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Optimizacija hladilno-grelnega sistema v orodjih za tlačno litje

Optimization of cooling-heating system in HPDC tools

Povzetek

Tehnologija tlačnega litja je postopek izdelave ulitkov v trajne forme. Med litjem, strjevanjem in ohlajanjem ulitka v jeklenem orodju prihaja do prenašanja toplote iz ulitka na orodje, kar povzroči segrevanje orodja. Da se prepreči premočno segrevanje, se v orodjih uporablja hladilno-grelni sistem, ki v začetku obratovanja zagotovi hitrejše doseganje delovne temperature orodja, kasneje pa odvajanje odvečne toplote iz orodja. V delu je opisana problematika konvencionalnega orodja in vplivi toplotnega utrujanja le-tega ter nastanek s tem povezanih poškodb na orodju. Na podlagi analize obstoječega orodja je bila narejena in s programskim orodjem ProCAST preverjena idejna zasnova novega orodja s spremenjenimi hladilnimi kanali. Na podlagi uspešnih rezultatov ter analiz je bilo izdelano novo orodje.

Ključne besede: tlačno litje, napetosti, življenjska doba orodij

Abstract

High pressure die-casting process (HPDC) is a permanent mould casting technology. During one cycle the melts' heat is transported into a steel tool which is a reason for the heating of a tool. In order to prevent overheating the heating-cooling system is positioned in the tool. Cooling-heating system heats up the tool at the beginning of the casting process and cools the tool in further production of castings. The paper describes the problems of the conventional tool with defect analysis as a result of thermal loading. Based on the analysis of the existing tool made by ProCAST software the change of the heating-cooling system in a tool was prepared and verified. In further the new tool was produced.

Keywords: HPDC process, stresses, tool lifetime

1 Uvod

Tlačno litje je tako v tehnološki kot tudi v znanstveni praksi postopek izjemnega pomena za izdelavo ulitkov za avtomobilsko in letalsko industrijo ter telekomunikacije. Tehnologija tlačnega litja je ciklični proizvodni proces, primeren za masovno proizvodnjo ulitkov, in je v moderni svetovni

1 Introduction

High Pressure die-casting process (HPDC) is very interesting for technological and scientific practice. HPDC process is used for production of parts for automotive industry, aeronautics etc. HPDC process is a cyclic process appropriate for mass production and is one of the most important casting livarski industriji ena najbolj razširjenih tehnologij. V zadnjem času so se razvijale zlitine za tlačno litje [1 – 3], materiali za izdelavo orodij [4] predvsem pa regulacija in nadzor različnih parametrov [5 – 7] pri vbrizgavanju taline v orodje, saj je tako nadzorovana plinska in krčilna poroznost ulitkov. Raziskave s področja toplotnega utrujanja orodij [8, 9] in kemijskih reakcij na mejni površini ulitek–orodje so postale tudi zelo pomembno komercialno vprašanje, saj kratka življenjska doba in stroški izdelave orodja pomembno vplivajo na končne stroške proizvodnje, zato industrija prednostno podpira razvoj programskih okolij za simulacijo različnih parametrov v proizvodnem procesu litja. Dosedanje temperiranje orodij temelji na hladilno-grelnih sistemih, ki so omejeni le na nekaj samostojnih krogotokov. Nadalje je težava v sistemu izvedbe hladilno-grelnih kanalov, ki jih danes izdelujejo le s tehnologijo vrtanja in zapiranja slepih izvrtin s čepi [10]. V znanstveni in strokovni periodiki, ki obravnava problematiko temperiranja orodij za tlačno litje, danes ni zaslediti drugačnih rešitev. Zasledimo lahko študije prednosti sistemov s prilagojenimi hladilnimi kanali in načine optimizacije teh sistemov predvsem v orodjih za brizganje polimerov [11 – 16] ali pa se hladilne kanale v orodjih za brizganje polimerov lahko izdela tudi s 3D-tiskanjem [17]. Ugotovitve kažejo, da hladilno-grelni sistem ni dovolj učinkovit, če je nameščen predaleč od površine orodja za tlačno litje. Od tod sledi, da je mogoče edino z namestitvijo kanalov pod površino livne votline oziroma tam, kjer je to potrebno, zagotoviti ustrezen prenos toplote iz ulitka preko orodja na hladilni medij [18].

