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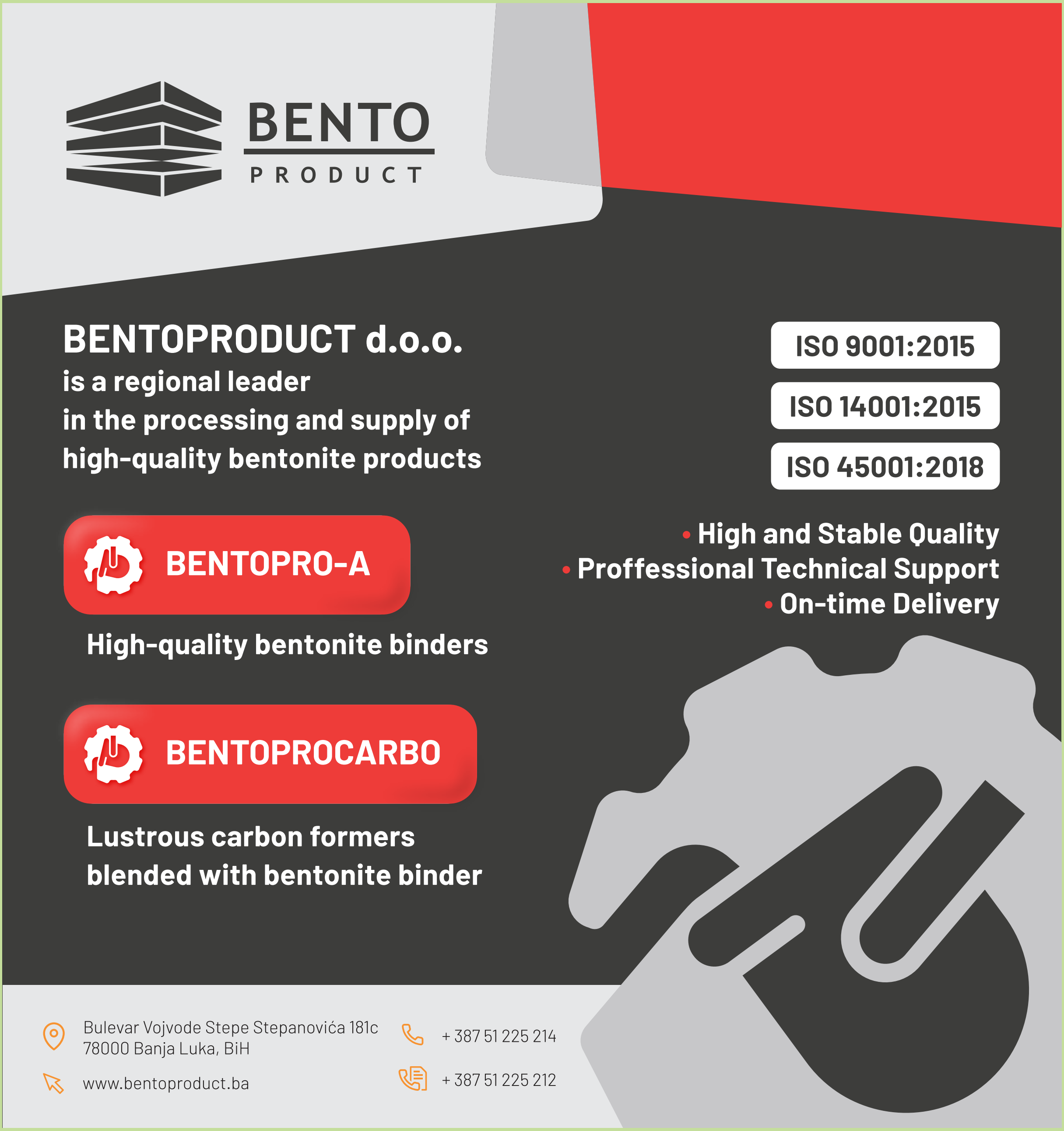

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Vesuvius Inc. (Cleveland Foundry), USA / ZDA

Ocenjevanje dizajnov železnih filtrirnih plošč SEDEX* – 30 let pozneje

Evaluating SEDEX* Iron Filter Print Designs – 30 Years Later

1 Uvod

Ta uvodni prispevek se osredotoča na analizo in vrednotenje več konceptov oblikovanja filtrirne plošče z uporabo programske opreme za simulacijo procesa litja, ki uporablja sofisticirane modele prvega načela za analizo toka tekočine. Cilj tega dela je raziskati težave, s katerimi se srečujejo v livarnah, in povečati koristi filtracije za dovajanje taljene kovine najboljše možne kakovosti v votlino forme, kar zgotavlja proizvodnjo visokokakovostnih ulitkov. Analiza temelji na industrijskih standardih zasnove filtrirnih plošč, ki predstavljajo osnovo za primerjave pretoka tekočine, rezultate pa smo primerjali z zasnovami filtrirnih plošč, ki smo jih spremenili z namenom izboljšanja izkoristka.

V industriji ustaljene filtrirne plošče so opredeljene kot filtrirne plošče, zasnovane med uvodnim razvojem filtrov za železne ulitke. Nekatere ključne zahteve za optimalne rezultate so bile identificirane med razvojem, vključno z naslednjimi.[1–4, 6–11]

- Povečanje izpostavljenosti vhodne strani filtra, da bi zagotovili največji skupni pretok.
- Povečanje podpore (na štirih straneh), da bi zagotovili, da inercijske sile na filter zaradi toka železa ne presežejo trdnosti filtra.
- Zmanjšanje verjetnosti, da bi železo potovalo okoli filtra (in ne skozi njega), in sicer z oblikovanjem podporne strani na izhodu filtrirne plošče, ki se ujema s tolerančnimi dimenzijami filtra.

1 Introduction

This initial work focuses on the analysis and evaluation of several filter print design concepts using casting process simulation software employing sophisticated, first principal fluid flow analysis models. The goal of this work is to investigate problems experienced in foundries and maximise the benefits of filtration to deliver the best possible quality molten metal to the mould cavity, thereby producing high-quality castings. The analysis uses industry standard filter print designs as the baseline for the fluid flow comparisons and compares these results to filter print designs that have been altered for yield improvement.

Industry standard filter prints are defined as those designed during the initial filter development for iron castings. Some of the key requirements for optimal results were identified during the development, including the following.[1-4,6-11]

- Maximise exposure of the filter inlet face to ensure maximum total flow
- Maximise (four-sided) support to ensure that the inertial forces on the filter from the iron flow do not surpass the strength of the filter
- Minimise the possibility of iron passing around (not through) the filter by designing the support ledge on the filter print outlet to match filter tolerance dimensions
- Minimise turbulence by designing the filter print volumes such that the flow smoothly transitions from inlet to outlet

- Zmanjšanje turbulence z oblikovanjem filtrirnih plošč s takšno prostornino, da pretok neovirano prehaja od vhoda do izhoda.

Kombinacije teh značilnosti so se uporabile za opredelitev temeljev za standarde oblikovanja filtrirnih plošč. V zadnjih 30 letih so te zasnove neprekinjeno preskušali, skozi uporabo in med ocenjevanjem v livarnah pa so se rahlo izboljšale. Prve simulacije, izvedene v tej študiji, so bile uporabljene za oceno teh standardnih modelov.

Izboljšanje izkoristka je velika prednostna naloga vseh livarn, dovajalni sistemi kakor tudi vsi drugi postopki litja pa se zaradi zmanjšanja teže skrbno analizirajo. Včasih se za zmanjšanje teže izvedejo spremembe standardnih filtrirnih plošč brez podrobne analize učinka na lastnosti pretoka tekočine dovajalnega sistema.

Spremembe, ki negativno vplivajo na pretok tekočine kovine vodijo v povečanje turbulence, neenakomeren pretok in zmanjšano učinkovitost filtriranja. V tej študiji je bilo ovrednotenih tudi več takšnih situacij.

Rezultati tega prispevka obsegajo več idej o tem, kako najbolje oblikovati filtrirne plošče in razdelilne sisteme, ki so uporabni za vse pripomočke za filtriranje železa.

2 Analitska metoda

Kot izhodišče za začetek analize smo izbrali standardne kvadratne vodoravne in navpične filtrirne plošče 75 mm x 75 mm x 22 mm (2,95 x 2,95 x 0,866 palca). Na obeh vrstah filtrirnih plošč smo izvedli več modifikacij, da bi ocenili učinek takšnih sprememb zasnove na dinamiko tekočin.

Vse analize pretoka tekočine smo izvedli z uporabo programske opreme

These combined characteristics were used to define the basis for standard filter print design. Over the past 30 years, these designs have been continually tested and have slightly evolved through applications and foundry evaluations. The first simulations conducted in this study were used to evaluate these standard designs.

Yield improvement is a high priority for all foundries, and gating systems are analysed as carefully as all other aspects of the casting process to reduce weight. Alterations are sometimes made to standard filter prints to reduce weight without careful analysis of the effect on the fluid flow properties on the gating system.

Changes that adversely affect molten metal fluid flow can result in increased turbulence, non-uniform flow, and a reduction in filtration efficiency. Several of these situations were also evaluated in this study.

The results of this work include several ideas on how to best design filter prints and runner systems that apply to all iron filtration devices.

2 Method of Analysis

Standard 75 mm x 75 mm x 22 mm (2.95 x 2.95 x 0.866 inch) thick square horizontal and vertical filter prints were chosen as the baseline to begin the analysis. Several modifications were made to both types of filter prints to evaluate the effect of these design modifications on fluid dynamics.

All fluid flow analyses were conducted using MAGMA5 (Version 5.3.0.4) with Solver 5. The mesh size for all simulations was approximately 10 million elements (700,000 metal cells). The metal dataset represents ASTM A536-84 (80-55-06/GGG-60) grade ductile iron poured at 1400°C (2552°F) into a sand mould. The plate casting is approximately 305x610x76mm (12x24x3in)

MAGMA5 (različica 5.3.0.4) z dodatkom Solver 5. Velikost mreže za vse simulacije je bila približno 10 milijonov elementov (700.000 kovinskih celic). Nabor podatkov o kovini predstavlja siva litina razreda ASTM A536-84 (80-55-06/GGG-60), v peščeno formo ulita pri temperaturi 1.400 °C (2.552 °F). Ulitek plošče ima dimenzijo pribl. 305 x 610 x 76 mm (12 x 24 x 3 in) in tehta približno 100 kg (220 lb). Skupna teža med litjem je bila približno 110 kg (242 lb).

Filter smo ponazorili s standardnimi podatki o padcu tlaka med filtracijo s peno 10 ppi v primeru 22 mm (0,866 palca) debelega filtra SEDEX[5]. V vseh primerih se je program izvajal s funkcijo »Samodejni nadzor polnjenja«. Program je bil za vse simulacije prisiljen vzdrževati višino taline v livarskem lijaku na 70 %, s čimer so bili zagotovljeni enako pogoji litja v vseh simuliranih različicah. Čas polnjenja je bil za vse konfiguracije približno 24 sekund, kar predstavlja hitrost pretoka približno 4,5 kg/s (10 lb/s).

Zasnove dovajalnega sistema, ocenjene v tem poročilu, so reprezentativne za tiste dovajalne sisteme, ki se uporabljajo v industrijskih standardih, pri visokem tlaku, s svežim peskom ter z avtomatizirano opremo za formanje.

Območje dušenja je bilo izračunano na podlagi Enačbe 1.

$$A = \frac{W}{tDC\sqrt{2gH}} \qquad \text{Enačba (1)}$$

Vrh lijaka smo izračunali z Enačbo 2.

$$A_{\text{Vrh lijaka}} = \frac{V_{PL} \text{ x } A_{PL}}{V_{ST}} \qquad \text{Enačba (2)}$$

Lijak ima zožitev pod kotom treh stopinj, ki omogoča odstranjevanje forme.

Sistem dovodnega kanala temelji na razmerju lijak:razdelilni kanal:dovodni kanal 1,0:1, 1:1,2

in dimension and approximately 100 kg (220 lb) in weight. The total pour weight was approximately 110kg (242lb).

The filter was represented using standard 10ppi, foam filtration pressure drop data for a 22mm (0.866in) thick SEDEX filter[5]. In all cases, the program was run using the “Automatic Filling Control” feature. Specifically, the program was forced to maintain a pouring cup metal height of 70% for all the simulations, thus ensuring identical pouring conditions for all versions simulated. Fill time was approximately 24 seconds for all configurations, representing a flow rate of approximately 4.5kg/s (10lb/s).

The gating designs evaluated in this report are representative of those in use on industry standards, high pressure, green sand, automated moulding equipment.

The choke area was calculated using Equation 1.

$$A = \frac{W}{tDC\sqrt{2gH}} \qquad \text{Eqn. (1)}$$

The top of the sprue was calculated using Equation 2.

$$A_{\text{Sprue Top}} = \frac{V_{PL} \text{ x } A_{PL}}{V_{ST}} \qquad \text{Eqn. (2)}$$

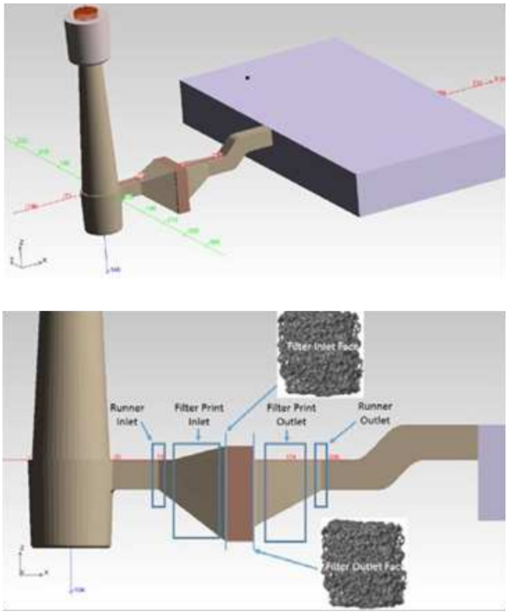
The sprue was tapered at a three-degree angle to allow for mould stripping.

The runner system follows a ratio of Sprue: Runner: Ingate of 1.0:1.1:1.2

The baseline vertical filter print configuration is shown in Figure 1.

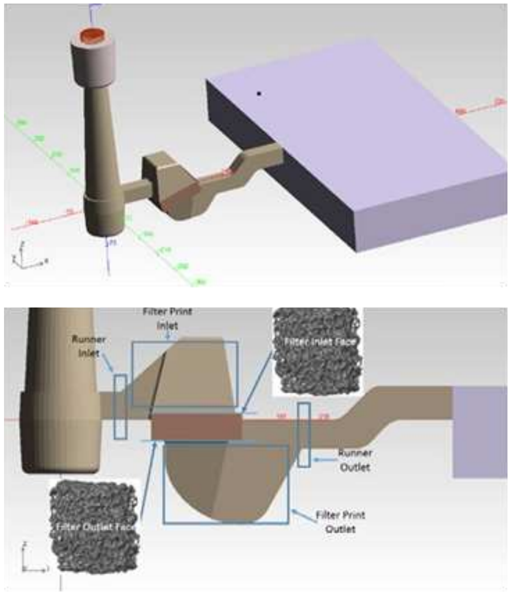
All simulations were conducted on a Dell Precision 7810 Tower workstation utilising 8 cores. CPU time for each simulation was approximately 10 hours.

The baseline horizontal filter print configuration is shown in Figure 2.



Slika 1. Standardna navpična filtrirna plošča

Figure 1. Standard vertical filter print



Slika 2. Standardna vodoravna filtrirna plošča

Figure 2. Standard horizontal filter print

Osnovna navpična konfiguracija filtrirne plošče je prikazana na Sliki 1.

