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Načrtovanje orodja in procesa tlačnega litja s pomočjo FEM analize

HPDC Tool and Process Design Using FEM Analysis

Izvleček

Danes je uporaba numeričnih simulacij pri načrtovanju proizvodov standardna pot pri večini podjetij. V livarstvu načrtovanje tehnologije litja temelji pretežno na uporabi posebnih numeričnih programov. V članku bo predstavljen razvoj tehnologije litja za kompleksen ulitek. Z uporabo numerične simulacije so bili testirani številni ulivni sistemi, cilj testiranj pa je bilo optimiziranja polnitve livne votline in ulivanja ulitka s sprejemljivimi livarskimi napakami. Simulacija zajema tudi analizo napetosti in deformacij v orodju ter ulitku z upoštevanjem hladilno grelnega sistema v orodju. Z uporabo numeričnih simulacij je celotna tehnologija lahko optimizirana do take mere, da začetek proizvodnje poteka brez večjih težav. Celotna analiza nam lahko napove zaplete, ki lahko nastanejo v celotnem obdobju izdelave ulitka.

Ključne besede: tlačno litje, razvoj tehnologije litja, FEM analiza, ProCAST

Abstract

Using numerical simulations in product development is today a standard way for most of the companies. Especially on the field of foundry the casting technology development for a part is based on the numerical simulations. In this article will be presented technology development for a casting. Using numerical simulations several gating systems were tested to achieve best possible melt flow and casting with acceptable casting defect. The simulation includes analysis of stresses and deformations in the casting and in the tool considering toll heating and cooling system. With numerical simulations complete casting process can be optimized to minimize problems when the production starts. Also, we can predict the problems that can be critical during the production lifetime.

Key words: HPDC, casting process design, FEM analysis, ProCAST

Uvod

Za nekatere livarne je uporaba numeričnih simulacij vsakodnevna praksa. Livarne namreč hitro ugotovijo, da uporaba numeričnih simulacij ni samo prednost pred konkurenco, ampak obvezen tehnološki korak za izdelavo kakovostnih izdelkov po sprejemljivi ceni. Razvoj programskih paketov mora slediti potrebam livarn in zagotoviti podporo ter računanje vseh

Introduction

Using numerical simulations for some foundries is a fact in these days. Some foundries that are just starting to use numerical simulations realize that the benefits from using numerical simulations is not a competitor's advantage but it is a must to produce quality parts for a reasonable price. To cover all foundry technologies software producers must be in constant livarskih tehnologij. Večina programskih paketov pokriva več ali manj vse livarske tehnologije, posamezni paketi pa lahko omogočajo samo točno določeno livarsko tehnologijo. Programski paketi za reševanje temeljijo na različnih numeričnih metodah: Metoda končnih diferenc, Metoda končnih elementov, Metoda 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 kokili oziroma formi, lahko izračunamo deformacijo ulitka in izračunamo nastale napetosti. Iz rezultatov lahko predvidimo lokacijo napake, zaostale napetosti, velikost in amplitude deformacije ter napovemo mikrostrukture in mehanske lastnosti.

Za najbolj optimalne rezultate uporabe numeričnega izračuna je potrebno numerične simulacije vključiti že na začetku izdelave ali celo že pri samem dizajniranju ulitka. V prvi simulaciji se izračuna samo strjevanje ulitka in ugotovi najbolj kritična mesta. Nato sledi izdelava ulivno napajalnega sistema ter dizajniranje hladilno grelnega sistema v primeru tehnologije tlačnega litja. Ko so livarske napake v sprejemljivih tolerancah, sledi optimizacija hladilno grelnega sistema. Z ustrezno optimizacijo hladilno grelnega sistema lahko vplivamo na življenjsko dobo orodja.