V delu je bil raziskan in izdelan inovativni koncept postavitve hladilno-grelnega sistema, ki zagotavlja rešitev vprašanja usmerjenega strjevanja ulitkov ter podaljšanja življenjske dobe orodja.

technologies. Recently the research is done on HPDC casting alloys [1 – 3], die materials [4] and most important on regulation of different parameters of the process [5 – 7] such as melt injection important for gas and shrinkage porosity. Research from the field of thermal loading of the tool [8, 9] and chemical reactions on the interface melt/die are still important questions since they influence the die for a lifetime. In order to reduce costs for die production the development of software for simulation of the HPDC process is supported.

An important process in a HPDC technology is the heating-cooling system of the tool conducted by several loops of cooling channels through the tool. Cooling channels are usually produced by drilling [10] and in recent publications there is no evidence of different technologies used for production of cooling channels. There are some papers describing adjusted cooling channels at production of polymers [11 –16] where they can be also produced by 3D printing [17]. Findings are showing that cooling channels are not effective if they are positioned away from the die cavity, so they should be positioned closer to the die cavity surface in order to extract the heat from the die more effectively [18].

The paper describes the investigation and production of the new and innovative heating-cooling system for the tool in order to improve directional solidification of castings and to extend the lifetime of the die.

2 Experimental

The case of research was a HPDC tool with two casting cavities as presented in Fig. 1a and the distributor presented in Fig. 1b. The tool was produced from tool steel UTOPMO2 with the chemical composition presented in

2 Eksperimentalno delo

Predmet izvedenih preiskav je bilo dvognezdno orodje za tlačno litje, predstavljeno na sliki 1a, ter razdelilec, predstavljen na sliki 1b. Oba sta izdelana iz jekla UTOPMO2, katerega kemijska sestava je podana v tabeli 1. Orodje je bilo toplotno obdelano, poboljšano ter nitridirano. Pomična in stabilna stran orodja imata enake dimenzije 300 × 300 × 100 mm. Kot hladilno sredstvo za hlajenje orodja je bila uporabljena voda.

Za analizo poteka cikla in uskladitev rezultatov je bila uporabljena termovizija. Rezultati termovizije so bili uporabljeni za preverjanje točnosti izračuna tehnologije litja z računalniškim orodjem ProCAST. Numerični izračuni so podali rezultate, kot so segrevanje in ohlajanje orodja med delovanjem ter napetostno stanje orodja med cikličnim toplotnim obremenjevanjem. Analizirane so bile tudi napake na porušenem orodju.

Glede na numerične izračune je bila postavljena nova zasnova hladilnega sistema v orodju in razdelilcu ter preverjena v praksi.

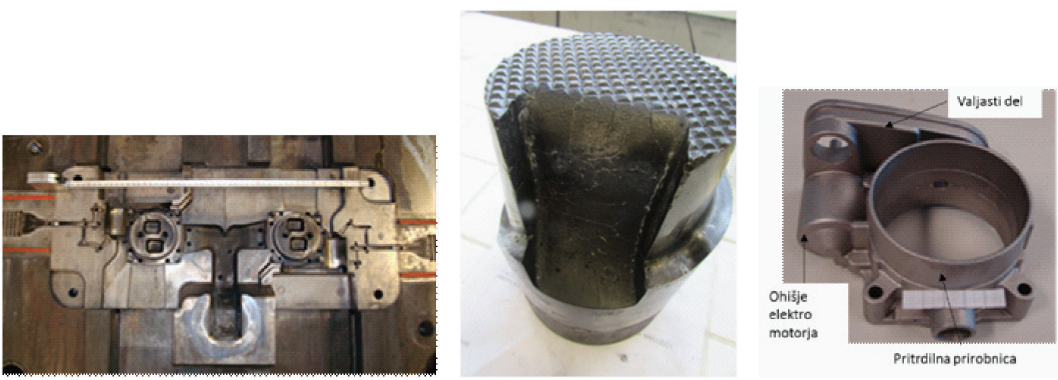
Table 1. The tool was hardened, tempered and nitrated. Both parts of a tool have the same dimensions 300 × 300 × 100 mm. Water was used as a cooling agent for a tool. The casting produced by this tool was a carburettor from AlSi9Cu3 alloy presented in Fig. 1c.

