja dovodnih kanalov, ki niso omogočali lomljenja ulitkov iz ulivnega sistema. Na Sliki 10 je primer, kako se ulitki ne odlomijo in ostanejo na ulivnem sistemu, kar pa ni sprejemljivo, saj to pomeni dodatno, predvsem ročno delo. Pri ploščah, ki so se odlomile in ki so bile potem naknadno ročno odlomljene, je ostal tudi večji ostanek dovodnega kanala na obodu plošče, kar je prav tako predstavljalo dodaten problem pri mehanski obdelavi.

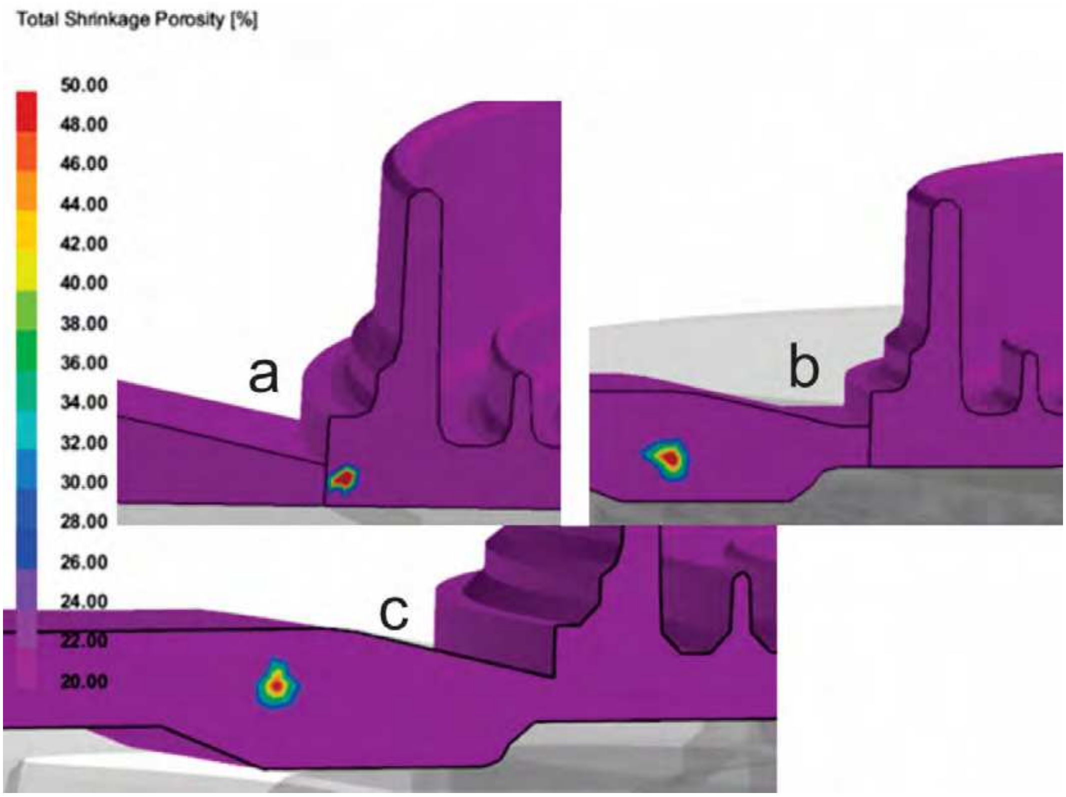
Pri drugi optimizaciji smo zmanjšali debelino dovodnih kanalov na meji med dovodnim kanalom ter grelnimi ploščami ter

dependent variable in this calculation based on empirical values from software users. The HTC was 550 W/m2K for a liquid melt and when the alloy solidifies, the HTC was 400 W/m2K. This definition of HTC better describes the boundary condition because it accounts for the formation of a gap at the casting and mold boundary as the casting shrinks during solidification and cooling. The defined absolute values of HTC are suitable because of the minimum temperature difference between the measured and calculated temperature.

With the initial optimization of the gates, shrinkage porosity was moved from the critical area into the gating system. However, an additional problem arose during production when the gates were too thick and the castings did not break out of the gating system by themselves. Figure 10 shows castings that did not break out of the gating system by themselves and caused additional manual work, which is not acceptable. An additional problem was also the extra material for machining in the gate area, which was not planned in the existing machining program.

Slika 10. Neodlomljeni ulitki po prvi optimizaciji.

Figure 10. Unbroken castings from the gating system with the first optimization.



Slika 11. Izračunana verjetnost za nastanek poroznosti; a) obstoječe stanje; b) optimizacija ena, c) optimizacija dva.

Figure 11. Calculated probability for shrinkage porosity; a) existing production; b) optimization one, c) optimization two.

približali ojačitev dovodnega kanala bližje meji med dovodnim kanalom ter grelno ploščo kot pomoč pri zmanjšanemu modulu na meji in da bi zagotovimo manjši ostanek dovodnega kanala pri lomljenju ulitka iz ulivno napajalnega sistema – Slika 7.

Z drugo optimizacijo se je mesto poroznosti z območja pripetja ulitka še dodatno premaknilo, tako da je bil osnovni problem odpravljen. Mesto in velikost poroznosti za vse tri različice na podlagi numeričnega izračuna sta prikazana na Sliki 11. Tudi ostanek dovodnega kanala po odlomljenem ulitku iz ulivno-napajalnega

In the second optimization, the thickness of the gates in contact with the casting was reduced and the increasing thermal modulus was moved closer to the heating plate. With this geometry optimization, we achieve a lower thermal modulus at the gate connection to the casting, and the residue on the casting after separation of the casting from the gating system is minimized so that there are no problems when machining the heating plate - Figure 7. In the second optimization, the porosity was additionally removed from the critical area. The location and size of the sistema je bil po drugi optimizaciji sprejemljiv.

4 Zaključki

Z uporabo numeričnih izračunov smo uspešno ugotovili vzrok za nastanek napak kot tudi preizkusili predlog za optimizacijo, s katero se je mesto poroznosti premaknilo v dovodni sistem, tako da ne predstavlja napake na ulitku. Za zagotovitev natančnosti rezultatov smo med procesom strjevanja in ohlajanja ulitka merili temperaturo in potrdili pravilno opredeljen prestopnostni koeficient, ki ga običajno opredelimo na podlagi izkušenj.

Krčilno poroznost smo odpravili s povečanjem dovodnih kanalov, ki so prevzeli funkcijo napajalnika.

Delež izmeta zaradi poroznosti se je zmanjšali s 3 % na 1,5 %.

porosity predicted by numerical calculations are shown in Figure 11.

4 Conclusion

Numerical calculations were used to determine the cause of the casting defect. The proposed optimization was first analyzed with numerical calculation, in which the shrinkage porosity was moved to the point where it no longer caused problems. The defects calculated with the numerical calculation corresponded with defects from production when the optimized solutions were implemented in production. Using measured temperatures in the mold during solidification of the casting and cooling of the mold, we calibrate the heat transfer coefficient for the foundry to make more accurate calculations for other castings as well.

By optimizing the gates, which now also act as feeders, we reduce the number of defected castings due to shrinkage porosity. The number of defective parts has been reduced from 3 % to 1,5 %.

5 Viri / References

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