Eksperiment

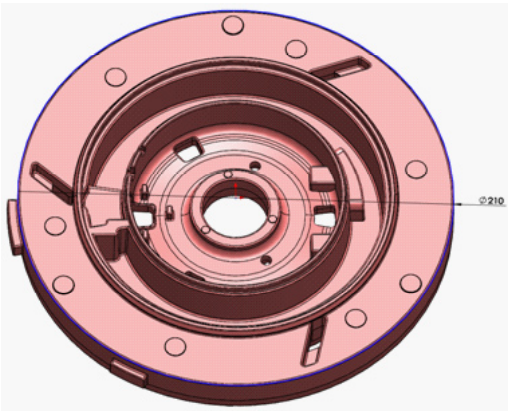
S pomočjo uporabe ProCAST-a (programski paket za numerične izračune livarskih procesov) je bila definirana livarska tehnologija za litje diska na Sliki 1. Uporabljena je bila zlitina AlSi9Cu3. Temperatura taline v zadrževalni peči je bila 680°C. Neto masa ulitka je bila 2,3 kg. Gravura orodja je bila izdelana iz orodnega jekla za delo v vročem H11. Geometrija

development and cover all new features to stay in touch with industry demands. Most software covers all the foundry technologies and some of the special foundry technology variants. Software solutions are based on several different methods from Finite Differences method, Finite Element Method, Control Volume Method, etc. [1, 2]. In addition to the basic results like gas and shrinkage porosity, flow analysis, temperature field in the casting and in the die software are able to predict deformations and residual stresses. Simulation software helps to address defect detection, residual stresses, part distortion, microstructure and mechanical properties prediction.

For the appropriate use of numerical simulations in casting technology development, they must be included from start of the designing. In the very first simulation only the solidification of the casting without gating system must be calculated to find where the castings defect will be most problematic. After this, the gating system is designed with cooling and/or heating system planned, in case High Pressure Die Casting (HPDC) technology will be used. When casting defects are in acceptable limits, optimization of heating and cooling system is done to get deformation of the casting in desirable limits. With optimization of heating and cooling system in the die, we can have an influence on the tool fatigue.

Experimental

Using ProCAST - numerical simulation software for foundry processes, we made the development of foundry process for a disc, which is presented on Figure 1. Casting is made of AlSi9Cu3 aluminum alloy. Pouring temperature of the melt from the holding furnace was 680 °C. Casting weight is 2,3 kg neto. The die was made from H11 hot orodja je prikazana na Sliki 2. Na Sliki 3 lahko vidimo hladilno grelni sistem orodja. Hladilni kanali so izdelani z vrtanjem, tako da sistem kanalov in čepov tvori zanko za kroženje medija. Medij v hladilnem sistemu orodja je olje, v razbijalcu pa voda.



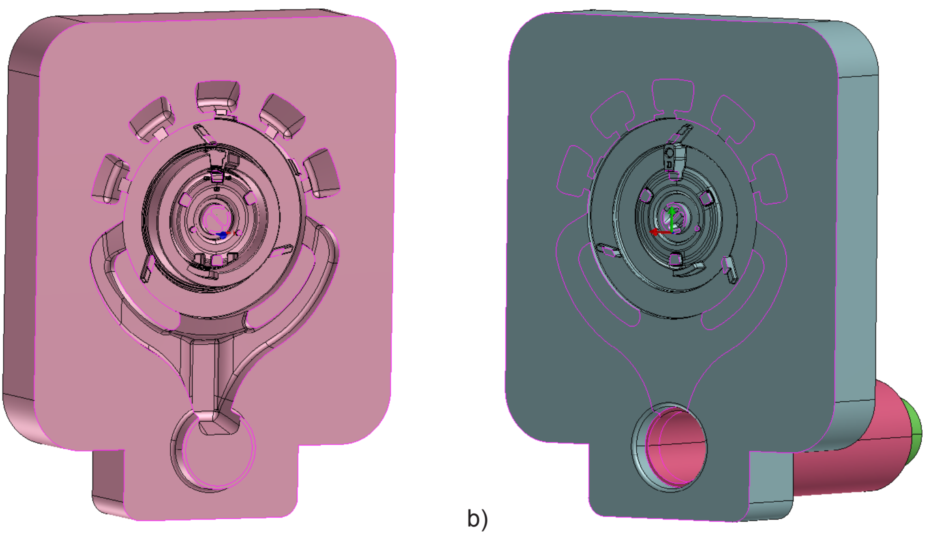
Slika 1. CAD model diska

Figure 1. CAD geometry of a disc

work tool steel. The geometry of the die is presented on Figure 2. In Figure 3 the heating and cooling system can be seen. The heating and cooling system is made with drilling of the holes to make a closed loop for cooling media circulation. Cooling media in the die is oil, in the distributor cooing media is water.