Vse simulacije smo izvedli na delovni postaji Dell Precision 7810 Tower z uporabo 8 jeder. Čas CPE za vsako simulacijo je bil približno 10 ur.

Osnovna vodoravna konfiguracija filtrirne plošče je prikazana na Sliki 2.

3 Rezultati in razprava

Vsi prikazani rezultati pretoka tekočine so analitični in temeljijo na enačbah pretoka Navier-Stokes. Napovedi pretoka iz tega prvega glavnega pristopa dinamike tekočin so več desetletij potrjevali v številnih industrijah in aplikacijah, med drugim tudi v povezavi s tallno. Pričakuje se, da bodo prikazani primerjalni rezultati zelo pomenljivi in natančni. Vendar pa bodo v prihodnjem delu izvedeni livarski preskusi za nadaljnjo

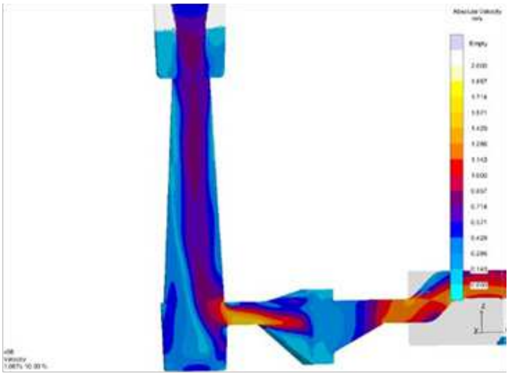
3 Results and Discussion

All fluid flow results shown are analytical and based on the Navier-Stokes flow equations. Flow predictions from this first principal fluid dynamic approach have been validated for several decades in many industries and applications, including molten metal applications. The expectation is that the comparative results shown should be very meaningful and accurate. However, foundry trials will be conducted in future work to further validate the conclusions presented in this paper.

4 Vertical Filter Print Example

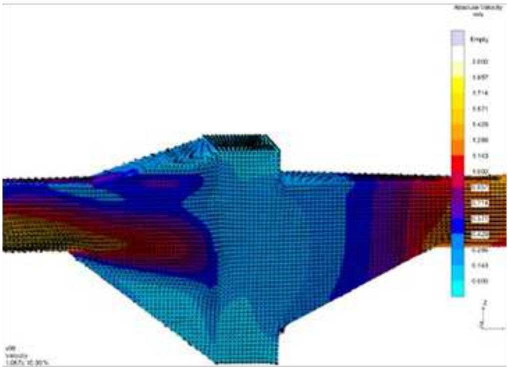
The flow characteristics for a standard vertical filter print are shown in Figure 3. The colors represent flow velocities.

At 10% filled, the flow is a steady state in and around the filter print. The color scale



Slika 3. Prečni prerez sredinske črte dovajalnega sistema standardne navpične filtrirne plošče, hitrost pretoka sistema pri napolnjenosti 10 %

Figure 3. Centerline cross-section of standard vertical filter print gating system flow velocity at 10% filled



Slika 4. Prečni prerez sredinske črte standardne navpične filtrirne plošče, hitrost pretoka pri napolnjenosti 10 %

Figure 4. Centerline cross-section of standard vertical filter print flow velocity at 10% filled

potrditev zaključkov, predstavljenih v tem prispevku.

4 Primer navpične filtrirne plošče

Značilnosti pretoka za standardno navpično filtrirno ploščo so prikazane na Sliki 3. Barve predstavljajo hitrost pretoka.

Pri napolnjenosti 10 % je pretok v filtrirni plošči in okoli nje enakomeren. Barvna lestvica sega od svetlo modre (nizka hitrost, blizu 0,2 m/s (0,66 ft/s) do bele (višja hitrost, blizu 2,0 m/s (6,6 ft/s). Pretok skozi filter je približno 0,3–0,4 m/s (1-1,3 ft/s), pretok pred filtrom pa je laminaren in zajema celoten filter. Pretok za filtrom je enakomeren in stabilen.

Prečni prerez skozi sredino filtrirne plošče v istem časovnem koraku prikazuje hitrost tekočine in vektorje pretoka (Slika 4).

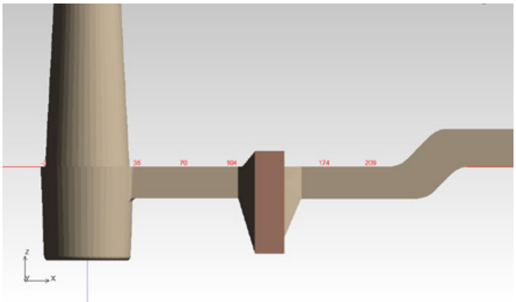
Ta slika jasno prikazuje enakomeren pretok in izkoristek celotne površine filtra za nadzor pretoka in filtracijo. Takšen sistem filtrirne plošče in dovajalnega sistema je goes from light blue (low velocity, near 0.2m/s (0.66 ft/s) to white (higher velocity, near 2.0 m/s (6.6 ft/s). Flow through the filter is approximately 0.3-0.4 m/s (1-1.3 ft/s), and the flow before the filter is laminar and covers the entire filter. Flow after the filter is uniform and stable.

A cross-section through the middle of the filter print at this same time step shows the fluid velocity and flow vectors (Figure 4).

This image clearly shows the uniform flow, and the utilisation of the entire filter face for both flow control and filtration. This can be considered a well-designed filter print and gating system and will serve as a baseline for this vertical filter print section of this study.

In application, extreme changes have sometimes been made to standard filter prints to save weight, increase yield, and/or fit within pattern plate restrictions. Figure 5 shows one actual example.

While this design results in a 35% weight reduction in the filter print design (0.9kgs, 2lbs), the flow characteristics in the



Slika 5. Navpična filtrirna plošča z močno zmanjšano vhodno in izhodno površino

Figure 5. Vertical filter print with filter print inlet and outlet areas significantly reduced

dobro zasnovan in bo služil kot osnova za ta odsek navpične filtrirne plošče v tej študiji.

V praksi se včasih za prihranek pri teži, povečanje izkoristka in/ali izpolnjevanje omejitev vzorčne plošče uporabljajo skrajne spremembe standardnih filtrirnih plošč. Slika 5 prikazuje primer iz prakse.

Ta zasnova omogoča 35-odstotno zmanjšanje teže zasnove filtrirne plošče (0,9 kg, 2 lb), vendar pa ima negativen vpliv na lastnosti pretoka v filtrirni plošči in dovajalnem sistemu.

Slika 6 prikazuje značilnosti pretoka na središčni črti filtrirne plošče in dovajalnega sistema pri napolnjenosti 6,5 %.

(Opomba: rezultati za vse dizajne se primerjajo z rezultati standardnih oblik filtrirnih plošč. Standardni rezultati so prikazani na spodnjih slikah v primerjalnih podobah za primere navpične filtrirne plošče.)

Zaradi ostrih kotov spremenjene vhodne odprtine filtrirne plošče se tok pospeši proti središču vhodne odprtine filtra in se začne nato premikati skozi filter, preden popolnoma napolni območje vhodne odprtine filtrirne plošče. Značilnosti pretoka za standardno zasnovo filtrirne plošče so povezane z bolj enakomerno porazdeljenim filter print and gating system are adversely affected.

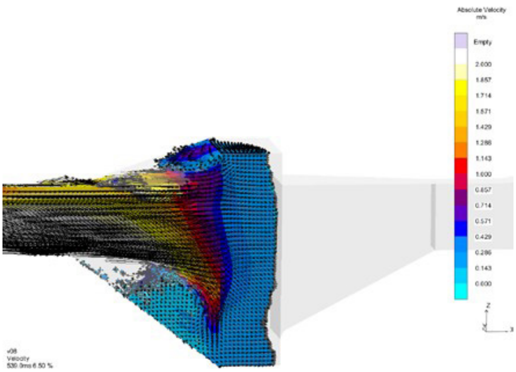
Figure 6 shows the flow characteristics at the centerline of the filter print and gating system at 6.5% filled.

(Note: The results for all designs are compared to the standard filter print design results. The standard results are shown as the bottom image in the comparative figures for the vertical filter print examples.)

Because of the sharp angles of the modified filter print inlet, the flow accelerates into the center of the filter inlet face and begins to move through the filter before completely filling up the filter print inlet area. The flow characteristics for the standard filter print design show a more evenly distributed flow pattern within the filter print inlet and at the filter inlet face.

The high filter inlet faces velocities of the reduced filter print inlet area design results in some very high filter exit face velocities, as shown in Figure 7.

Ideally, the filter should reduce flow energy and turbulence by acting as a flow discontinuity. However, this effect is



Slika 6. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano vhodno in izhodno površino filtrirne plošče, napolnjenost 6,5 %

Figure 6. Flow comparison for vertical filter print with filter print inlet and outlet areas significantly reduced at 6.5% filled

pretokom znotraj vhodne odprtine filtrirne plošče kot tudi na njeni vhodni površini.

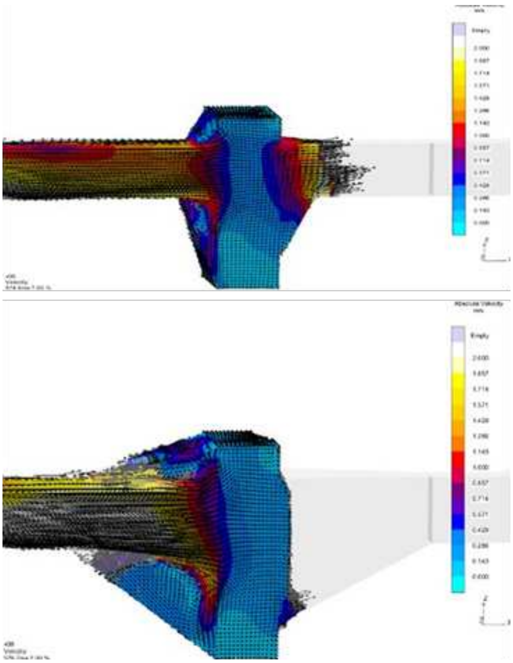
Visoke hitrosti pri vhodni površini filtra v primeru zmanjšane zasnove vhodne površine filtrirne plošče povzročijo zelo visoke hitrosti pri izhodni površini filtra, kot je prikazano na Sliki 7.

V popolnem primeru bi moral filter zmanjšati energijo toka in turbulenco tako, da deluje kot diskontinuiteta toka. Vendar je ta učinek zmanjšan, kadar se uporablja zgolj majhna površina filtra. To je jasno prikazano na Sliki 7, kjer je s filtrirno ploščo z zmanjšano površino povezan tok, ki izstopa iz filtra z visoko hitrostjo, medtem

mitigated if only a small area of the filter is being utilized. This is shown clearly in Figure 7, with the reduced area filter print showing flow exiting the filter at high velocity, while the standard design shows the entire filter filled with metal at very low velocity, and minimal metal flow exiting the filter itself at this time step.

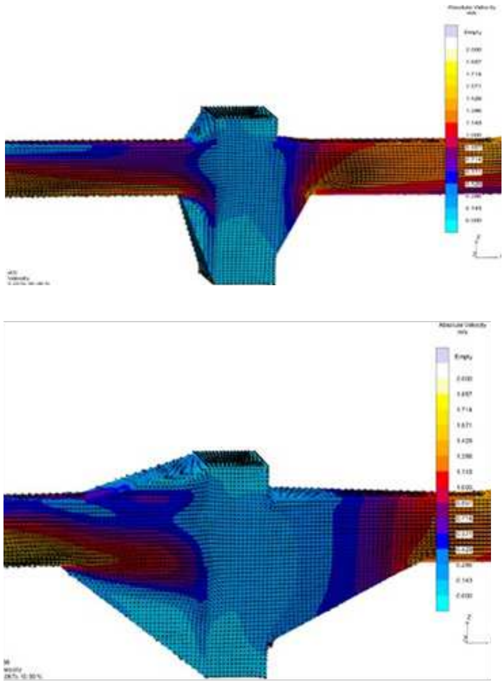
In Figure 8, this continues to be the case even at steady state flow.

Even at a steady state, the reduced area filter print design is not allowing the entire filter print inlet area to be used and instead is pushing the metal through the center of the filter. This results in the non-uniform



Slika 7. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano vhodno in izhodno površino filtrirne plošče, napolnjenost 7,0 %

Figure 7. Flow comparison for vertical filter print with filter print inlet and outlet areas significantly reduced at 7.0% filled



Slika 8. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano vhodno in izhodno površino filtrirne plošče, napolnjenost 10,0 %

Figure 8. Flow comparison for vertical filter print with filter print inlet and outlet areas significantly reduced at 10.0% filled

ko se pri standardni zasnovi celoten filter s kovino napolni pri zelo nizki hitrosti, iz filtra pa v tem koraku izhaja minimalni tok kovine.

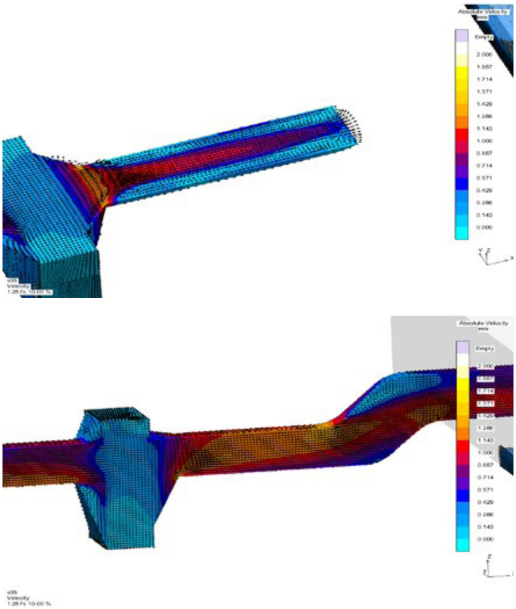
Na Sliki 8 se to nadaljuje tudi v primeru enakomernega pretoka.

Tudi v stabilnem stanju zasnova filtrirne plošče z zmanjšano površino ne dovoljuje uporabe celotnega vhodnega območja filtrirne plošče, temveč se kovina potiska skozi sredino filtra. Posledica je neenakomeren pretok za filtrom in možnost turbulence. To primerjamo s profilom enotnega pretoka pri standardni zasnovi filtrirne plošče, zlasti na izhodni strani filtra, izhodni odprtini filtrirne plošče in navzdol v razdelilnem kanalu.

Prav tako zaradi strmega naklona izhodne odprtine filtrirne plošče tok poteka navzgor, kar negativno vpliva na stabilnost flow behind the filter, and the potential for turbulence. Contrast this with the uniform flow profile shown for the standard filter print design, particularly at the filter outlet face, the filter print outlet, and downstream in the runner.

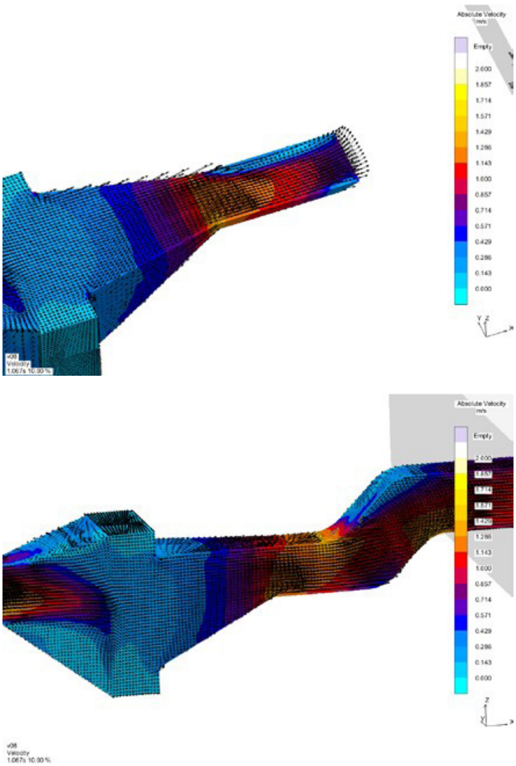
Also, due to the steep angle of the filter print outlet, the flow is launched upward, thus adversely influencing the stability of the flow downstream. This can be seen more clearly in Figure 9.