In order to analyse the casting cycle and to correlate measured and calculated results the thermal imaging was used. Results of thermal imaging were used to correlate and verify the calculated results made by the numerical simulation programme ProCAST. Calculated results gave information about heating and cooling of a tool during process of casting and predicted stress results in a tool as a result of cyclic thermal loading. The analysis of defects on a destructed tool was made in order to analyse the critical spots in a tool.

Tabela 1: Kemijska sestava orodnega jekla UTOPMO2 v mas. %

Table 1: Chemical composition of tool steel

C	Si	Mn	Cr	Mo	V
0,40	1,05	0,40	5,15	1,35	1,00



(a) (b) (c)

Slika 1: Dvognezdno orodje (a), razdelilec (b) in ulitek uplinjača (c)

Figure 1: Two casting cavity HPDC tool (a), distributor (b) and the casting (c)

3 Rezultati in diskusija

Analiza cikličnega toplotnega obremenjevanja obstoječega orodja na sliki 2 in 3 prikazuje, da je stabilni del orodja za približno 130 °C bolj toplotno obremenjen na mestu izoblikovanja prirobnice ulitka kot pomični del. To se vidi tudi iz življenjske dobe, saj je pomični del izdelal 95332 ciklov stabilni pa le 73070 ciklov. Izdelana je bila nova stabilna stran orodja z novo postavitvijo hladilno-grelnega sistema, kot prikazuje slika 4. Analiza cikličnega toplotnega obremenjevanja obstoječega in novega stanja stabilnega dela orodja je pokazala, da je najvišja temperatura v 9. ciklu za obstoječe stanje okoli 297 °C in za novo stanje okoli 285 °C oziroma za 12 °C nižja, kar prikazuje slika 5. Najvišja amplituda povprečne normalne napetosti na kritičnem mestu v 9. ciklu za obstoječe stanje je 1080 N/mm^2 in za novo stanje 700 N/mm^2 oziroma 36 % manjša, kar prikazuje slika 6. Glede na omenjene izračunane rezultate, bi se mogla življenjska doba orodja podaljšati, kar pa v praksi ni bilo do konca preverjeno, saj se je proizvodnja ulitka prekinila, ko je orodje izdelalo 9474 ciklov. Obstoječi stabilni del orodje je do porušitve izdelal 73070 ciklov litij.

Na obstoječem stabilnem delu orodja je bila analizirana obraba in razpoka na mestu f, kjer je bil izrezan vzorec in primerjan z mestom n, kjer obrabe ni bilo, kot prikazuje slika 7. Prikazane so tudi ostale poškodbe na orodju, kot so mehanska obraba zaradi adhezije ter toplotne razpoke na orodju, na istih mestih, kjer so izračunane največje napetosti (slika 6). Profil trdot po metodi Vickers na mestu f, kjer je prišlo do mehanske obrabe, in na mestu n, brez mehanske obrabe, kaže padec mikrotrdote z 1050 HV0,1 na 940 HV0,1 (slika 8).

Izdelan je bil tudi nov hladilno-grelni sistem na razdelilcu. Analiza cikličnega

According to numerical calculations the new heating-cooling system was made in a new tool and a new distributor and verified in practise.