Based on CAD geometry FEM mesh is generated and process parameters needed for HPDC technology are defined in preprocess advisor. Most important parameters used are presented in Table 1. Thermodynamic data of casted alloy and used steel for die was chosen from software's standard database.

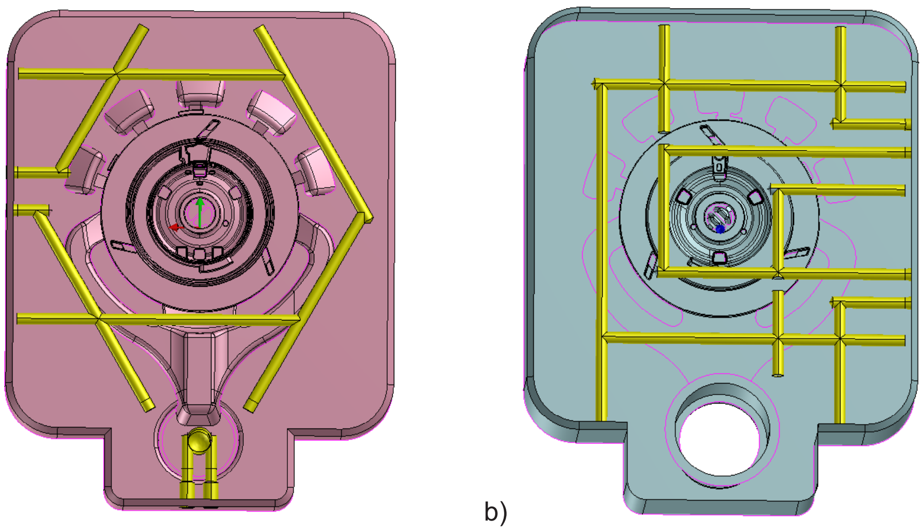
Using these data for calculation, the results of numerical calculation were in compliance with measured when casting was casted in production. For accurate results of numerical simulation complete process was simulated. First calculation of steady temperature state in the die is calculated.



a) b)

Slika 2. CAD model orodja; a) gibljiva stran orodja, b) stabilna stran orodja

Figure 2. CAD geometry of the tool; a) movable side of the die, b) fixed side of the die



a) b)

Slika 3. Hladilni kanali v orodju; a) gibljiva stran orodja, b) stabilna stran orodja

Figure 3. Cooling channels in the die; a) movable side of the die, b) fixed side of the die

Tabela 1. Uporabljeni parametri litja

Table 1. Casting parameters for numerical simulation

	Parameter	vrednost / value	enota / units
1	temperatura litja / Casting temperature	680	°C
2	temperatura hladilnega medija - olje / Cooling media - oil	200	°C
3	temperatura hladilnega medija – voda / Cooling media - water	25	°C
4	prestopnostni koeficient: hladilni sistem - olje / Heat transfer coefficient: cooling system-oil	2000	W/m^2
5	prestopnostni koeficient: hladilni sistem - voda / Heat transfer coefficient: cooling system-water	2200	W/m^2
6	prestopnostni koeficient: orodje – ulitek (talina) / Heat transfer coefficient: die – casting (not solidified)	1500	W/m^2
7	prestopnostni koeficient: orodje – ulitek (strjeno) / Heat transfer coefficient: die – casting (solidified)	1250	W/m^2

Na podlagi CAD geometrije se izdela mreža končnih elementov. Za simulacijo je potrebno definirati in vnesti procesne ter robne pogoje za tlačno litje. Najbolj pomembni podatki so predstavljeni v Tabeli 1. Lastnosti ulivane zlitine in uporabljenega jekla so izbrane iz standardne podatkovne baze programa.