Figure 9 shows a top view of a cross-section taken near the bottom of the runner bar, just after the filter print. For the reduced



Slika 9. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano vhodno in izhodno površino filtrirne plošče, napolnjenost 10,0 %

Figure 9. Flow comparison for vertical filter print with filter print inlet and outlet areas significantly reduced at 10.0% filled



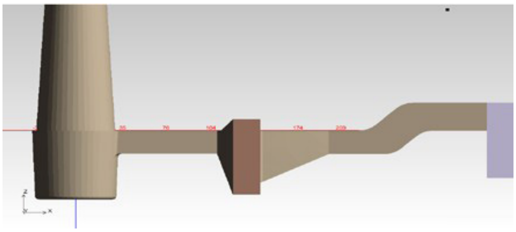
Slika 10. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano vhodno in izhodno površino filtrirne plošče, napolnjenost 10,0 %

Figure 10. Flow comparison for vertical filter print with filter print inlet and outlet areas significantly reduced at 10.0% filled

toka v smeri navzdol. To je jasneje razvidno na Sliki 9.

Slika 9 prikazuje posnetek ptičje perspektive prečnega prereza, posnet blizu dna dovodnega kanala neposredno za filtrirno ploščo. Pri zasnovi filtrirne plošče z zmanjšano površino je treba upoštevati, da se tok na obeh straneh razdelilnega kanala premika zelo počasi, in kar je najpomembneje, da se vrtinči v nasprotni smeri predvidenega toka. Potisk kovinskega toka v smeri navzgor zaradi ostrega kota je ustvaril velik in neugoden vrtinčni tok, ki tok počasi potiska nazaj. Ta položaj obstaja je primeren za spodnjo tretjino tega razdelilnega kanala. Standardna zasnova filtrirne plošče prikazuje območje počasnega toka blizu dna razdelilnega kanala na eni strani, vendar so značilnosti primarnega toka veliko enotnejše z vidika hitrosti in smeri.

Slika 10 prikazuje pogled s strani na razdelilni kanal v istem časovnem koraku in kaže jasno razliko med obema oblikama, pri čemer zagotavlja standardna filtrirna plošča enakomernejši, bolje nadzorovan pretok kovine v ulitek.



Slika 11. Navpična filtrirna plošča z močno zmanjšano vhodno površino filtrirne plošče

Figure 11. Vertical filter print with filter print inlet area significantly reduced

Zmanjšanje površine filtrirne plošče na ta način zagotavlja majhno povečanje izkoristka (0,9 kg oz. 2 funta prihranka) ima znatne škodljive učinke na lastnosti pretoka v vhodni odprtini filtrirne plošče, vhodni

area filter print design, note that the flow at both sides of the runner bar is moving very slowly, and most importantly, in the opposite direction of the intended flow. The upward thrust of the metal flow due to the steep angle has created a large, adverse eddy current driving the flow slowly backward. This situation exists for the bottom third of this runner bar. The standard filter print design shows an area of slow flow near the bottom of the runner on one side, but the primary flow characteristics are much more uniform in velocity and direction.

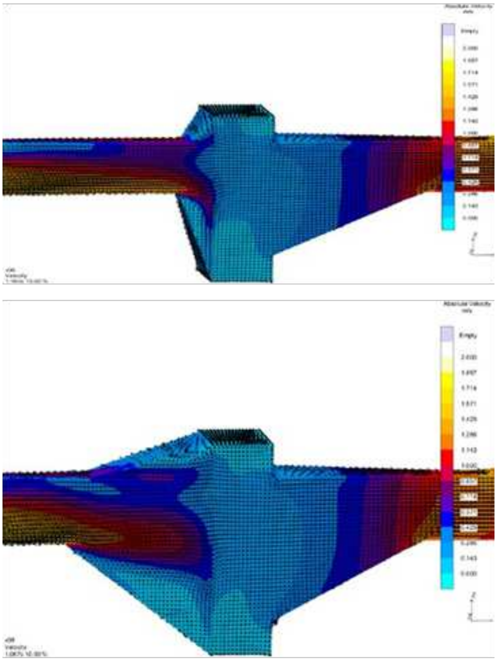
Figure 10 shows a side view of the runner bar at the same time step, and shows a clear difference between the two designs, with the standard filter print providing more uniform, controlled metal flow to the casting.

Reducing the area of the filter print in this fashion to slightly increase yield (0.9kg, 2lbs saved) has significant adverse effects on the flow characteristics in the filter print inlet, the filter inlet face, the filter outlet face, the filter print outlet, and in the downstream runner bar. This type of alteration is not recommended for best practice filter print design.

Figure 11 shows a configuration with the area of the filter print outlet modified to match the standard print shown in Figure 1, but the reduced filter print inlet area is unchanged.

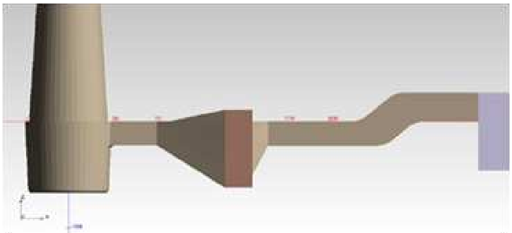
In this case, the issues in the filter print inlet area and at the filter inlet face remain the same as discussed previously, but the flow after the filter shows clear improvement. In Figure 12, note how similar the filter outlet face and filter print outlet flow profiles appear when comparing the reduced filter print inlet area configuration with the standard filter print.

The main difference between this configuration and the standard filter print is the dramatically higher flow velocities at the filter inlet face for the reduced area design



Slika 12. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano vhodno površino filtrirne plošče, napolnjenost 10,0 %

Figure 12. Flow comparison for vertical filter print with filter print inlet area significantly reduced at 10.0% filled



Slika 13. Navpična filtrirna plošča z močno zmanjšano izhodno površino filtrirne plošče

Figure 13. Vertical filter print with filter print outlet area significantly reduced

površini filtra, izhodni površini filtra, izhodni odprtini filtrirne plošče in v spodnjem razdelilnem kanalu. Ta vrsta spremembe za najboljšo prakso oblikovanja filtrirne plošče ni priporočljiva.

and the fact that only a small portion of the filter is being used. This is the same situation discussed in the previous configuration, but the yield argument is even more clear this time.

Reducing the area of the filter print inlet only saves 0.6kg (1.3lb), but adversely affects the flow such that the entire filter area is not being used to efficiently filter inclusions from the metal. Again, this small yield improvement has a significant adverse effect on the flow and is not recommended in practice.

Figure 13 shows a similar design with the area reduced at the filter print outlet only.

Reducing the area of the filter print outlet only will save just 0.3kg (0.66lb), and result in very poor flow exiting the filter print. The flow comparison is shown in Figure 14.

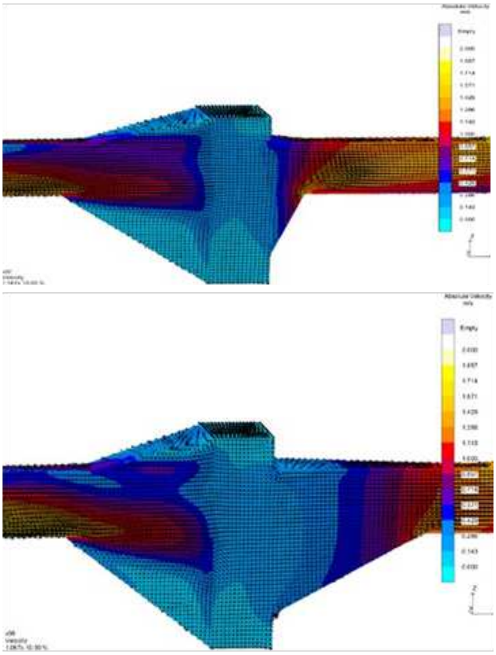
In this case, the flow in the filter print inlet and at the filter inlet face has the same beneficial characteristics as that of the standard filter print. However, the flow at the filter outlet face, within the filter print outlet, and in the downstream runner, bar exhibits all of the same poor characteristics shown in Figures 7-10. A filter print design that adversely affects the flow characteristics and delivers minimal yield improvement should not be considered practical.

5 Vertical Filter Print with Slag Trap Example

Figure 15 shows the standard configuration with an addition of a slag trap before the filter.

This change only adds approximately 0.23kgs (0.5lbs) to the filter print design but results in a positive impact on the overall flow characteristics of the filter print itself.

The filter print with a properly designed slag trap displays all of the high-quality flow characteristics shown in the standard

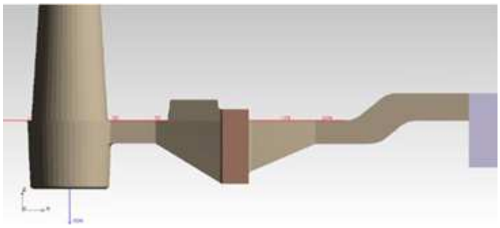


Slika 14. Primerjava pretoka za navpično filtrirno ploščo z močno zmanjšano izhodno površino filtrirne plošče, napolnjenost 10,0 %

Figure 14. Flow comparison for vertical filter print with filter print outlet area significantly reduced at 10.0% filled

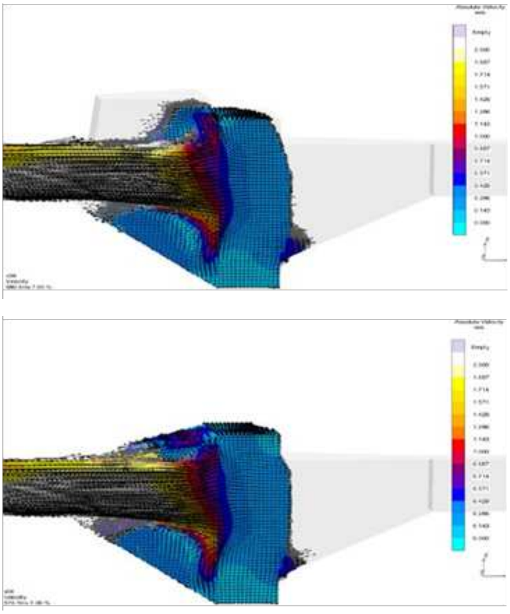
Slika 11 prikazuje konfiguracijo s spremenjeno površino izhodne odprtine filtrirne plošče, ki je enaka standardni plošči, prikazani na Sliki 1, vendar je zmanjšana vhodna površina filtrirne plošče nespremenjena.

V tem primeru se ohranijo težave v površini vhodne odprtine pri filtrirni plošči in na sprednji strani vhodne odprtine filtra, kot je že bilo omenjeno, vendar pa se tok za filtrom očitno izboljša. Na Sliki 12 je mogoče opaziti, kako zelo podobni so profili toka izhodne odprtine filtra in izhodne odprtine filtrirne plošče, če primerjamo konfiguracijo zmanjšane vhodne površine filtrirne plošče s standardno filtrirno ploščo.



Slika 15. Standardna navpična filtrirna plošča z lovilnikom žlindre

Figure 15. Standard vertical filter print with slag trap



Slika 16. Primerjava pretoka standardne navpične filtrirne plošče z lovilnikom žlindre in brez njega pri napolnjenosti 7,0 %

Figure 16. Flow comparison for standard vertical filter print with and without slag trap at 7.0% filled

filter print, with the added benefit of better filter print inlet flow and potentially better filtration efficiency. Figure 16 shows how the trap begins to work as soon as the metal reaches the filter.

Glavna razlika med to konfiguracijo in standardno filtrirno ploščo je bistveno višja hitrost pretoka na vhodni površini filtra pri zasnovi z zmanjšano površino in dejstvo, da se uporablja zgolj majhen del filtra. Gre za enako situacijo, o kateri smo razpravljali pri prejšnji konfiguraciji, vendar je argument izkoristka tokrat še bolj očiten.

Zmanjšanje površine vhodne odprtine filtrirne plošče prihrani samo 0,6 kg (1,3 lb), vendar negativno vpliva na pretok, tako da se celotno območje filtra ne uporablja za učinkovito filtriranje vključkov iz kovine. Tudi to majhno izboljšanje izkoristka ima znaten škodljiv učinek na pretok in se v praksi ne priporoča.

Slika 13 prikazuje podobno zasnovo z zmanjšano površino samo na izhodu filtrirne plošče.

Z zmanjšanjem površine samo izhodne odprtine filtrirne plošče se prihrani zgolj 0,3 kg (0,66 lb), pretok pri izhodu iz filtrirne plošče pa se močno poslabša. Primerjava pretoka je prikazana na Sliki 14.

V tem primeru ima pretok v vhodni odprtini filtrirne plošče in na vhodni strani filtra enako ugodne lastnosti kot pri standardni filtrirni plošči. Vendar ima tok na izhodni strani filtra znotraj izhodne odprtine filtrirne plošče in v spodnjem razdelilnem kanalu enake negativne lastnosti, kot so prikazane na Slikah 7–10. Zasnova filtrirne plošče, ki negativno vpliva na značilnosti pretoka in zagotavlja minimalno izboljšanje izkoristka, ne velja za praktično.

5 Primer navpične filtrirne plošče z lovilnikom žlindre

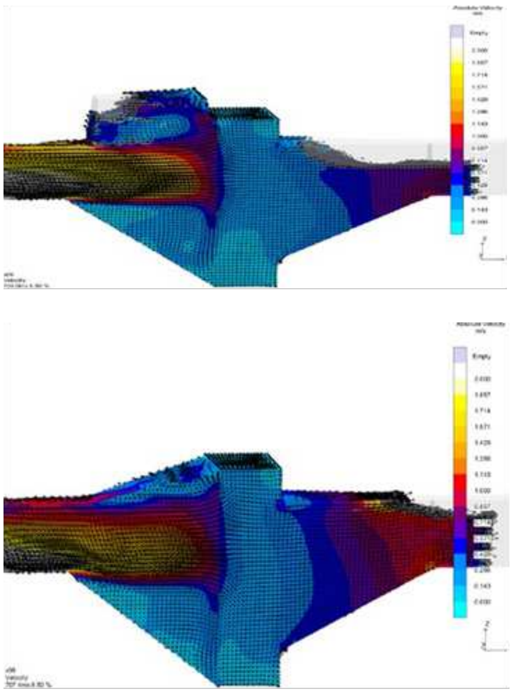
Slika 15 prikazuje standardno konfiguracijo z vključitvijo lovilnika žlindre pred filtrom.

Ta sprememba doda zasnovi filtrirne plošče samo približno 0,23 kg (0,5 lb), vendar je njena posledica pozitiven vpliv

Note that the bottom of the filter print inlet has filled quickly and that the flow is washing the filter inlet face and moving upwards into the slag trap area.

At 8.5% (Figure 17), the flow is nearly stabilised, and the slag trap is forcing the initial metal into a beneficial counter-clockwise eddy current, thus potentially allowing inclusions to reverse direction and slowly float upward into the trap. The standard filter print without the slag trap also has a small area of beneficial eddy currents at the top of the filter print inlet, but very little space to trap and retain inclusions.

By 9% filled (Figure 18), the filter print is fully flooded, including the slag trap.