3 Results and Discussion

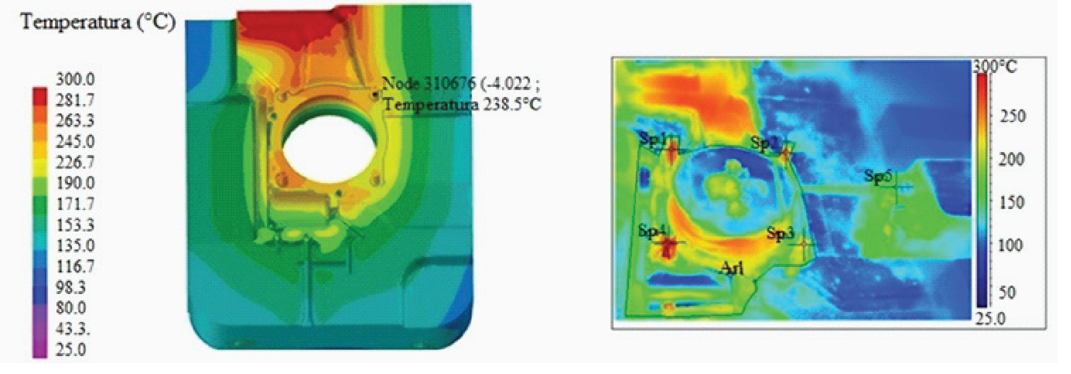
Analysis of cyclic thermal loading of a tool showed that the stable part of a tool has a 130 °C higher temperature than the moving part of a tool at the position shown in Figs. 2 and 3. The picture is taken before the spraying of a tool. The lifetime of a stable part of a tool was 73070 cycles whereas the lifetime of a moving part of a tool was 95332 cycles, which confirms that higher temperatures have a negative effect on lifetime. A new stable part of a tool was produced with newly positioned heating-cooling channels nearer to the casting cavity (Fig. 4). Analysis of thermal loadings showed the difference in temperature for old and new tool where the temperature of the old tool was 297 °C and the temperature of a new tool was 285 °C shown in Fig. 5. The lower temperatures brought also changes in stress formation during cycles. Fig. 6presents the most critical spot of a moving part of a tool and shows that amplitude of average normal stresses is lowered from 1080 N/mm^2 to 700 N/mm^2, which means 36 % lower loadings. According to calculations the lifetime of a tool should increase. The new tool made only 9474 cycles due to the end of the casting production.

The stable part of an old tool was analysed for defects caused by cyclic thermal loading. Fig. 7 is showing thermal fatigue cracks and wear at spot f where the tool was loaded by the melt andat spot n where there were no loadings. Also other defects are presented such as adhesion, wear and cracks on the same places as calculated by ProCAST software (Fig. 6).

toplotnega obremenjevanja obstoječega in novega razdelilca je prikazana na sliki 9. Temperatura v kritični točki razdelilca z obstoječim hladilno-grelnim sistemom je 235,3 °C, z novim hladilno-grelnim sistemom pa 94,7 °C. Temperatura se je zaradi učinkovitega delovanja novega hladilno-grelnega sistema na razdelilcu

Profile of Vickers hardness presented in Fig. 8 shows the lowered hardness on spot f where the wear occurred. The hardness is lowered from 1050 HV0,1 to 940 HV0,1.

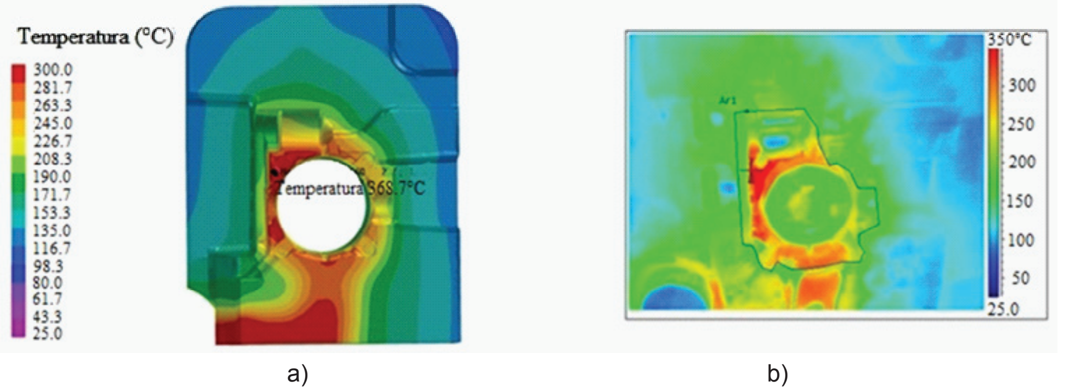
As mentioned also the distributor was analysed and according to calculated results and changed cooling system the new distributor was produced. Analysis



a) b)