Steady temperature state calculation in the die is important for accurate result of filling and solidification because the temperature in the die is not homogenous. Big influence on the steady state temperature has heating and cooling system parameters – cooling media and temperature – used parameters are presented in Table 1. Using steady state

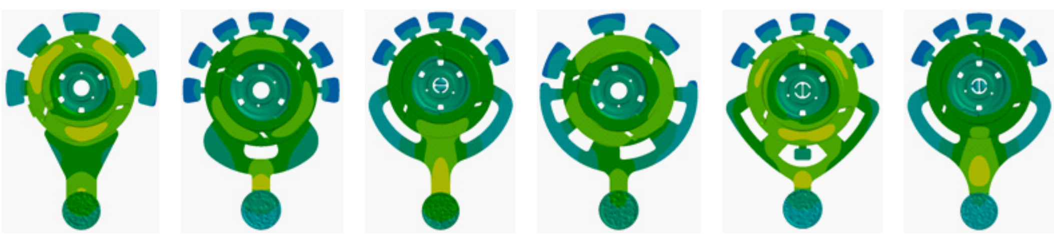
Uporabljeni podatki za numerični izračun v Tabeli 1 so bili potrjeni in izmerjeni pri litju v proizvodnji. Za natančne rezultate numerične simulacije je bil izračunan celotni proces litja. Najprej se je izračunalo stacionarno temperaturno polje v orodju. Izračun stacionarnega temperaturnega stanja v orodju pomembno vpliva na točnost numeričnega izračuna litja in strjevanja, saj tako upoštevamo bolj realne robne pogoje oziroma upoštevamo realno nehomogeno temperaturo v orodju. Največji vpliv na temperaturno polje orodja pri numeričnem izračunu doprinesejo parametri za hladilno grelni sistem v orodju – temperature in hladilni medij. Parametri so predstavljeni v Tabeli 1. Rezultati stacionarnega temperaturnega polja so bili nato uporabljeni za izračun polnjenja in strjevanje ulitka.

temperature field filling and solidification calculation was done. In HPDC casting process it is important to calculate also the filling of the casting chamber and complete process of piston movement. During this phase melt cools down and if piston movement is not optimized additional air can be entrapped. Optimal piston movement for this casting is presented in Table 2. The table presents piston velocity depended with piston position in the casting chamber. With all these parameters taking into account, the calculated filling and solidification of the casting is more accurate. Several different gating systems were simulated. Different gating system are presented in Figure 4. The stress analysis was also calculated to see stresses in the die.

Tabela 2. Hitrost bata v odvisnosti od lokacije bata v livni komori

Table 2. Piston velocity depending on piston position in casting chamber

Lokacija bata glede na začetno lokacijo [mm] / Piston position from start [mm]	Hitrost bata [m/s] / Piston velocity [m/s]	Komentar / Comment
0	0,5	prva faza / 1st phase
165	0,5	druga faza, strel / 2nd phase, shot
175	2,3	druga faza, strel / 2nd phase, shot
350	2,3	tretja faza / 3rd phase, high pressure
380	0	tretja faza / 3rd phase, high pressure



Slika 4. Različni ulivni sistemi, ki so bili izračunani za polnjenje ulitka – zadnja verzija je bila uporabljena za končno izdelavo orodja

Figure 4. Different gating system tested for filling of the casting – last version was used for production

Pri tehnologiji tlačnega litja je pomembno, da se pri izračunu upošteva tudi polnjenje livne komore in celoten proces strela – premikanje bata. V tej fazi temperatura taline pade, hitrosti premikanja bata pa morajo biti optimizirane, da ne pride do dodatnega ujetega zraka v talini. Optimizirani parametri premikanja bata za litje diska so predstavljeni v Tabeli 2. Tabela prikazuje hitrost premikanja bata v odvisnosti od lokacije bata v livni komori. Z upoštevanjem vseh teh optimiziranih parametrov je izračun polnjenja in strjevanja ulitka bolj natančen. Izračunanih je bilo več verzij polnjenja in strjevanja glede na različne možne ulivne sisteme. Ulivni sistemi, ki so bili uporabljeni za računanje, so predstavljeni na Sliki 4. Za najbolj optimalen ulivno napajalni sistem je bil na koncu narejen tudi izračun napetosti v orodju.