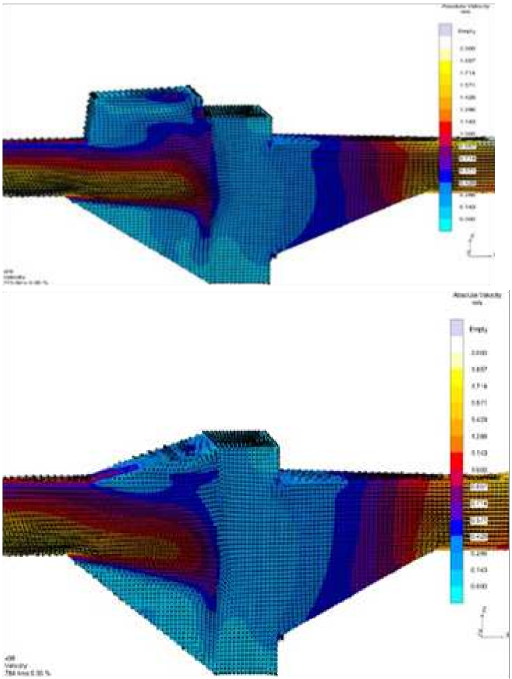
Slika 17. Primerjava pretoka standardne navpične filtrirne plošče z lovilnikom žlindre in brez njega pri napolnjenosti 8,5 %

Figure 17. Flow comparison for standard vertical filter print with and without slag trap at 8.5% filled

na splošne lastnosti pretoka same filtrirne plošče.

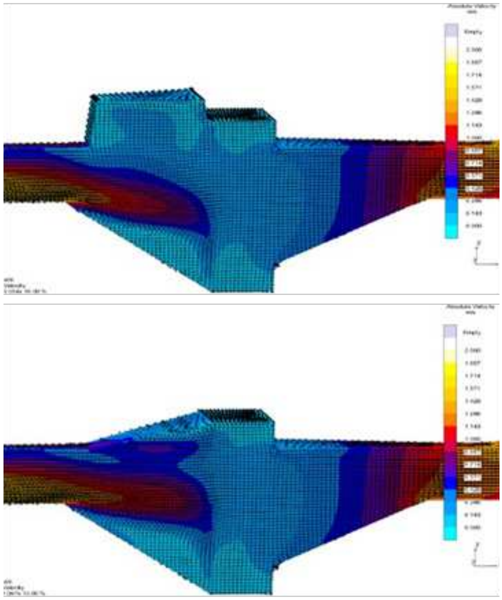
Filtrirna plošča s pravilno oblikovanim lovilnikom žlindre prikazuje vse lastnosti visokokakovostnega pretoka, kot so

There are still some small beneficial eddy currents in the trap. By 10% filled (Figure 19), the filter print is fully stabilised and any inclusions that entered the slag trap will remain.



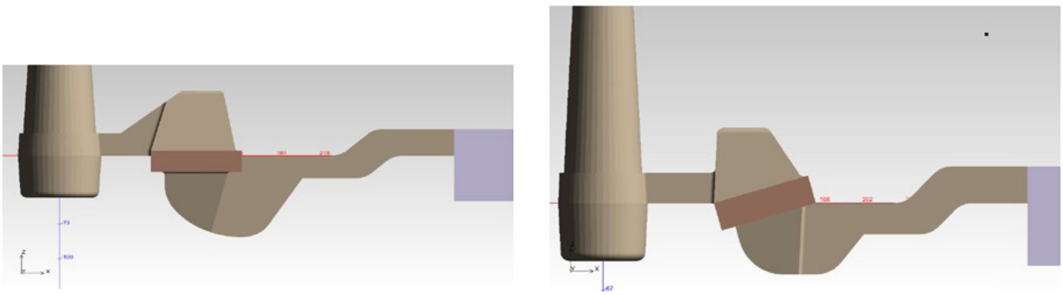
Slika 18. Primerjava pretoka standardne navpične filtrirne plošče z lovilnikom žlindre in brez njega pri napolnjenosti 9,0 %

Figure 18. Flow comparison for standard vertical filter print with and without slag trap at 9.0% filled



Slika 19. Primerjava pretoka standardne navpične filtrirne plošče z lovilnikom žlindre in brez njega pri napolnjenosti 10,0 %

Figure 19. Flow comparison for standard vertical filter print with and without slag trap at 10.0% filled



Slika 20. Standardna in poševna filtrirna plošča

Figure 20. Standard vs angled horizontal filter print

značilne za standardne filtrirne plošče, z dodatno prednostjo boljšega vhodnega pretoka filtrirne plošče in potencialno učinkovitejše filtracije. Slika 16 prikazuje, kako lovilnik začne delovati v trenutku, ko kovina doseže filter.

Pomnite, da se je dno vhodne površine filtrirne plošče napolnilo hitro in da tok izpira vhodno površino filtra in se premika navzgor v območje lovilnika žlindre.

Pri napolnjenosti 8,5 % (Slika 17) je tok skoraj stabiliziran in lovilnik žlindre prisili začetno kovino v ugoden vrtinčni tok v nasprotni smeri urinega kazalca, kar potencialno omogoča vključkom, da spremenijo smer in počasi lebdijo navzgor v lovilnik. Standardna filtrirna plošča brez lovilnika žlindre ima tudi majhno območje koristnih vrtinčnih tokov na vrhu vhoda filtrirne plošče, a hkrati zelo malo prostora za lovljenje in zadrževanje vključkov.

Pri napolnjenosti 9 % (Slika 18) je filtrirna plošča v celoti zalita, vključno z lovilnikom žlindre. V lovilniku se ohrani nekaj majhnih koristnih vrtinčnih tokov. Pri napolnjenosti 10 % (Slika 19) je filtrirna plošča popolnoma stabilizirana in vsi vključki, ki so vstopili v lovilnik žlindre, bodo ostali ujeti.

Dodatek majhne površine za lovljenje žlindre v vhodni odprtini filtrirne plošče izboljša značilnosti zasnove razdelilnega kanala in zmožnost ujemanja vključkov filtrirne plošče. Gre za pomembne koristi ob minimalnem zmanjšanju izkoristka.

6 Primer vodoravne filtrirne plošče

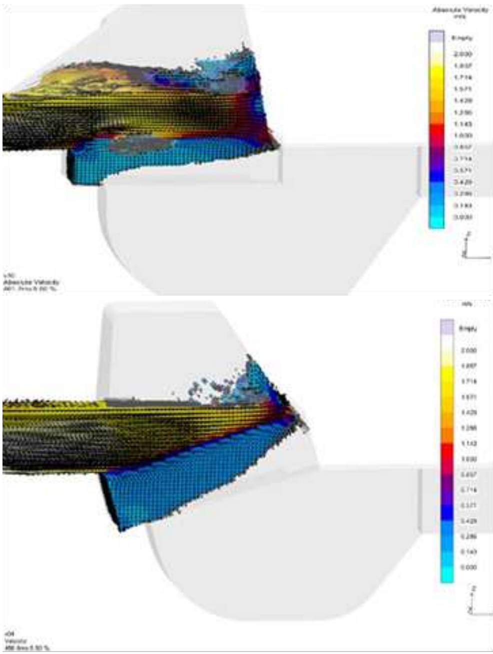
Pri vodoravnih zasnovah filtrirnih plošč je mogoče zagotoviti nekaj pomembnih prednosti v povezavi z učinkovitostjo filtracije preprosto s postavitvijo filtra pod kotom glede na tok. Slika 20 prikazuje standardno vodoravno filtrirno ploščo v

Adding a small area to trap slag in the filter print inlet improves the flow characteristics of the runner design and the ability of the filter print to trap inclusions. These are significant benefits for a minimal reduction in yield.

6 Horizontal Filter Print Example

For horizontal filter print designs, some significant advantages to filtration efficiency can be gained simply by placing the filter at an angle relative to the flow. Figure 20 shows a standard horizontal filter print compared to an angled filter print configuration.

Figure 21 shows the flow velocity comparison at 5.5% filled.



Slika 21. Primerjava pretoka med standardno in poševno filtrirno ploščo pri napolnjenosti 5,5 %

Figure 21. Flow comparison for standard vs angled horizontal filter print at 5.5% filled

primerjavi s konfiguracijo filtrirne plošče pod kotom.

Slika 21 prikazuje primerjavo hitrosti pretoka pri napolnjenosti 5,5 %.

Filter pod kotom lažje sprejme tok in zagotavlja bolj enoten vzorec toka znotraj filtra in nad vhodno površino.

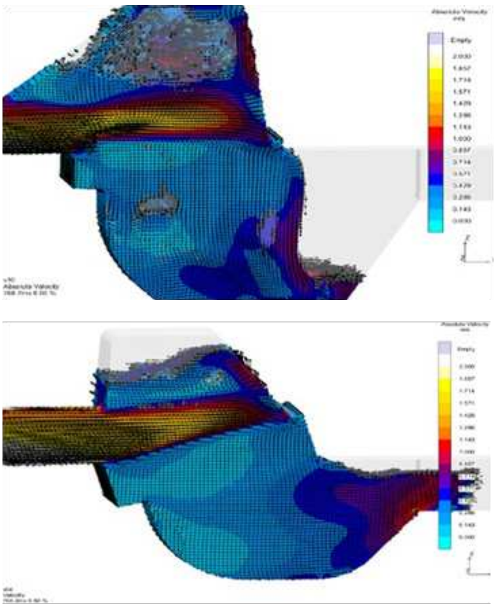
Pri napolnjenosti 8,5 % (Slika 22) je profil toka filtrirne plošče pod kotom v celoti vzpostavljen in popolnoma enakomeren. Koristni vrtinčni tok je viden na vhodu filtrirne plošče ter povečuje učinkovitost lovilnika žlindre. Nastanek vrtinčnega toka je neposredna posledica filtra pod kotom.

Pri 10-odstotni napolnjenosti (Slika 23) obe filtrirni plošči delujeta v enakomernem stanju in ustvarjata enoten vzorec toka.

The angled filter more readily accepts the flow and provides a more uniform flow pattern both within and above the filter inlet face.

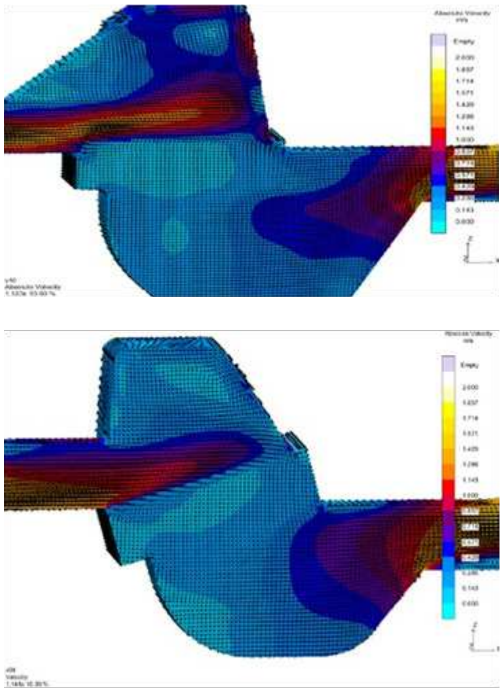
At 8.5% filled (Figure 22), the angled filter print flow profile is fully established, and uniform throughout. A beneficial eddy current is visible within the filter print inlet which enhances the effectiveness of the slag trap. The formation of the eddy current is a direct result of the angled filter.

At 10% filled (Figure 23), both filter prints are operating at steady state conditions, and both produce a uniform flow pattern. The angled design does a better job of distributing and minimising the flow energy at the filter inlet face and outlet face.



Slika 22. Primerjava pretoka med standardno in poševno filtrirno ploščo pri napolnjenosti 8,5 %

Figure 22. Flow comparison for standard vs angled horizontal filter print at 8.5% filled



Slika 23. Primerjava pretoka med standardno in poševno filtrirno ploščo pri napolnjenosti 10,0 %

Figure 23. Flow comparison for standard vs angled horizontal filter print at 10.0% filled

Zasnova pod kotom bolje porazdeli in zmanjša energijo pretoka na vhodni in izhodni strani filtra.

Druga prednost filtra pod kotom je, da se tok usmeri čez vhodno stran filtra in potencialno odstrani vse vključke, ki so se morda ujeli v sam filter. Ti odstranjeni odmaknjeni vključki bi se nato lahko ujeli v vrtinčni tok in se mehansko premaknili v lovilnik žlindre.

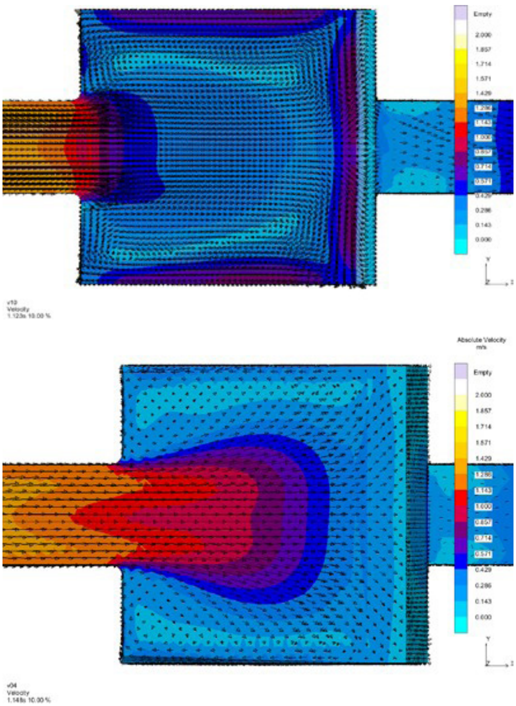
Hitrosti na vhodni strani filtra so prikazane v ptičji perspektivi na Sliki 24.

(Da bi ustvarili sliko za filter pod kotom, je bila prirezana ravnina zasukana okoli osi y, da se ujema z ravnino filtra.) Slika 24 dejansko prikazuje ptičjo perspektivo profila

Another advantage of angling the filter is to direct the flow across the filter inlet face to potentially dislodge any inclusions that may have become trapped on the filter itself. These dislodged inclusions could then get entrained into the eddy current and be mechanically moved into the slag trap.

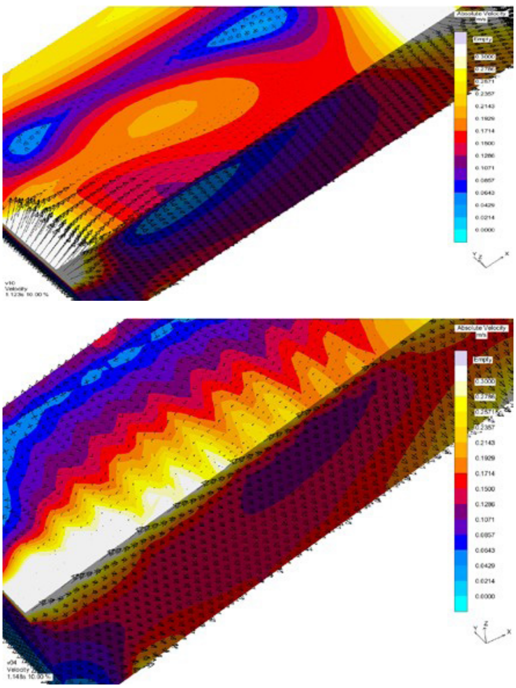
The velocities at the filter inlet face are shown in the top view in Figure 24.

(To create the image for the angled filter, the clipping plane was rotated around the y-axis to match the plane of the filter.) Figure 24 essentially shows a top view of the flow profile at the filter inlet face. For both cases, the metal flow is clearly moving across the filter inlet face from one end



Slika 24. Primerjava pretoka na vhodni površini filtra med standardno in poševno filtrirno ploščo pri napolnjenosti 10,0 %

Figure 24. Flow comparison at the filter inlet face for standard vs angled horizontal filter print at 10.0% filled



Slika 25. Primerjava pretoka na središčni črti filtra za standardno in poševno filtrirno ploščo pri napolnjenosti 10,0 %

Figure 25. Flow comparison at filter centerline for standard and angled horizontal filter print at 10.0% filled

toka na vhodni strani filtra. V obeh primerih se tok kovine očitno premika prek vhodne strani filtra od enega konca do drugega, kar je bolj izrazito pri filtru pod kotom, kot je razvidno na sliki spodaj. Pri filtru pod kotom se tudi tok skozi filter pomika hitreje, kot je prikazano na Sliki 25.