Slika 2: Obstoječi pomični del orodja pred mazanjem: a) izračun s programskim orodjem ProCast rezultat prikazuje temperaturo 238,5 °C, b) eksperiment posnet s termovizijsko kamero na istem mestu pa temperaturo 249,2 °C

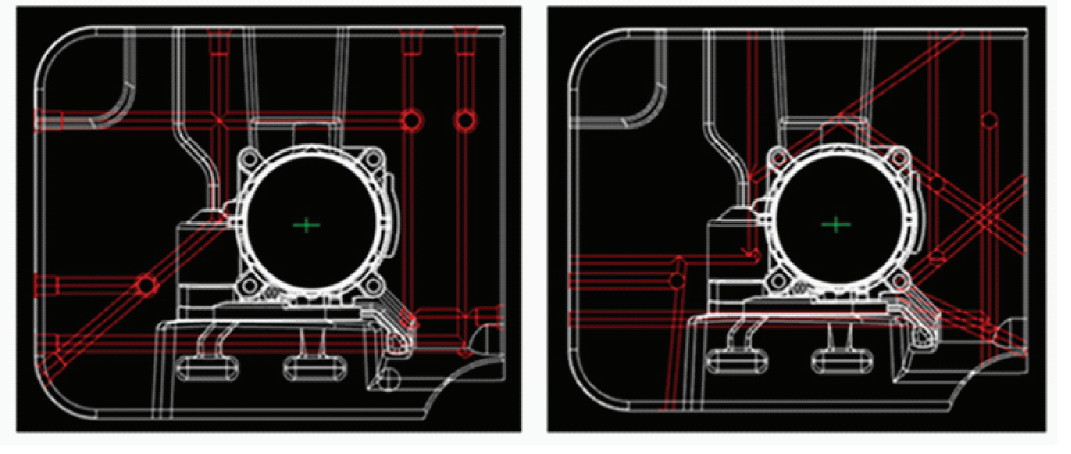
Figure 2: Calculated temperature field of movable part of a tool (a) and thermal imaging of a surface of same part before spraying



a) b)

Slika 3: Obstoječi stabilni del orodja pred mazanjem: a) izračun s programskim orodjem ProCast rezultat prikazuje temperaturo 368,7 °C, b) eksperiment posnet s termovizijsko kamero na istem mestu pa temperaturo večjo od 360 °C

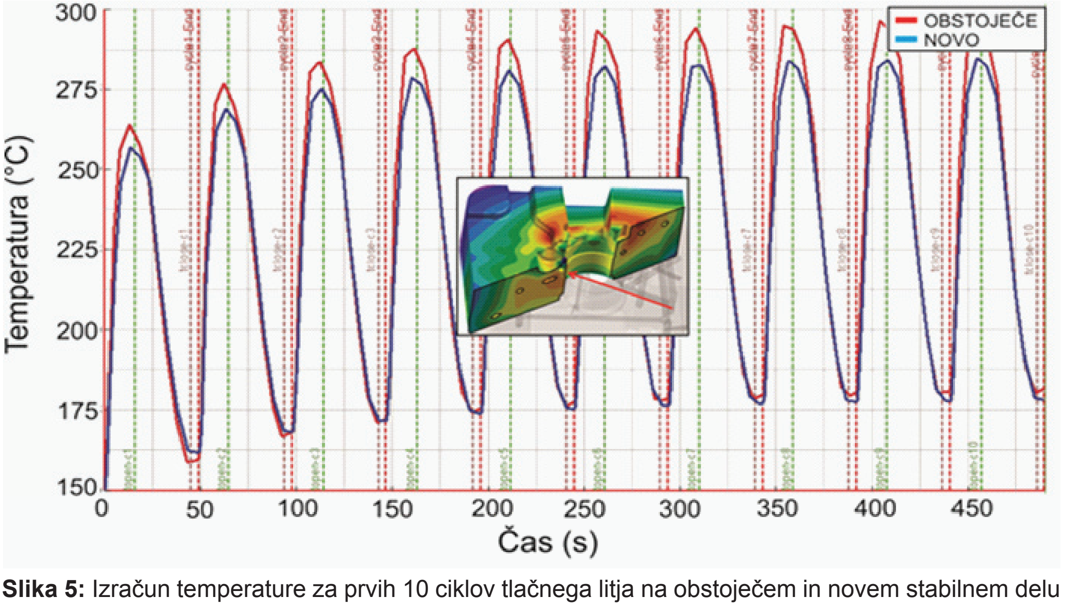
Figure 3: Calculated temperature field of stable part of a tool a) and thermal imaging of a surface of same part before spraying