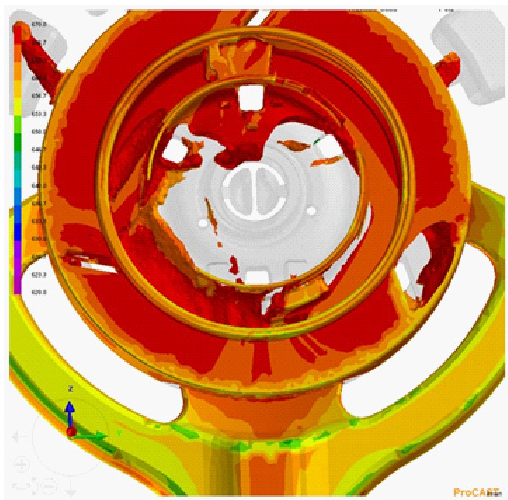
Rezultati

Analiza izračuna numerične simulacije polnjenja in strjevanja ter uporaba parametrov iz izračuna v realnem procesu izdelave ulitka pokaže veliko stopnjo ujemanja napak med izračunom in realnim ulitkom. Sekvenca polnjenja s temperaturnim poljem je prikazana na sliki 5. Lokacija preliva v sredini ulitka omogoča, da ujeti zrak lahko zapusti livno votlino. Numerični izračun predvideva nekaj poroznosti v ulitku, ki je prikazana na Sliki 6a. Rentgenski posnetek izdelanega ulitka poroznosti ne zazna – Slika 6b.

Izračunano stacionarno temperaturno polje v orodju po 15 ciklih je prikazano na Sliki 7. Na Sliki 7a je prikazana stabilna stran orodja, Slika 7b pa kaže gibljivi del orodja. Stacionarno temperaturno polje je doseženo po 15 ciklih. Sprememba temperature v prvih petnajstih ciklih za nekaj točk na stabilni gravuri je prikazana

Results

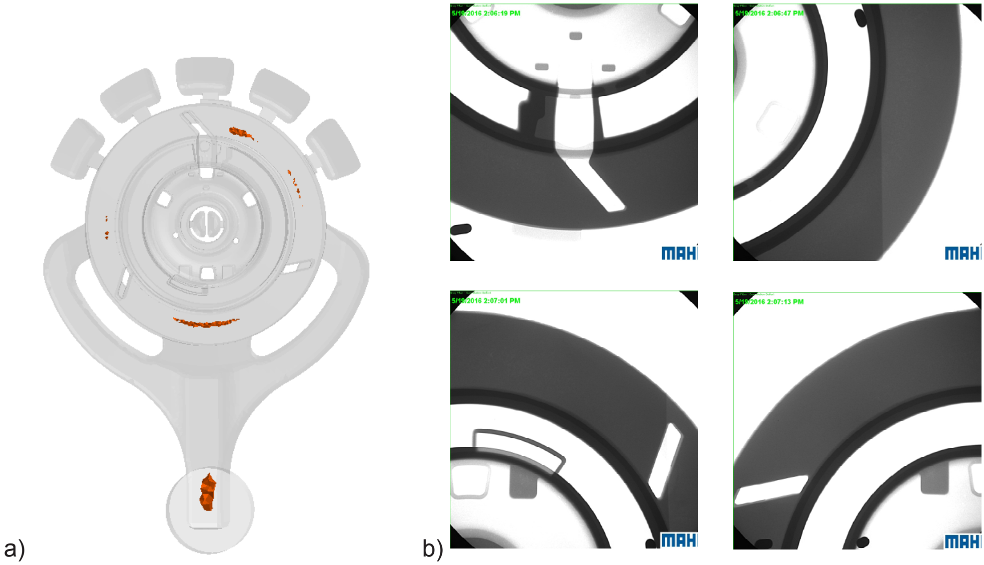
Calculated results of filling and solidification of the casting using parameters from the production are in coloration with real casted casting. The sequence of filling with temperature filed is presented in Figure 5. The construction of overflow in the center enables the entrapped air to escape from the casting cavity. Calculation predicted small porosity in some parts of the disk and is presented in Figure 6a, but when x-ray of a casting was done, no porosity was found in the casting. X-ray figures of a casting is in Figure 6b.