Podobe na Sliki 25 predstavljajo zgolj geometrijo filtra (brez filtrirne plošče ali dovajalnega sistema), podobe pa so zasukane zaradi lažje primerjave. Slika zgoraj prikazuje standardno vodoravno usmerjeno konfiguracijo, medtem ko slika spodaj prikazuje konfiguracijo filtra pod kotom.

Filtri so bili prerezani vzdolž središčne črte, lestvica pa je bila prilagojena (zmanjšana) tako, da prikaže smer toka in jasneje razmeji razlike v hitrosti.

S tega pogleda slika spodaj prikazuje izpiranje vhodne površine filtra pod kotom, ki jo predstavljajo vzporedni vektorji na vhodni strani filtra in celo nekaj milimetrov znotraj globine samega filtra. Če primerjamo, nakazujeta samo dva majhna odseka vodoravnega filtra (zgornja slika) vzporedni tok na vhodni strani filtra, pa še to samo na površini samega filtra in ne v njegovi globini.

Prednosti mehanskega delovanja premikanja vključkov od vhodne površine filtra do lovilnika žlindre so dvakratne: filtru omogoča, da deluje pri največjem pretoku, ker je na površini filtra ujetih manj delcev, ki omejujejo pretok kovine skozi filter. Poleg tega lahko v primeru kovin, ki vsebujejo znatne količine žlindre, to omogoči delovanje filtra z večjo zmogljivostjo kot pri standardno orientiranih filtrirnih plošč, saj lahko skozi njih prehaja več kovine, preden se na koncu zamaši ali obloži z žlindro ali drugimi vključki.

Na splošno je postavitev filtra pod naklonom glede na tok kovine koristna za hitrost pretoka filtra in učinkovitost filtracije.

to the other, but more prominently in the angled filter case, as seen in the bottom image. For the angled filter, the flow is also moving more quickly through the filter, as shown in Figure 25.

The images in Figure 25 represent only the filter geometry (no filter print or gating), and the images are rotated for comparative viewing and as such are not in their normal orientation. The top image represents the standard horizontally oriented configuration while the bottom image represents the angled filter configuration.

The filters have been sectioned along the centerline, and the scale has been adjusted (reduced) to show the flow direction and to delineate more clearly the velocity differences.

From this view, the bottom image shows the washing of the angled filter inlet face, represented by the parallel vectors on the filter inlet face and even a few millimeters into the filter thickness itself. By comparison, only two small sections of the horizontal filter (top image) show parallel flow at the filter inlet face, and even then, only on the surface of the filter itself, not into the filter thickness.

The benefits of the mechanical action of moving inclusions from the filter inlet face to the slag trap are two-fold. This action allows the filter to operate at maximum flow rate because there are fewer particles trapped on the surface of the filter restricting the metal flow through the filter. In addition, for metal-containing significant slag levels, may also allow the filter to operate at a higher capacity than standard filter print orientations because of the opportunity to pass more metal through the filter before ultimately becoming blocked or caked with slag or other inclusions.

Overall, placing the filter at an incline relative to the metal stream is beneficial to the filter flow rate capability and filtration efficiency.

7 Sklepi

Včasih se za izboljšanje izkoristka izvedejo spremembe standardnih filtrirnih plošč brez podrobne analize učinka na lastnosti pretoka tekočine v dovajalnem sistemu. Ta začetna študija je ovrednotila učinek več sprememb zasnove filtrirnih plošč na kakovost pretoka kovine v filtrirni plošči, dovodnem kanalu kot tudi skozi sam filter.

Na splošno so zaključki naslednji:

- Velika zmanjšanja vhodnih in izhodnih površin filtrirne plošče ter ostri koti v sami plošči negativno spremenijo značilnosti toka, kar privede do neenakomernega toka in turbulence.
  >> Izboljšanje izkoristka je minimalno
  >> Ni priporočljivo
- Lovilnik žlindre pred vhodno površino filtra sproži vrtinčni tok, ki se suče levo, ki deluje na površino filtra in pomaga pri lovljenju vključkov.
  >> Priporočeno
- Pri vodoravnih aplikacijah je nagib filtra glede na tok kovine koristen za zagotavljanje hitrosti pretoka skozi filter in učinkovito filtracijo.
  >> Priporočeno

Ta prispevek predstavlja začetno, teoretično študijo različnih modelov filtrirnih plošč SEDEX in njihovega vpliva na značilnosti pretoka. Načrtovano je prihodnje delo za pregled dodatnih konceptov oblikovanja in validacijo teh konfiguracij z uporabo staljene kovine.

7 Conclusions

Alterations are sometimes made to standard filter prints to improve yield without careful analysis of the effect on the fluid flow properties of the gating system. This initial study evaluated the effect of several filter print design changes on the quality of metal flow in the filter print, the runner system, and through the filter itself.

In general, the conclusions are as follows:

- Large reductions in filter print inlet and outlet areas, and sharp angles within the print itself adversely alter the flow characteristics resulting in non-uniform flow and turbulence
  >> Yield improvement is minimal
  >> Not recommended
- A slag trap designed before the filter inlet face induces a counter-clockwise eddy current that washes the filter face and assists with the trapping of inclusions.
  >> Recommended
- In horizontal applications, angling the filter relative to the metal stream is beneficial to the filter flow rate capability and filtration efficiency.
  >> Recommended

This paper constitutes the initial, theoretical study of various SEDEX filter print designs and their effect on flow characteristics. Future work is planned to review additional design concepts and validate these configurations with molten metal.

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Oblikovanje in izdelava ulitka bata motorja indijskega lahkega motornega vozila s postopkom tridimenzionalnega tiska: študija

Design and Manufacture of Engine Piston Casting of Indian Light Motor Vehicle by Three-Dimensional Printing Process: A Study

Povzetek

Indija je četrti največji proizvajalec lahkih motornih vozil (LMV) na svetu. V Indiji se letno proizvede okoli štiri milijone lahkih motornih vozil. Avtomobil je vozilo s kolesi, ki nosi lastno težo in je namenjeno prevažanju med destinacijami. Sestavljen je iz pribl. 15.000 delov, ki tvorijo njegove podsisteme, kot so motor, pogonski sistem, vzmetenje, zavorni sistem, električni sistemi, šasija in karoserija. Beseda »avtomobil« izhaja iz grške besede »autos«, ki pomeni »jaz«, in latinske besede »mobiles«, ki pomeni »gibljiv«. Avtomobile lahko glede na zmogljivost razvrstimo na dvokolesnike, trikolesnike, lahka motorna vozila, gospodarska vozila (tovornjaki in avtobusi). Lahka motorna vozila poganjajo motorji z notranjim zgorevanjem (ICE), ki delujejo na bencin, dizel, plin ali elektriko. Podsisteme motorjev z notranjim izgorevanjem sestavljajo okrov motorja, glava valja, bat z ojnico, ročična gred vključno z odmično gredjo in ventili. Bat je del motorja, ki toplotno in tlačno energijo, ki nastane pri zgorevanju goriva, pretvori v mehanska dela. Bat motorja je najkompleksnejši sestavni del pri avtomobilu. Izmed vseh sestavnih delov zahtevajo bati največ spretnosti za načrtovanje ulitka, ki obsega tradicionalne proizvodne postopke, in sicer litje v pesek, tlačno litje in litje s stiskanjem. Tradicionalne metode so dolgotrajnejše, med postopki pa se zavrže večja količina kovine. Zato se je treba poslužiti najnovejšega proizvodnega postopka, ki se imenuje tridimenzionalno tiskanje (3DPP). Gre za novonastajajočo proizvodno tehnologijo, ki se uporablja za izdelavo dejanskih delov z uporabo podatkov CAD, in sicer z dodajanjem materiala različnih oblik (trdni, tekoči in praškasti) v plasteh. S tehnologijo 3-D tiskanja je mogoče natisniti predmet plast za plastjo z nanosom materiala neposredno iz računalniško podprtega modela.

Večina proizvajalcev batov se poslužuje običajnih proizvodnih metod. Zato smo v tem prispevku proučili načrtovanje in izdelavo ulitja bata s pomočjo tehnologije 3DPP.

Ključne besede: avtomobil, lahko motorno vozilo, motor z notranjim izgorevanjem, zasnova bata, postopek 3-D tiskanja

Abstract

India is the fourth largest light motor vehicle (LMV) manufacturer in the world. It produces around four million LMVs annually. An automobile is a wheeled vehicle that carries its own weight and transports from one destination to another. It consists of around 15,000 parts for its sub-systems like engine, transmission, suspension, brake system, electrical systems and chassis and body. The word ‘automobile’ is derived from Greek ‘autos’ meaning ‘self’, and Latin ‘mobiles’ meaning ‘moveable’. Automobiles may be classified from the point of capacity are two-wheelers, three-wheelers, light motor vehicles, and commercial vehicles (trucks and buses). LMVs are propelled by internal combustion engines (ICE) which are fueled by either petrol, diesel, gas, and electricity. ICE sub-systems comprise of cylinder block, cylinder head, piston with connecting rod, and crankshaft including camshaft and valves. The piston is the part of the engine which converts heat and pressure energy liberated by fuel combustion into mechanical works. An engine piston is the most complex component among the automobiles. Out of these components pistons are required high skill to design the casting which involves traditional manufacturing processes namely sand casting, pressure die casting, and squeezed casting. The traditional methods are time-consuming and more wastage of metal. So, there is a need to go for the latest manufacturing process called three-dimensional printing process (3DPP). It is an emerging manufacturing technology used to fabricate real-life parts, using CAD data by adding material in layer fashion in distinct forms (solid, liquid, and powder). 3-D printing technology can print an object layer by layer deposition of material directly from a computer-aided design model.

Most of the piston manufacturers have been following conventional methods for the manufacture of piston casting. Hence in the present work, an attempt has been made to study the design and manufacturing of piston casting by 3DPP.

Keywords: Automobile, Light Motor Vehicle, I C Engine, Piston design, 3 D Printing Process

1 Uvod

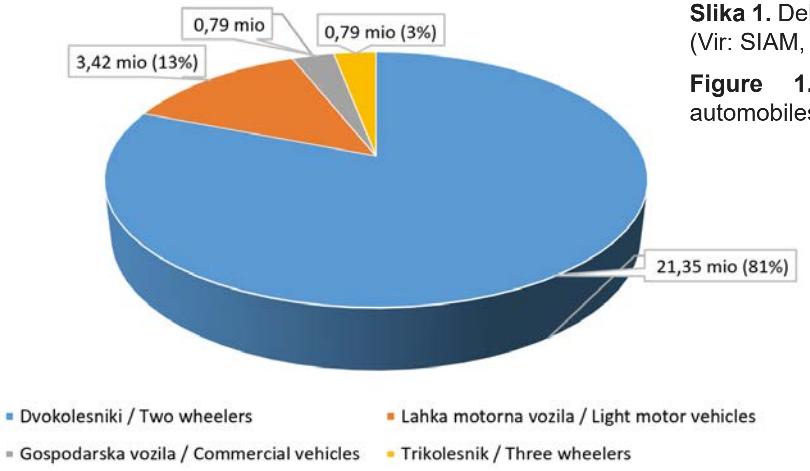
Indijska avtomobilska industrija je v letu 2020 proizvedla približno [1–3] 26,36 milijona vseh avtomobilov, vključno s 3,42 milijona (13 %) lahkih motornih vozil. Avtomobil [4] je vozilo na kolesih, ki nosi lasten motor in prevaža potnike od enega cilja do drugega. Avtomobil je sestavljen iz sedmih glavnih podsistemov: motorja, pogonskega sistema, šasije, karoserije, zavornega sistema, vzmetenja in električnega sistema. Avtomobile lahko glede na zmogljivost razvrstimo na dvokolesnike in trikolesnike, lahka motorna vozila in gospodarska vozila. Indijski tržni delež avtomobilov je prikazan na Sliki 1. Levji delež trga predstavljajo dvokolesniki (81 %), ki jim sledijo lahka motorna vozila (13 %).

Sistem lahkega motornega vozila [5] je sestavljen iz šasije, motorja, električnega sistema, pogonskega sistema, sistema vzmetenja, zavornega sistema in karoserije. Šasija obsega motor, pogonski sistem, sistem vzmetenja, krmilni sistem in zavore.

1 Introduction

Indian automobile industry produces around [1-3] 26.36 million of all automobiles including 3.42 million (13%) LMVs in the year 2020 AD. An automobile [4] is a wheeled vehicle that carries its own motor and transports passengers from one destination to another destination. An automobile consists of major seven sub-systems like engine, transmission system, chassis, body, braking system, suspension system and electrical system. Automobiles may be classified from the point of capacity as two and three wheelers, light motor vehicles, and commercial vehicles. The Indian market share of automobiles are depicted in the Figure 1. Lion's share of market is two wheelers (81%) followed by LMVs (13%).

An LMV system [5] consists of a chassis, engine, electrical system, transmission system, suspension system, brake system, and body. The chassis houses the engine, transmission system, suspension system,



Slika 1. Deleži na trgu avtomobilov (Vir: SIAM, Indija)

Figure 1. Market share of automobiles (Source: SIAM, India)

Motor zagotavlja pogonsko moč za vse različne funkcije, ki jih mora vozilo opravljati. Na splošno je motor sestavljen iz motorja z notranjim zgorevanjem, ki lahko obsega vžig s svečko ali kompresijski vžig. Električni sistem zagotavlja elektriko za zagon motorja, polnjenje akumulatorja in napaja razsvetljavo in drugo dodatno opremo. Prenosni sistem je sestavljen iz sklopke, menjalnika, ki zagotavlja različna razmerja izhodnega navora, kardanske gredi za prenos navora od menjalnika do zadnje osi in diferenciala do pogonskih koles. Blažilni sistem, ki absorbira udarce pnevmatik in koles na neravnem cestišču. Zavorni sistem je namenjen zaustavitvi vozila na najmanjši možni razdalji. Karoserija obsega prostore za motor, potnike ter prtljago ali tovor. Proizvodnja lahkih motornih vozil je med letoma 2005 in 2021 nenehno naraščala, v času pandemije covida pa je upadla.

Lahka motorna vozila se izdelujejo z litjem, oblikovanjem, spajanjem in rezanjem kovin ter s kombinacijo teh postopkov. Lahka motorna vozila glede na maso v več kot 60 % sestavljajo kovinski ulitki. Nastajajoče tehnologije, kot sta aditivna proizvodnja ali 3-D tiskanje [6], se danes uporabljajo zaradi manjše potrebe po

steering system and brakes. The engine provides the motive power for all the various functions that the vehicle may be called upon to perform. Generally, an engine consists of an internal combustion engine which may either spark ignition or compression ignition engine. The electrical system gives electricity for cranking the engine, charging the battery and giving power to lighting and other accessories. The transmission system consists of a clutch, a gearbox that provides different ratios of torque output, a propeller shaft to transmit the torque from gearbox to the rear axle, and a differential gear to the driving wheels. The suspension system, absorbs the shock of the tires and wheels meeting the uneven surface of the road. The brake system is provided to stop the vehicle within the smallest possible distance. The body provides compartments for the engine, passengers, and luggage or cargo. The LMV production has been increasing from 2005 to 2021 AD continuously but declined during the covid pandemic time.