a) b)

Slika 4: Stabilni dela orodja: a) obstoječe stanje, b) novo stanje

Figure 4: Positioning of heating-cooling system in a stable part of a tool: old tool a) and new tool b)

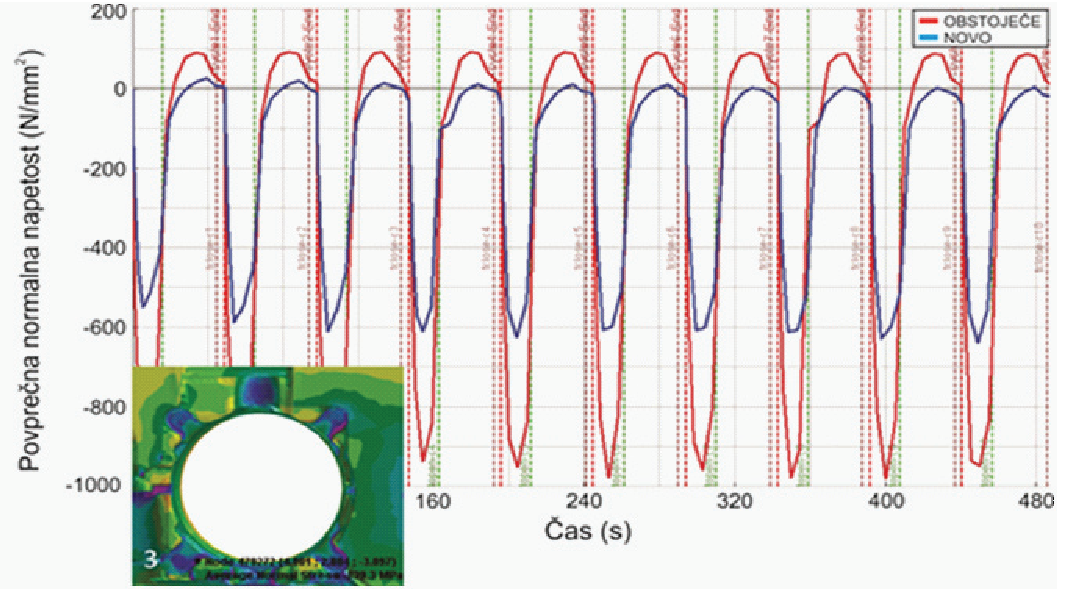


Slika 5: Izračun temperature za prvih 10 ciklov tlačnega litja na obstoječem in novem stabilnem delu orodja

Figure 5: Temperature during cycling in an old (red) and new tool (blue)