Slika 5. Sekvenca polnjenja s temperaturnim poljem taline

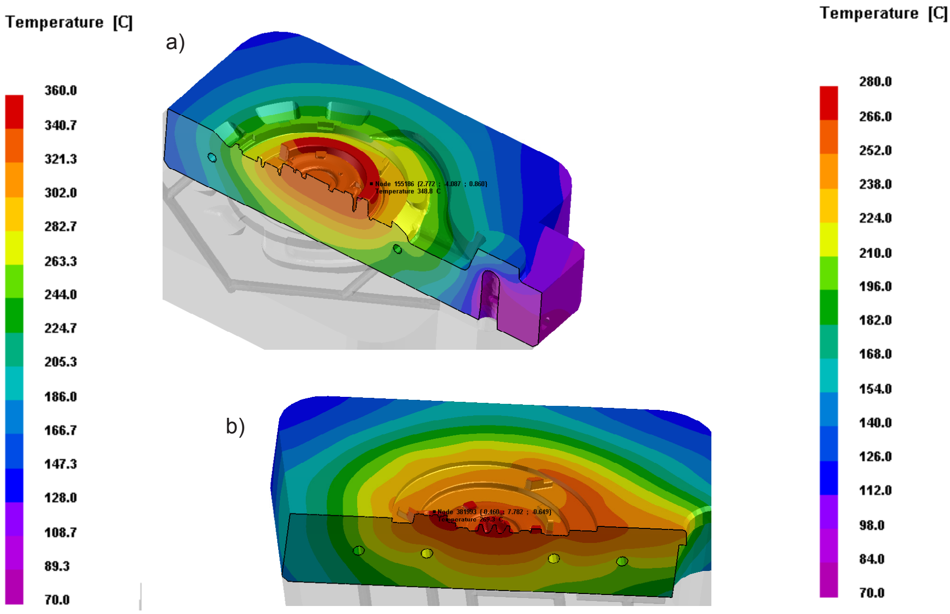
Figure 5. Sequence of the filling and temperature of the melt during filling

The calculated steady state temperature field after 15 cycles is presented in Figure 7. Figure 7a shows stable part of the die and Figure 7b presents the moving part of the die. The steady state temperature is reached after 15 cycles. The temperature change for first 15 cycles in some selected points



Slika 6. a) izračunana mesta možnega nastanka poroznosti; b) rentgenska slika ulitka

Figure 6. a) calculated possibility of porosity; b) x-ray photos of the casting

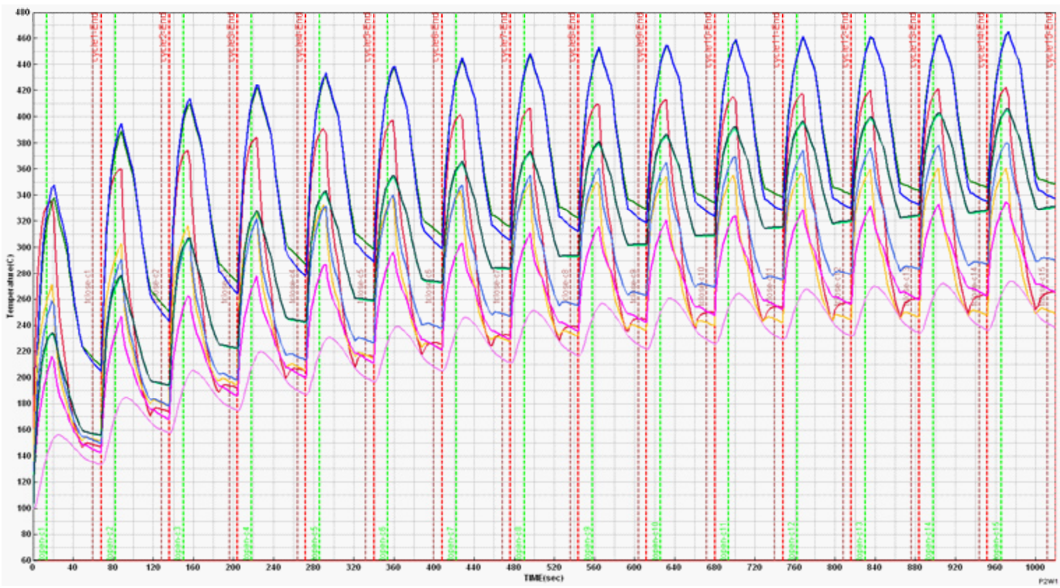


Slika 7. Izračunano stacionarno temperaturno polje; a) gibljiva stran orodja, b) stabilna stran orodja

Figure 7. Calculated steady state temperature field; a) movable part of the die, b) fixed side of the die