LMVs are manufactured by casting, forming, joining, and metal cutting and their combinations. More than 60% are metal castings by mass of LMV. Emerging orodju, proizvodnih korakih in odpadkov. 3-D tiskanje, poznano tudi pod imenom aditivna proizvodnja (AM), je »postopek nanašanja materialov plast za plastjo za izdelavo končnih komponent na podlagi modela 3-D CAD«. S programsko opremo se oblikuje objekt CAD, ki se nato poveže s 3-D tiskalnikom. Oblikovalcem omogoča prilagodljivost za pripravo prilagojene oblike izdelka in posledično tiskanje sestavnih delov, ki jih morda ni mogoče izdelati z drugimi običajnimi proizvodnimi metodami. Uporaba tradicionalnih proizvodnih metod predvideva sestavljanje različnih delov, medtem ko je mogoče s 3-D tiskanjem velike kose končne komponente natisniti z enim samim postopkom. Kompleksne in zapletene komponente je mogoče izdelati z znatnim zmanjšanjem časa izdelave, stroškov in zavrženega materiala. Sčasoma se je 3-D tiskanje razvilo v uporaben postopek za izdelavo izdelkov za končne uporabnike v različnih panogah. Izdelava delov s to tehniko omogoča v primerjavi s tradicionalnimi proizvodnimi postopki veliko prednosti.

Malo verjetno je, da bo 3-D tiskanje nadomestilo številne tradicionalne proizvodne metode, vendar obstaja veliko področij za uporabo, kjer je mogoče s 3-D tiskalnikom iz funkcionalnega materiala hitro in z visoko natančnostjo proizvesti del. Oblikovalcem omogoča razumevanje prednosti 3-D tiskanja ugodnejše odločanje pri izbiri proizvodne tehnike, kar vodi v proizvodnjo optimalnega izdelka. Ena od glavnih prednosti aditivne proizvodnje je hitrost, s katero je mogoče izdelati dele v primerjavi s tradicionalnimi proizvodnimi metodami. Zapletene oblike je mogoče naložiti iz modela CAD in jih natisniti v nekaj urah. Prednost tega je hitro preverjanje in razvoj različnih dizajnov. Medtem ko je v preteklosti morda trajalo nekaj dni ali celo tednov, preden smo prejeli prototip,

technologies like Additive Manufacturing or 3-D printing [6] are used nowadays because of less tooling, manufacturing steps, and less wastage. 3-D printing, also known as additive manufacturing (AM), is “a process of depositing the materials layer by layer to make final components from 3 D CAD model”. The CAD software design the object, which is then interfaced with a 3-D printer. It gives flexibility to designers to create customized product designs and in turn print the components which may not be possible to be manufactured by any conventional manufacturing methods. Unlike traditional manufacturing methods, the different parts are assembled, whereas 3-D printing can print large pieces of a final component in a single process. Complex and intricate components can be manufactured with a substantial reduction in manufacturing time, costs, and material wastage. It has evolved over a period of time into a matured process for being able to fabricate end-use products in various industries. There are plenty of advantages compared to traditional manufacturing processes while manufacturing the parts with this technique.

3-D printing is unlikely to replace many traditional manufacturing methods yet there are many applications where a 3-D printer is able to deliver a design quickly, with high accuracy from a functional material. Understanding the advantages of 3-D printing allows designers to make better decisions when selecting a manufacturing technique that results from delivery of the optimal product. One of the main advantages of additive manufacturing is the speed at which parts can be produced compared to traditional manufacturing methods. Complicated designs can be uploaded from a CAD model and printed in a few hours. The advantage of this is the rapid verification and development je lahko z aditivno proizvodnjo model v rokah oblikovalca že v nekaj urah. Medtem ko stroji za bolj industrijsko naravnano aditivno proizvodnjo potrebujejo dlje časa za tiskanje in naknadno obdelavo dela, ponuja zmožnost izdelave funkcionalnih končnih delov majhnih do srednjih količin veliko prednost z vidika prihranka časa v primerjavi s tradicionalnimi proizvodnimi tehnikami.

Odpira nove priložnosti in daje upanje številnim možnostim za podjetja, ki želijo izboljšati učinkovitost proizvodnje. Omogoča tiskanje kovin, uveljavljene termoplastike in keramike. Z uporabo te metode lahko industrije izboljšajo učinkovitost svojih proizvodnih linij. Z uvedbo tehnologije 3-D tiskanja se bo povečala hitrost proizvodnje, hkrati pa se bodo zmanjšali stroški. Zaradi predlogov potrošnikov so specifikacije proizvedenih končnih izdelkov skladne s potrebami naročnikov. Uporabna je v avtomobilski industriji, kmetijstvu, zdravstvu in vesoljski industriji, in sicer za masovno prilagajanje in proizvodnjo vseh vrst odprtokodnih modelov. Sočasno pa je ta metoda ob prilagoditvi primerna tudi za proizvodno industrijo. Ta tehnika na primer vpliva na gospodarstva držav, ki so odvisne od velikega števila nizkokvalificiranih delovnih mest. Na splošno je tehnologija 3-D tiskanja dandanes postala prepoznana kot zmogljiva in izvedljiva možnost v razviti proizvodni industriji.

2 Pregled literature

R Dolan in sod. [7] so v študiji zasnove bata za težke obremenitve IAV prikazali, da 3-D tiskanje omogoča popolnoma nov pristop k zasnovi bata. S to novo tehnologijo je mogoče izdelati optimizirane zasnove zgorevalnih komor, ki niso rotacijsko simetrične in imajo lahko zajede, kar vodi do

of design ideas. Where in the past it may have taken days or even weeks to receive a prototype, additive manufacturing places a model in the hands of the designer within a few hours. While the more industrial additive manufacturing machines take longer to print and post process a part, the ability to produce functional end parts at low to mid volumes offers a huge time saving advantage when compared to traditional manufacturing techniques.

It opens new opportunities and gives hope to many possibilities for companies looking to improve manufacturing efficiency. It can print metals, traditional thermoplastics, and ceramics. By using this method, the industries may improve the efficiency of the production line. The adoption of 3-D printing technology will increase production speed while reducing costs. With the inputs from the consumers, the specifications of end product manufacturers as per the needs of the customer. It finds application in the automotive industry, agriculture, healthcare, and aerospace industries for the mass customization, and production of any type of open-source design. Simultaneously, the adaption of this method is also invited in the manufacturing industry. For instance, this technique sometimes affects the economy of countries that rely on a large number of low skilled jobs. In general, 3-D printing technology has become prominent now-a-days as a powerful and feasible technique in advanced manufacturing industry.

2 Literature Review

R Dolan et al., [7] demonstrated by the IAV heavy-duty piston design study, 3-D printing enables a completely new approach to piston design. Optimized designs of piston bowl shapes, which are no longer rotationally symmetrical and can have undercuts, are znatnega izboljšanja mešanja zraka in goriva ter procesa zgorevanja. Rakesh Kumar in sod. [8] so izpostavili različne aplikacije 3-D tiskalnikov v različnih sektorjih. Povzeli so tudi prednosti, slabosti, prihodnost in izzive, da bi ta njihov dokument lahko postal vodilo za prihodnje raziskovalce, ki delajo na področju 3-D tiskanja. Venkat Ramana in sod. [9] so zasnovali ročično gred za večvaljni motor in njen 3-D model ustvarili s programsko opremo za modeliranje CATIA V5R20. Vinod Gokhare in sod. [10] so predstavili zgodovino 3-D tiskanja in proučili proces 3-D tiskanja ter kateri materiali se uporabljajo pri izdelavi 3-D tiskanih predmetov in med njimi izbrali najboljše materiale, ki so primerni za naš 3-D tiskalnik. A. Dalvi [11] je zaključil, da je akrilonitril butadien stiren najmočnejši material za 3-D tiskanje, ki lahko prenese obremenitev 47 KN do napetosti tečenja. Rezultati FEA kažejo, da je akrilonitril butadien stiren močan, ko je izpostavljen natezni ali tlačni obremenitvi zaradi 3-D tiskanja. SK Subbrayalu in sod. [12] so razpravljali o raziskovalnih vprašanjih in izzivih avtomobilskih livarn, analizirali komponente motorja in njihove materiale ter vpliv na porabo goriva. Uporaba neželeznih kovin in zlitin ter strojev za tlačno litje vodi v manjšo porabo energije in krajši čas cikla. Brodarac in sod. [13] so raziskali zaporedje strjevanja zlitine AlSi11 in določili mikrostrukturne sestavine s termodinamičnim modeliranjem in diferencialno kalorimetrijo. Razpravljali so tudi o odstotku aluminijevih zlitin za evropske avtomobile.

possible with this new technology and lead to significant improvement in air-fuel mixing and combustion process. Rakesh Kumar et al. [8] highlighted the distinct 3-D printer applications in different sectors. Also summarizes the merits, demerits, future, and challenges, so that this review paper could become the torch bearer for the futuristic researchers working in the area of 3-D printing. Venkat Ramana et al., [9] designed a crankshaft for multi-cylinder engine and its 3-D-models were created using modeling software CATIA V5R20. Vinod Gokhare et al. [10] presented the history of 3-D printing and studied about the process of 3-D printing and what materials are used in the manufacture of 3-D printed objects, and select the best materials among them which are suitable for our 3-D printing machine. A Dalvi [11] concluded that Acrylonitrile Butadiene Styrene is the strongest 3-D printing material that can carry a load of 47 KN up to Yield stress. FEA results show that Acrylonitrile Butadiene Styrene is strong when subjected to tensile or compressive loading 3-D Printing. S K Subbrayalu et al.,[12] discussed research issues and challenges of Automotive Foundries, analysed engine components and their materials, and effect on fuel consumption. The use of nonferrous metals and alloys and die casting machines reduces energy consumption and cycle time. Brodarac et al., [13] investigated the solidification sequence of AlSi11 alloy and established microstructural constituents with thermodynamic modeling and differential calorimetry. Al alloys percentage for European cars was also discussed.

3 Tridimenzionalni proces tiskanja in njegovi podsistemi

3.1 Zgodovina procesa tridimenzionalnega tiskanja

Leta 1986 je Charles W. Hull izumil in patentiral prvi znani 3-D tiskalnik. V svojem patentu je opisal postopek stereo litografije, s katerim je mogoče konstruirati dele s strjevanjem plasti fotopolimera (smole). Po treh letih je leta 1989 Scott Crump patentiral še en 3-D tiskarski stroj, ki deluje na podlagi metode ciljnega nanašanja (FDM). Nato je Adrian Bowyer razvil napravo Rep Rap (Replicating Rapid Prototyper), za katero je na voljo brezplačna programska oprema z odprtokodno kodo, večina delov pa je izdelana s postopkom aditivne proizvodnje. Na podlagi teh neprekinjenih izboljšav so se znižali stroški. Največji industrijski 3-D tiskarski sistem na svetu je sistem VX 4000 podjetja Voxeljet AG iz Nemčije s prostornino 4000x2000x1000 mm, ki je namenjen tiskanju peščenih jeder za livarsko industrijo, izdelan pa je bil leta 2020. Različne industrijske aplikacije [14], kot so avtomobilska, vesoljska, elektronska, medicinska, akademska, vojaška, arhitekturna in druge industrije, so predstavljene na Sliki 2. To pomeni, da je postopek tiskanja 3-D zaradi količin zavrženega materiala in masovne proizvodnjo z manj delovne sile široko sprejet v različnih industrijah. Avtomobilska in vesoljska industrija sta vodilni panogi, kjer se ta proces uporablja za zvečanje proizvodnje komponent.

3.2 Klasifikacija postopkov tridimenzionalnega tiskanja

3-D tiskanje lahko na splošno razvrstimo v dva razreda, in sicer glede na agregatno

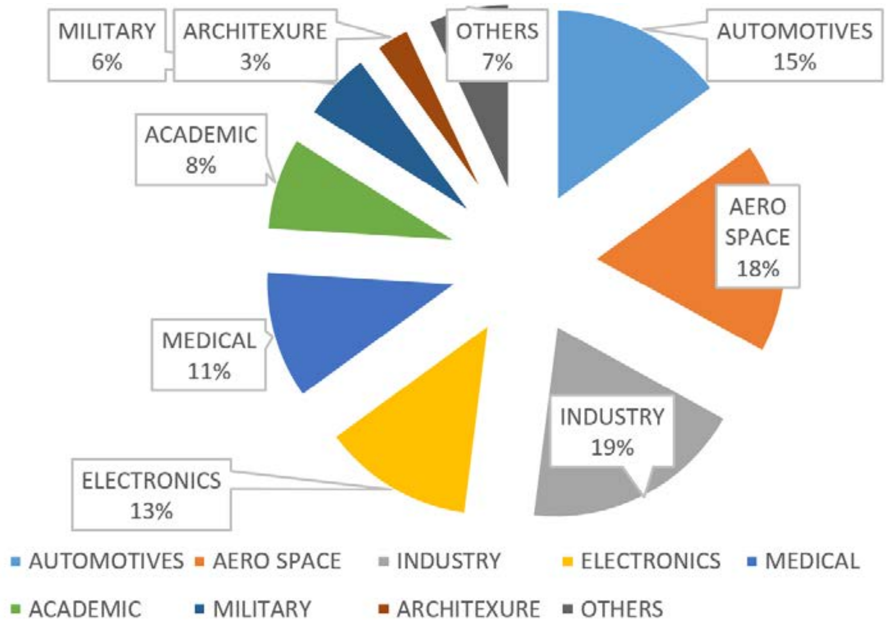
3 Three-Dimensional Printing Process and its Sub-Systems

3.1 History of Three-Dimensional Printing Process

In 1986, Charles W. Hull invented and patented the first known 3-D printer. In his patent, he narrated the stereo lithography process where it is possible to construct parts by solidifying layers of a photopolymer (resin). After three years, another 3-D printing machine was patented by Scott Crump that uses Fused Deposition Modelling (FDM) in 1989. Later Adrian Bowyer developed Rep Rap (Replicating Rapid Prototyper), where free equipment software is provided with open-source code and the majority of parts are produced through Additive Manufacturing Process. With these continuous improvements first low cost. The world's largest industrial 3-D printing system Voxeljet AG,2021, VX 4000 system for a volume of 4000x2000x1000 mm for core printing in in Germany in 2020. Various industry applications [14] such as automotives, aerospace, electronics, medical, academic, military, architecture and other industries are presented in Figure 2 and this implies 3DP process is widely accepted by the different industries owing wastage of material as well as mass production with less man power. Automobile industries and aerospace industries are the leading industries where this process finds the application towards the augmenting the production of components.