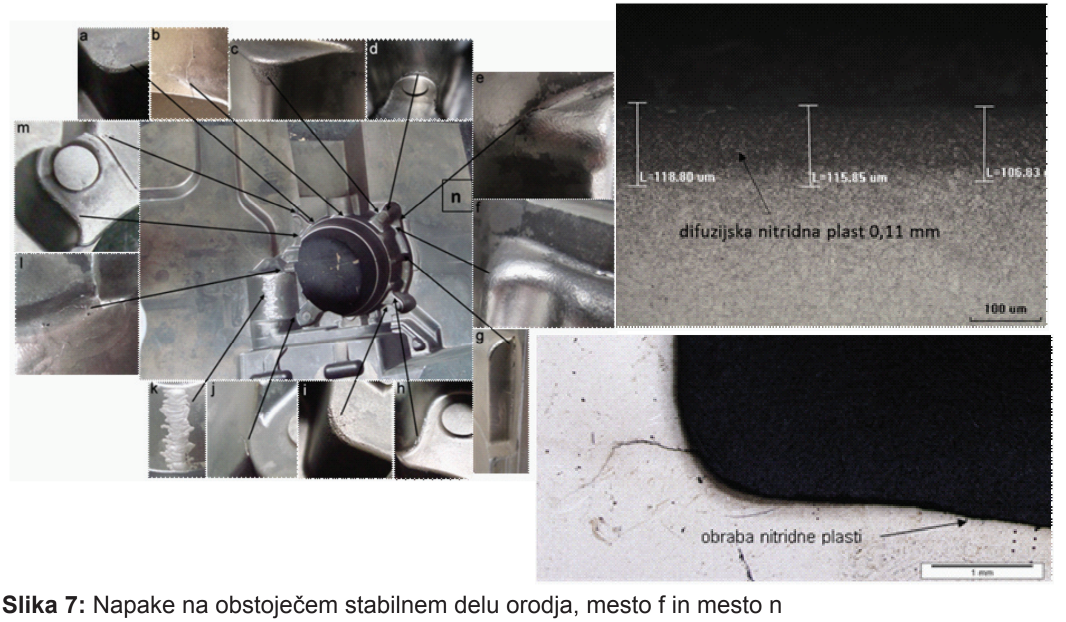
zmanjšala za 60 %. Kritično mesto prikazuje povprečno normalno napetost 109 N/mm^2 na obstoječem razdelilcu in

of thermal loadings presented in Fig. 9 is showing differences in temperatures and average normal stresses for the old and



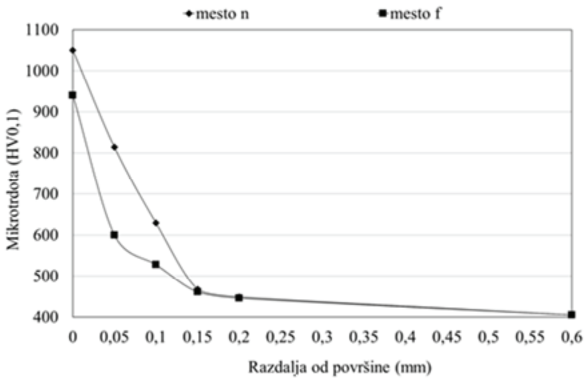
Slika 6: Izračun normalnih napetosti na kritičnem mestu 3 za prvih 10 ciklov tlačnega litja na obstoječem in novem stabilnem delu orodja

Figure 6: Calculated average normal stresses during cycling in an old (red) and new tool (blue)



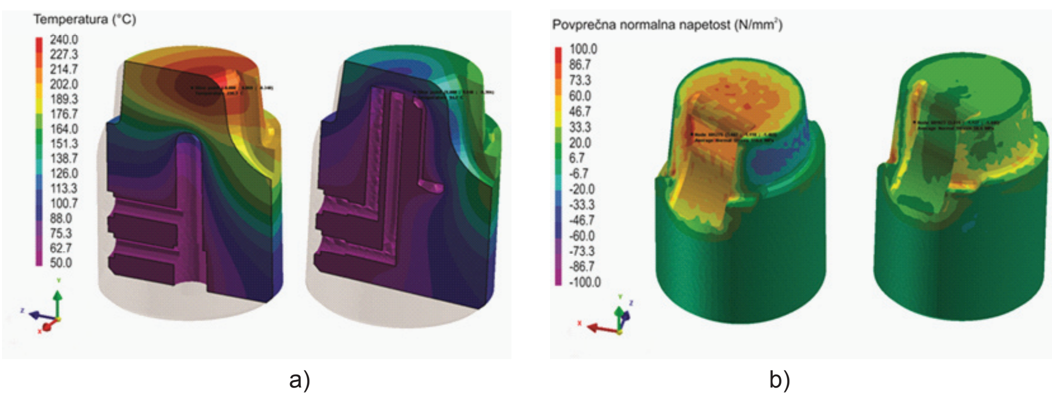
Slika 7: Napake na obstoječem stabilnem delu orodja, mesto f in mesto n