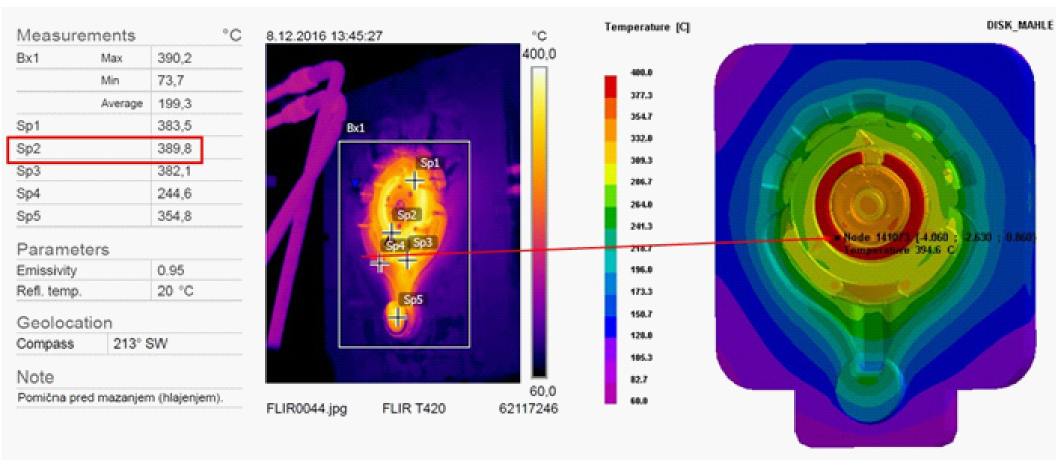
na grafu na Sliki 8. Temperaturno polje, fotografirano s termo kamero takoj po izmetu ulitka iz orodja na gibljivi strani, in izračunano temperaturno polje v istem času

on a stable part of the die are presented in Figure 8. Temperature field made with thermo camera right after the casting is ejected on a movable side of the die and



Slika 8. Temperatura izbranih točk za prvih petnajst ciklov na gibljivem delu orodja

Figure 8. Temperature at some points for first 15 cycles on the movable side of the die

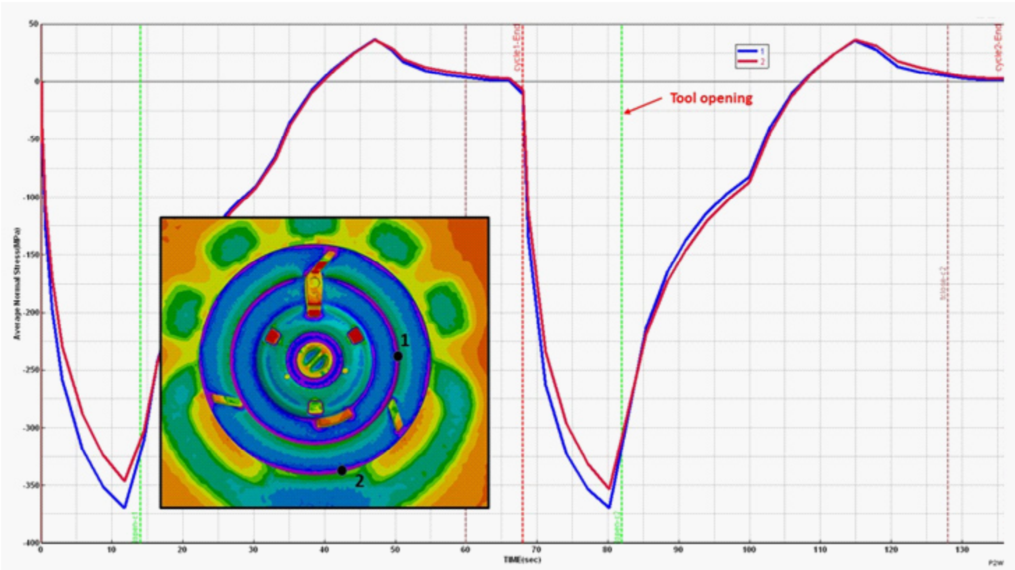


Slika 9. Izmerjeno in izračunano temperaturno polje na gibljivem delu orodja po izmetu ulitka

Figure 9. Measured and calculated temperature field on the movable side of the die after casting ejection