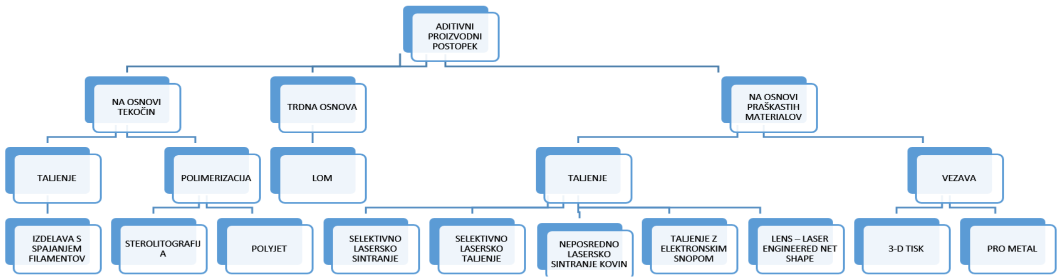
3. Classification of Three-Dimensional Printing Processes

3-D printing can be broadly classified into two classes, namely, on the physical state of the raw material, i.e., liquid-, solid- or



Slika 2. Industrijske aplikacije 3-D tiskanja

Figure 2. Industrial applications of 3-D printing



Slika 3. Razvrstitev postopka 3-D tiskanja

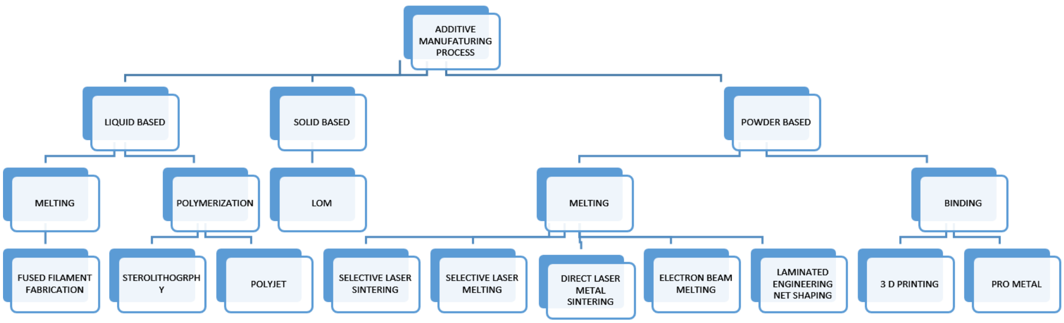


Figure 3. Classification of 3-D Printing Process

stanje surovine, torej postopke, ki predvidevajo uporabo tekočin, trdnih snovi ali praškastih materialov, in glede na način, kako se snov spoji na molekularni ravni, tj. toplotno, z ultravijolično svetlobo, laserjem ali elektronskim snopom. Najpogosteje uporabljeni postopki 3-D tiskanja so razdeljeni v naslednje tri kategorije, in sicer na trdni osnovi (FDM), na tekoči osnovi (SLA, IJP) in na osnovi praškastih materialov (SLM, SLS, EBM), kot je prikazano na Sliki 3.

3.3 Materiali, uporabljeni za tridimenzionalno tiskanje

Tehnologija 3-D tiskanja kovin je pridobila pozornost v vesoljski, avtomobilski, medicinski in proizvodni industriji, in sicer zaradi prednosti, ki jih proces zagotavlja. Materiali, ki se uporabljajo v tiskanju 3-D, so aluminijeve zlitine, zlitine na osnovi kobalta, zlitine na osnovi niklja, nerjavna jekla in titanove zlitine. Uporablja se pri visokih napetostih in visokih delovnih temperaturah ter pogojih visokih napetosti za letalske in vesoljske komponente. Tehnologije 3-D tiskanja se pogosto uporabljajo za proizvodnjo polimernih komponent za oblikovanje prototipov funkcionalnih struktur s kompleksnimi geometrijami. Z uporabo metode ciljnega nanašanja (FDM) je mogoče 3-D tiskanje izkoristiti za nanašanja zaporednih plasti ekstrudiranega termoplastičnega filamenta, npr. iz polilaktične kisline (PLA), akrilonitril butadien stirena (ABS), polipropilena (PP) ali polietilena (PE).

3.4 Ulitek bata motorja lahkega motornega vozila

Bat, ki deluje [15–16] pri visoki temperaturi, visokem tlaku, v korozivnem okolju in

powder-based processes, and on the way in which the matter is fused on a molecular level, i.e., thermal, ultraviolet light, laser, or electrons beam. The most commonly applied 3-D printing processes are divided into the following three categories such as solid based (FDM), liquid-based (SLA, IJP), and powder base (SLM, SLS, EBM) are shown in Figure 3

3.3 Materials used for Three-Dimensional Printing

Metal 3-D printing technology gain industrial attention in aerospace, automobile, medical application, and manufacturing industry because the advantages existing by this process. The materials 3-D printed are aluminium alloys, cobalt-based alloys, nickel-based alloys, stainless steels, and titanium alloys. It is used in high stresses and high operating temperatures and high stress conditions for aerospace components. 3-D printing technologies are widely used for the production of polymer components to form prototypes to functional structures with difficult geometries. By using fused deposition modeling (FDM), it can form a 3-D printer through the deposition of successive layers of extruded thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP) or polyethylene (PE).

3.4 Light Motor Vehicle Engine Piston Casting

Piston, which operates [15-16] at high temperature, high pressure, corrosive, and wears conditions whilst operating at high speed, is the most significant portion of the motor. The pistons are located at the center of the internal combustion engine and pod pogoji obrabe, kadar deluje z visoko hitrostjo, je najpomembnejši del motorja. Bati se nahajajo v središču motorja z notranjim zgorevanjem, povratno gibanje čela bata, stranske stene in zgornjih obročkov pa ustvarja znaten pritisk. Za zmanjšanje visokih stopenj izpustov ogljika mora biti zgornji del bata zelo tanek. Da bi izpolnili povpraševanje po standardih Euro, morajo batni materiali in proizvodni postopki izpolnjevati stroge standarde, da bi ostali na pravi poti. Biti morajo izjemno močni, robustni in majhni. Zasnova bata obsega izračune bata, premera, skupne dolžine, dolžine valja, debeline krone, plašča, globine utora obročka, premera bata, vrzeli med dolžino obročkov in debeline zgornje površine med utorom.

3.5 Postopek tridimenzionalnega tiskanja

3-D tiskanje je aditivni proizvodni proces, s katerim se dodajajo številne plasti materialov za plastmi, dokler izdelek ni dokončan. 3-D tiskanje se izvaja z uporabo računalniško podprtega oblikovanja (CAD) ali laserskega skeniranja za ustvarjanje predmeta 3-D. Oblikovalski model je razrezan na več ravnin ali plasti, ki 3-D tiskalnik usmerjajo pri zaporednem nanašanju tankih plasti materiala eno na drugo, dokler ni izdelan končni izdelek.

Gre za proces 3-D izdelave predmeta od spodaj navzgor z nanašanjem plasti. Metoda je zato okolju prijaznejša, saj se v primerjavi s tradicionalno proizvodnjo ustvari zelo malo odpadnega materiala. Običajni proizvodni postopki, kot sta litje in formanje, ustvarijo predmet iz surovin v razsutem stanju, medtem ko se s subtraktivno strojno obdelavo, kot sta rezkanje in struženje, ustvari predmete od zgoraj navzdol z odstranjevanjem materialov, dokler ne nastane končni izdelek.

the reciprocating movement of the piston crown, sidewall, and top rings will create significant pressure. The piston top ground has to be very thin to decrease high carbon (HC) emissions. To meet the demand Euro standards, piston materials and production procedures must meet rigorous standards in order to stay on track. They must be extremely strong, robust, and light in weight. Piston design involves calculations of the piston, diameter, total length, barrel length, head thickness, skirt, depth of ring groove, piston pin diameter, the gap between rings length, and top land thickness.

3.5 Three-Dimensional Printing Process

3-D printing is an additive manufacturing process that adds many layers of materials upon layers until the product is built. 3-D printing uses a computer-aided design (CAD) or laser scan to create a 3-D object. The design model is sliced into several planes or layers, which direct the 3-D printer in depositing the successive thin layers of material upon each other to construct a final product.

The 3-D process creates the object from the bottom-up by adding layers. So, it is more efficient of the environment because there is very little waste material compared to traditional manufacturing. Conventional manufacturing processes such as casting and forming create the object from bulk raw materials, while subtractive machining such as milling, and turning create the objects from the top-down by subtracting and removing materials until getting the final product. 3-D printing process steps for LMV piston are shown in Figure 4. Various steps involve right from piston design to 3-D printing of the final product. In the first step the piston is designed as per the LMV specification followed by 3 CAD

Slika 4. Diagram poteka postopka 3-D tiskanja

Figure 4. Flow diagram of 3-D printing process

Koraki postopka 3-D tiskanja za bat lahkega motornega vozila so prikazani na Sliki 4. Ti različni koraki obsegajo vse od oblikovanja bata do 3-D tiskanja končnega izdelka. V prvem koraku je bil zasnovan bat po specifikaciji lahkega motornega vozila, sledil je model 3-D CAD, pripravljen z uporabo programa za 3-D modeliranje. Program ustvari datoteko STL, ki se nato pošlje 3-D tiskalniku. Ob tem programska oprema razreže dizajn na stotine ali bolj verjetno na tisoče horizontalnih plasti. Te plasti se natisnejo ena na drugo, dokler ni izdelan tridimenzionalni predmet. Oblikovalski model je razrezan na več ravnin, ki 3-D-tiskalnik usmerjajo pri zaporednem nanašanju tankih plasti materiala eno na drugo, dokler ne proizvede končni ulitek bata.

4 Oblikovanje in izdelava ulitka bata lahkega motornega vozila s 3-D tiskanjem

4.1 Zasnova bata

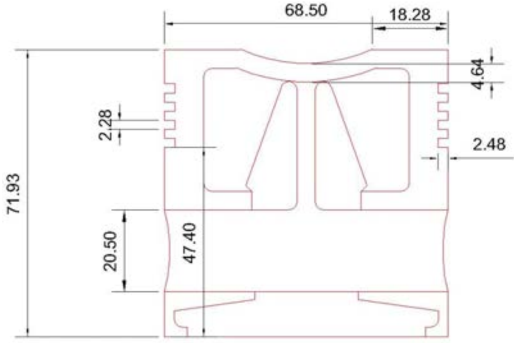
V preglednicah 1 in 2 je predstavljena kvantificirana in napovedana proizvodnja lahkih motornih vozil in potrebno letno

models using a 3-D modeling program. The program creates an STL file which is sent to the 3-D printer. Along the way, software slices the design into hundreds, or more likely thousands, of horizontal layers. These layers will be printed one on top the other until the 3-D object is made. The design model is sliced into several planes, which direct the 3-D printer in depositing the successive thin layers of material upon each other to construct a final piston casting.

4 Design and Manufacturing of Piston Casting of Light Motor Vehicle by 3-D Printing

4.1 Piston Design

Production of LMVs and number of pistons required annually quantified and forecasted and is presented in Tables 1 and 2. LMV engine specification for the 3-cylinder engine is presented in Table 3. Piston design and process parameters and calculations are shown in Table 4. The piston drawing is shown in Figure 5.



Slika 5. Specifikacije konstrukcije bata lahkega motornega vozila v mm

Figure 5. LMV piston design specifications in mm

število barov. Specifikacija motorja lahkega motornega vozila za 3-valjni motor je predstavljena v Preglednici 3. Zasnova bata in procesni parametri ter izračuni so prikazani v Preglednici 4. Skica bata je prikazana na Sliki 5.

4.2 Izdelava ulitkov batov s tehnologijo 3DPP

Bate izdelujemo s tehnikami litja v pesek, kokilami, stiskanjem ali z metalurgijo prahu. Te različne proizvodne tehnologije, ki se uporabljajo za izdelavo avtomobilskih batov, imajo različne vplive na mikrostrukturo ter fizikalne in mehanske lastnosti. Stiskanje in kokilno litje veljata za konvencionalni proizvodni tehnologiji. Po drugi strani pa so se pojavili novi proizvodni procesi, npr. tlačno litje (PDC), ki je avtomatiziran industrijski proces. Pri običajnem postopku tlačnega litja se staljena kovina vlije v brizgalni tulec iz lonca, potem ko kokila zaprta. Kovina se v kokilo potisne z gibanjem bata, ki premični del prisili, da se poravna s fiksnim delom.

Kovinski praškasti material se uporablja kot surovina v aditivni proizvodnji (AM). Izkazovati mora dobre lastnosti tečenja, sintranja in polnjenja. Da bi prilagodili različne materiale, so bile razvite različne tehnologije aditivne proizvodnje. Metoda ciljnega nanosa se obsežno uporablja za izdelavo prototipov iz materiala PLA. S 3-D tiskanjem je mogoče plast za plastjo natisniti celoten del v enem kosu. Zagotavlja prednost z vidika prilagodljivosti oblikovanja v proizvodnji majhnih serij delov. V tem prispevku se pri metodi tridimenzionalnega

4.2 Manufacture of Piston Casting by 3DPP

Pistons are manufactured by sand casting, gravity dies, pressure die, squeeze casting, or powder metallurgy techniques. These varieties of manufacturing techniques are employed for the fabrication of automobile pistons, each technique has its own impact on the microstructure, and physical and mechanical properties. Squeeze casting and gravity die casting are both considered conventional production technologies. New production processes, on the other hand, have emerged pressure die casting (PDC) is an automated industrial process. In a conventional die casting process, molten metal is poured into the shot sleeve by a ladle after the die is closed. The metal is driven into the die by a plunger (piston) movement, forcing the mobile part to align with the fixed part.

Metal powders are used as a raw material in additive manufacturing (AM). It must consist of good flow, sintering, and packing properties. In order to accommodate different materials different AM techniques evolved. The fused deposition method is a widely used prototyping technology that uses PLA as a material. 3-D printing is capable to print the whole part in one structure layer

Preglednica 1. Proizvodnja lahkih motornih vozil in ocena potreb po batih v letih 2005–2021

Table 1. Production of LMVs and estimation of piston requirement during 2005-21

Kategorija avtomobilov / Category of Automobile	Proizvodnja lahkih motornih vozil v milijonih / LMV production in millions
Proizvodnja lahkih motornih vozil od 2005 do 2020 / Light motor vehicle production from 2005 to 2020	46,30
Skupna proizvodnja batov za motor lahkega motornega vozila, (46,3x3) / Total piston production for LMV engine, (46.3x3)	138,9
Potrebni bati (10 %) za rezervne dele za obstoječa lahka motorna vozila / Piston required (10%) for spares for existing LMVs	13,89
Proizvodnja lahkih motornih vozil v letu 2021 / LMV production in 2021	3,06
Proizvodnja batov za trivaljne motorje za leto 2021 / Piston production for three cylinder engine for 2021	9,18
Skupna zahteva po batih na leto / Total piston requirement per annum	161,97
Enačba napovedane proizvodnje lahkih motornih vozil / Forecasted LMV production equation	0,1587x+1,5408
Enačba napovedane proizvodnje batov / Forecasted piston production equation	0,4869x+4,9523

Preglednica 2. Napovedovanje proizvodnje lahkih motornih vozil in potreb po batih za obdobje od 2022 do 2025

Table 2. Forecasting of LMV Production and Piston Requirement for 2022 to 2025

Letna proizvodnja / Annual production	Enačbe napovedovanja proizvodnje / Forecasting production equations	Ocenjena prihodnja proizvodnja v milijonih / Estimated future production in millions			
		FY22	FY23	FY24	FY25
Letna proizvodnja lahkih motornih vozil / Annual production of LMVs	0,1587x+1,5408	4,24	4,39	4,55	4,71
Letna proizvodnja batov / Annual production of pistons	0,4869x+4,9523	13,23	13,71	14,20	14,69

(3-D) tiskanja, razviti za izdelavo ulitka bata, dolžina hoda bata pri nizki hitrosti do točke prehoda imenuje dolžina prve faze, tlak brizganja se zmanjša na koncu, ko je v formo vbrizgana skoraj vsa tekoča kovina, ki se nato strdi.

Zaradi obsežne uporabe digitalne tehnologije v številnih aplikacijah se je priljubljenost aditivne proizvodnje (AM) ali tridimenzionalnega tiskanja (3DP)

by layer. It gives an advantage in design flexibility for low- volume customized parts. In the present work three-dimensional (3-D) printing method developed for piston casting the length of travel of the piston in the low velocity up to the changeover point is known as the first phase length and the injection pressure decreases at the end when nearly all the liquid metal is injected into the die and solidifies.

po vsem svetu povečala. Gre za proces konstruiranja dejanskih elementov na podlagi digitalnih informacij kos za kosom, vrstico za vrstico, površino za površino ali plast za plastjo, in sicer z uporabo orodij in programov za digitalno 3-D modeliranje. 3-D tiskanje je vrsta tiskanja, s katerim je mogoče izgraditi ali poustvariti samostoječe kompleksne strukture iz enega samega kosa. Velikost 3-D tiskalnika in materiali, ki se uporabljajo za tiskanje, vplivajo na kakovost komponent. S 3-D tiskalniki je mogoče natančno, enostavno in priročno izdelati dele, oblikovanje in tiskanje je hitro in stroškovno učinkovito in hkrati prilagodljivo najrazličnejšim uporabam.