Figure 7: Defects in a tool with thickness and wear of nitrated surface



Slika 8: Profil trdot po metodi Vickers na mestu mehanske obrabe f in na mestu brez mehanske obrabe n

Figure 8: Vickers hardness profiles on spots n and f



Slika 9: Obstoječa stanje rezdelilca (levo) ter novo stan Analiza cikličnega toplotnega obremenjevanja razdelilca

Figure 9: Old (left) and new (right) cooling system of a distributor: thermal field a), average normal stress field b)

58,4 N/mm^2 na novem razdelilcu. Zaradi učinkovitega delovanja novega hladilno-grelnega sistema se je povprečna normalna napetost na razdelilcu zmanjšala za 47 %. Obstoječemu razdelilcu se je življenjska doba iztekla po opravljenih 74928 ciklov litja. Novi razdelilec je opravil 102246 ciklov litja in je še v proizvodnem procesu. Življenjska doba razdelilca se je podaljšala za več kot 36 %.

new distributor. One can see that better and more effective cooling system affects the temperatures, where the temperature in a new distributor is only 94,7 °C while in an old one it is 235,3 °C. In this manner the temperature is 60 % lower. The lowered temperature is leading also to lowered induced stresses where stresses are lowered for 47 % from 109 N/mm^2 to 58,5 N/mm^2 in the most critical spot. The lifetime

4 Zaključki

Analize temperature in napetosti v orodju, opravljene s pomočjo računalniškega orodja ProCAST ter termovizije, so pokazale, da je stabilni del orodja bolj toplotno obremenjen, saj ima za do 130 °C višje temperature kot pomični del orodja. Posledica tega je, da je bila življenjska doba stabilnega dela orodja 73070 ciklov, pomičnega dela pa 95332 ciklov. Na podlagi izračunov je bil postavljen nov hladilno-grelni sistem bližje površini livne votline in izdelano novo orodje. Izračun amplitude povprečnih normalnih napetosti na obstoječem stabilnem orodju znaša 1080 N/mm^2, na novem stabilnem delu orodja pa 700 N/mm^2, kar pomeni daljšo življenjsko dobo orodja. Proizvodnja ulitka je bila prekinjena, zato novo orodje ni bilo do konca testirano.

Podobno so analize na razdelilcih pokazale podoben trend, saj je razdelilec z novim, učinkovitejšim hladilnim sistemom dosegal za 60 % nižjo temperaturo in je bila le 94,7 °C. Posledično so se povprečne normalne napetosti na novem razdelilcu zmanjšale za 47 % in so dosegale amplitudo 58,4 N/mm^2. Obstoječi razdelilec je opravil 74928 ciklov litja, novi pa več kot 102246 ciklov. Življenjska doba razdelilca se je na podlagi izračunanega novega hladilno-grelnega sistema podaljšala za več kot 36 %.

of an old distributor was 74928 cycles while the lifetime of a new one is at least 102246 cycles since it is still tested. In this way the lifetime is increased for more than 36 %.

4 Conclusions

Analyses of a tool made by ProCAST software and by thermal imaging showed that the stable part of a tool has an approximately 130 °C higher temperature which leads to a shorter lifetime of a tool. The stable part of a tool had a lifetime of 72070 cycles while the movable part of a tool had lifetime of 95332 cycles. Based on calculations the new position of the heating-cooling system has been made and the tool produced. This has resulted in lowered temperatures and lowered stresses in the tool. Calculation showed that the amplitude of average normal stresses in an old tool was 1080 N/mm^2 but in a new tool it was decreased to 700 N/mm^2. The lifetime of a new tool should increase but the tool was finally not tested since the casting production was stopped.

Similar analyses were done for the distributor and the same trend of results was observed. The distributor with a new and more effective cooling system reached about 60 % lower temperatures than with an old one. Maximum temperature in the new distributor was 94,7 °C. Lowered temperatures caused for 47 % lower stresses and average normal stresses reached only 58,4 N/mm^2. This lead to increased lifetime for over 36 %. An old distributor made 74928 cycles and the new one made over 102246 cycles and is still running.

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