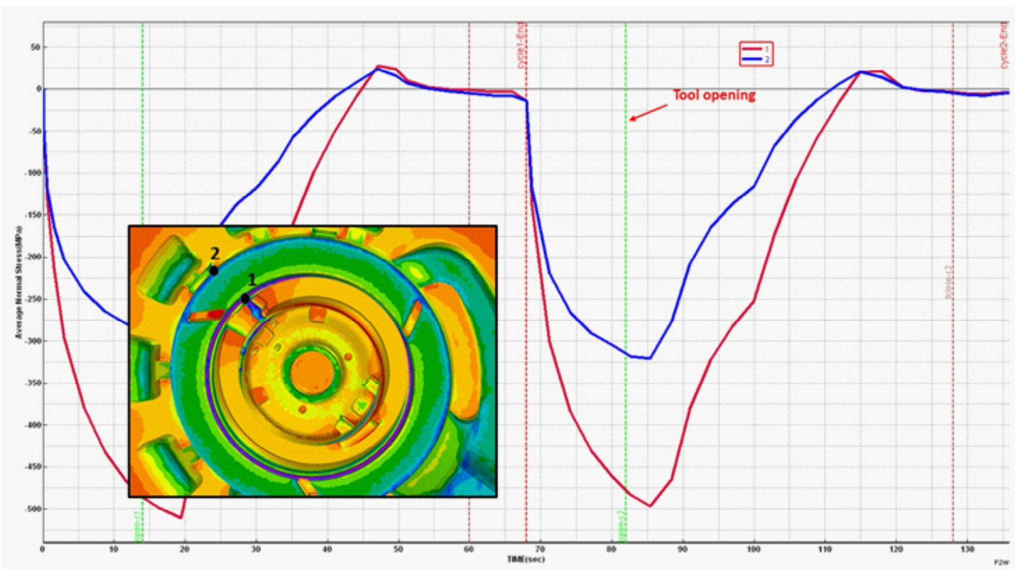
kaže zelo dobro ujemanje. Primerjava obeh temperaturnih polj je prikazana na Sliki 9.

temperature field calculated with simulation at the same moment has good matching.



Slika 10. Izračunane napetosti na označenih točkah na stabilnem delu orodja

Figure 10. Calculated stresses at marked points on the stabile part of the die



Slika 11. Izračunane napetosti na označenih točkah na gibljivem delu orodja

Figure 11. Calculated stresses at marked points on the movable part of the die

Rezultati izračunanih napetosti v orodju med delovnim ciklom so prikazani na Slikah 10 in 11. Izračunane vrednosti so pod 500 MPa. Izračunane vrednosti ne presegajo kritičnih vrednosti, ki bi pomembno vplivale na življenjsko dobo orodja.

Zaključki

Vključevanje numeričnih izračunov v prvih fazah načrtovanja livarske tehnologije za posamezni ulitek ima lahko pomembne vplive na stroške izdelave ulitka. Ko je uporaba numeričnih izračunov na visoki ravni in je analiza rezultatov izvedena kakovostno, se stroški izdelave ulitka lahko zmanjšajo.

V predstavljenem primeru je bil numerični izračun in optimizacija uporabljena od začetka procesa skozi celoten proces – polnjenje livne komore in optimizacija premika bata imata pomemben vpliv na kakovostne rezultate izračuna. Parametri za litje so optimizirani z numeričnim izračunom do te mere, da je potrebno te optimizirane parametre na stroju v proizvodnji samo še končno preveriti in na fino nastaviti - in izdelava kakovostnih ulitkov se začne.

The calculated and measured temperature field is presented in Figure 9.

Results of stress analysis in the die are presented in Figure 10 and 11. The calculated values on critical areas are below 500 MPa. These values are not critical for the tool lifetime.

Conclusions

Including numerical simulations in early stage of product development can have big influence on products costs during his lifetime. When development is on a high level of using advance numerical simulations and proper analysis of the results from start of the development process production, costs can be lowered.

In this case the development of the casting process using numerical simulation from the start – filling of the casting chamber and optimization of the piston movement has a big advantage. The casting parameters are optimized with simulation and, when these parameters are transferred to the production, the foundrymen only have to do the fine tuning of the parameters and then the production of quality castings can start.

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