Bati se izdelujejo z metodo ciljnega nanosa (FDM – Fused Deposition Method) ob uporabi polilaktične kisline (PLA – Poly Lactic Acid). PLA je biorazgradljiva termoplastika, ki se običajno uporablja za izdelavo prototipov. Gre za plastični material na rastlinski osnovi, ki je običajno izdelan iz koruznega škroba. Slika 3 prikazuje dimenzijo, upoštevano pri izdelavi. Najprej je bil dizajn izdelan v programski opremi AutoCAD in nato pretvorjen v datoteko .stl. Simplify 3D je programska oprema za rezanje, ki se uporablja za nadzor vseh vidikov in pretvorbo oblike v navodila, ki jih tiskalnik razume. Podloga je pred tiskom predhodno segreta, uporabljena je šoba s

Due to the extensive use of digital technology in a number of applications, Additive Manufacturing (AM) or 3-Dimensional Printing (3DP) has increased in popularity across the world. It is a process of constructing real items from digital information piece by piece, line by line, surface by surface, or layer by layer, utilizing 3-D digital modeling tools and programs. 3-D printing is a type of printing that can construct or recreate freestanding complex structures in a single piece. The size of a 3-D printer, as well as the materials utilized for printing, have an influence on component quality. 3-D printers have the potential to manufacture quality work pieces with precision, ease of use, convenience, rapid design and printing, cheap cost, and the capacity to adapt to a variety of applications.

A piston is being fabricated by the Fused Deposition Methods (FDM) method using Poly Lactic Acid (PLA). PLA is a biodegradable thermoplastic that is commonly used to create prototypes. It is a vegetable-based plastic material that commonly uses cornstarch as raw material. Figure 3 shows the dimension considered for fabrication. First, the design was made in AutoCAD and converted into stl file. Simplify 3-D is slicing software used to control every aspect and convert the

Preglednica 3. Specifikacija motorja lahkega motornega vozila

Table 3. The LMV engine specification

Parametri / Parameters	Vrednosti / Values
Vrsta motorja / Engine type	Štiritaktni bencinski motor / Four stroke petrol engine
Število valjev / Number of cylinders	3
Odprtina / Bore	68,5 mm
Hod / Stroke	72 mm
Prostornina / Volume	796 cm^3
Največja moč / Maximum power	48 KM pri 6000 vrt./min / 48PS@6000 rpm
Največji navor / Maximum torque	69 Nm pri 3500 vrt./min / 69Nm@ 3500 rpm
Kompresijsko razmerje / Compression ratio	10,3:1

Preglednica 4. Konstrukcijski parametri in izračun za bat motorja lahkega motornega vozila

Table 4. Design Parameters and Calculation for LMV Engine Piston

Specifikacije / Specifications	Parametri / Parameters	Mere so podane v mm / Dimensions are in mm
Debelina glave bata / Thickness of piston head (t_H)	$D\sqrt{\frac{3}{16} * P_{Max}/\sigma_t}$	4,64
Radialna debelina obroča / Radial thickness of ring (t_1)	$D\sqrt{3 * Pw/\sigma_t}$	2,48
Aksialna debelina obroča / Axial thickness of ring (t_2)	0.7 t_1 do/to t_1; t_2= 0,92 t_1	2,28
Debeline zgornje površine nad utorom / Top land thickness (b_1)	t_H do/to 1,2 t_H	5,57
Debelina površine med utori / Thickness of other land (b_2)	0,75 t_2 do/to t_2	1,71
Skupna dolžina bata / Total length of piston	1 do/to 1,5 D	71,93 (1,05 D)
Dolžina valja / Barrel length	Skupna dolžina bata / Total Length of Piston tH	67,29
Največja debelina valja / Maximum thickness of barrel (t_3)	0.03D+b*+4.5 *b=t_1+ 0.4	9,43
Debelina odprtega konca valja (zgoraj) / Open end of barrel thickness	0,20 do/to 0,30 t_3	2,36
Razmak med obročki / Gap between rings (t_L)	0,055D	3,76
Globina utora obročka / Depth of ring groove (D_r)	t_1+0,4	2,87
Premer bata / Piston pin diameter (P_{do})	0,3D do/to 0,45D, (0,3D)	20,5
Dolžina plašča bata / Length of piston skirt	0,65 do/to 0,8 D	47,4
Skupna dolžina bata / Total length of piston	1 do/to 1,5D	71,93 (1,05 D)

premerom 0,4 mm. Šoba se segreva, da tali plastiko, in je opremljena z mehanizmom, ki omogoča vklop in izklop toka staljene plastike. Ko se šoba premika po mizi glede na zahtevano geometrijo, nanese majhno količino ekstrudirane plastike, ki tvori posamezno plast. Končni natisnjeni izdelek in nastavitev stroja so prikazani na Sliki 6.

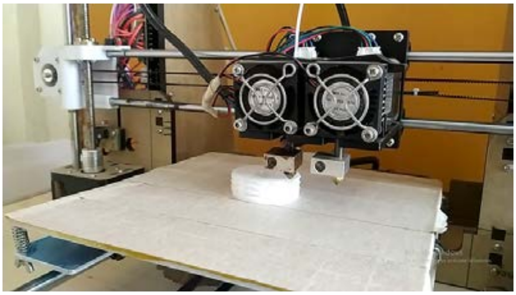
5 Sklepi

Lahka motorna vozila se pogosto uporabljajo za osebni prevoz in tudi uradne namene, njihova proizvodnja pa se v zadnjih 15 letih v Indiji nenehno povečuje (208 %). Predvideno povečanje proizvodnje lahkih motornih vozil

design into the instructions that the printer understood. The base is preheated before printing and used the nozzle diameter 0.4 mm. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The final printed product and the machine setup are shown in Figure 6.

5 Conclusions

Light motor vehicles are widely utilized for personal transportation and official s 4,24 na 4,71 milijona med letoma 2022 in 2025 in proizvodnje do leta 2025, na podlagi česar izhaja, da se potrebe po batih povečujejo s 13,23 na 14,69 milijona. Izbrali smo zahtevno komponento bata za motor lahkega motornega vozila in projektirali ulitek bata ter njegove parametre. Razvili smo inovativno tehnologija 3-D tiskanja za proizvodnjo batov te izdelali prototip bata.



Slika 6. Nastavitev 3-D tiskalnika FDM

Figure 6. Set-up of FDM 3-D printer

purposes and their production has been increasing continuously (208 %) during the last 15 years in India. Forecasted LMV production requirement 4.24 to 4.71 million from 2022 to 2025 AD and the piston requirement up to 2025 AD and it is found that piston requirements are increasing from 13.23 to 14.69 million. Selected a complicated component of the piston for LMV engine and designed piston casting and its parameters. Innovative technique of 3-D printing technology developed for piston manufacturing and prototype piston manufactured.

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Optimizacija ulivno-napajalnega sistema ulitka kape izolatorja iz bele temprane litine

Design Optimization of Gating System for Insulator Cap from White-Heart Malleable Iron

Povzetek

Ulivno-napajalni sistem za vertikalno litje v peščene forme mora biti dimenzioniran na način, da je tok taline čim manj turbulenten, da plini iz peščene forme in okoliški zrak niso ujeti v toku ter da med litjem ne prihaja do erozije peščene forme. Talina mora vstopiti v livno votlino na način, da povzroči temperaturno razliko, ki spodbuja usmerjeno strjevanje ulitka.

Med masovno proizvodnjo se lahko pri litju v peščene forme pojavijo številne napake, kot so plinska in krčilna poroznost, hladni spoji, vključki žlindre, razpoke v vročem, pripečen pesek, odkrušena forma itd. Računalniško podprte simulacije litja in strjevanja so dandanes ključne za optimizacijo parametrov procesa litja ter za predvidevanje možnih napak in tveganj, še preden te nastopijo. Z njimi lahko že v fazi razvoja orodja določimo najbolj optimalne pogoje litja in konstruiramo primeren ulivno-napajalni sistem glede na specifikacije ulitka. V tem članku je opisana optimizacija elementov ulivno-napajalnega sistema kape izolatorja, izdelane iz bele temprane litine. V podjetju Livarna Titan d.o.o. v Kamniku so namreč na tem artiklu beležili velik delež kakovostno neskladnih ulitkov. Korektivni ukrepi so bili izvedeni na podlagi enostavne termične analize »in situ« in računalniško podprtih izračunov litja in strjevanja z uporabo programskega paketa ProCAST.

Ključne besede: gravitacijsko litje, ulivno-napajalni sistem, temprana litina, simulacija, ProCAST

Abstract

The gating system for the vertical sand mold casting process must be dimensioned in such a way that the melt flows through it with as low turbulences as possible, that gases and ambient air are not trapped in the flow and that erosion of the sand mold does not occur during filling. The melt must also enter the casting cavity in a way that promotes directional solidification from the casting's hot spot through the feeder neck up to the feeder.

During mass production, casting defects such as gas and shrinkage porosity, cold shuts, slag inclusion, hot tears, burnt on the sand, mold defects, etc. can occur. Nowadays, computer-aided simulations of filling and solidification are crucial for optimizing the parameters of the casting process and for predicting possible errors and risks before they occur. With them, we can determine the most optimal casting conditions already in the tool development phase and construct a suitable gating system, according to the specifications of the casting.

This work describes the gating system optimization of insulator caps, made from white-heart malleable iron. To reduce the large number of scraped castings in the company

Livarna Titan, d.o.o. in Kamnik, a change was made to the casting tool based on “in-situ” thermal analysis and computer-aided calculations of filling and solidification using ProCAST simulation software package.

Keywords: gravity casting, gating system, malleable iron, simulation, ProCAST

1 Uvod

Zasnova ulivno-napajalnega sistema je v proizvodnem procesu vsake livarne ključnega pomena, saj le-ta neposredno vpliva na izplen taline (razmerje bruto/neto), delež izmeta in s tem tudi na produktivnost proizvodnje. Danes je med podjetji znižanje proizvodnih stroškov ključni cilj, h kateremu stremijo prav vsa. Visoke cene energentov (elektrika, plin) in vhodnih surovin (jekleni odpad, železove zlitine itd.) ter težave s pridobitvijo ustreznega kadra na trgu dela so vsa podjetja postavile v težek položaj. Livarne morajo zato proizvajati ulitke s čim nižjimi stroški in sočasno zagotavljati ustrezno kakovost. Pravilna zasnova ulivno-napajalnega sistema je zahtevna, a zelo pomembna naloga, zato je že med njegovim načrtovanjem pomembno zagotoviti, da litina pravočasno in enakomerno zapolni livno votlino. Vse parametre je kljub dolgoletnim izkušnjam težko upoštevati in pravilno oceniti, zato se tudi male in srednje livarne vse pogosteje odločajo za uporabo računalniško podprtih izračunov livarskih procesov.

Dimenzije ulivnih kanalov je treba izračunati glede na geometrijo izdelka, saj je lahko nepravilna zasnova glavni vzrok za napake, ki jih je mogoče zaznati na površini ali večinoma v notranjosti ulitkov. Slika 1 prikazuje obstoječi ulivno-napajalni sistem ulitka kape izolatorja z označenimi območji prisotne krčilne poroznosti.

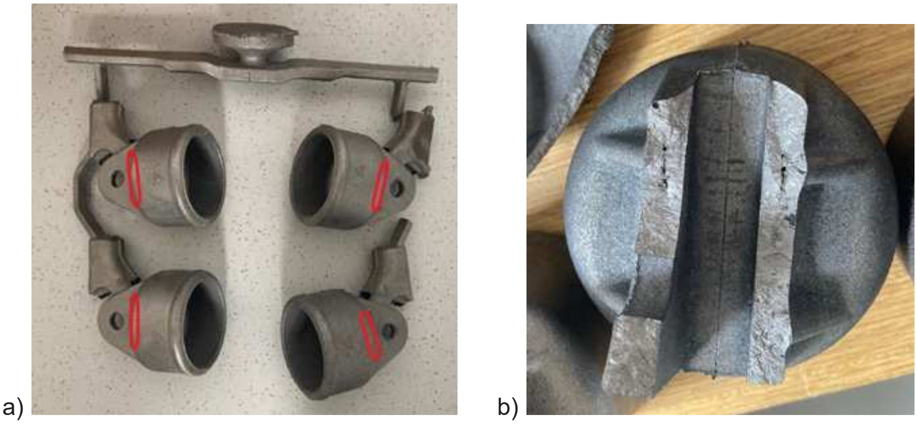
Preiskovan ulitek je kapa izolatorja, ki je sestavni del izolatorja za uporabo na visokonapetostnih daljnovodih. Ti so del prenosnega električnega omrežja,

1 Introduction

The design of the pouring and feeding system is of key importance in the production process of every foundry, as it directly affects the yield of the melt (gross/net ratio), the amount of scrap, and thus the productivity of production. Today, the reduction of production costs is a key goal for companies to strive towards, mainly due to the high prices of energy supply (electricity, gas) and input raw materials (steel scrap, ferroalloys, etc.) and problems with obtaining suitable personnel on the labor market. Foundries must therefore produce castings with the lowest possible costs and at the same time ensure the highest quality. The correct design of the gating system is a difficult but very important task. Therefore, already during its planning, it is important to ensure that the cast iron fills the casting cavity in a timely and uniform manner. Despite many years of experience, all parameters are difficult to take into account and correctly evaluate, which is why even small and medium-sized foundries are increasingly choosing to use computer-aided calculations of foundry processes.

The dimensions of the casting channels must be calculated according to the geometry of the product since improper design can be the main cause of defects that can be detected on the surface or mostly inside the castings. Figure 1 shows an existing gating system of an insulator cap with marked areas of shrinkage porosity.

The investigated casting is an insulator cap, an integral part of an insulator for use

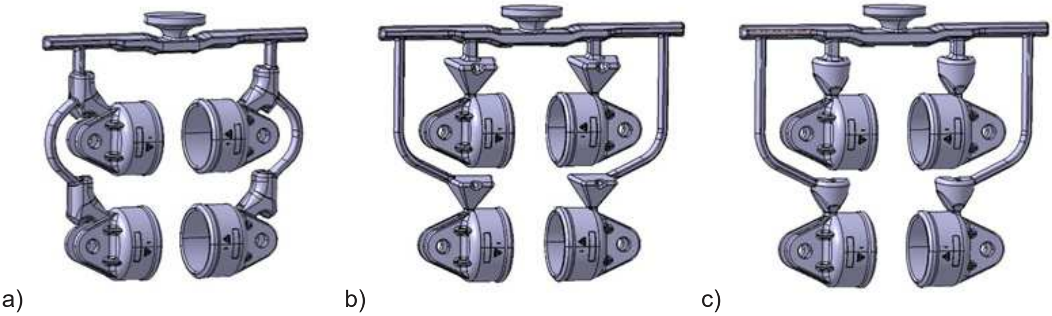


Slika 1. Obstoječi ulivno-napajalni sistem z označenimi območji krčilne poroznosti (a), porušen ulitek z vidno poroznostjo (b)

Figure 1. Existing gating system with marked areas of shrinkage porosity (a), casting with visible porosity (b)

ki povezuje elektrarne z razdelilnimi transformatorskimi postajami. Izolacijski nosilci oz. izolatorji so potrebni na mestih, kjer so nadzemni vodi pritrjeni na kovinske nosilce. Izolatorji zagotavljajo potrebno izolacijo med vodniki in nosilci ter preprečujejo uhajanje toka iz vodnikov v zemljo.

on high-voltage transmission lines. These are part of the transmission power network that connects power plants with distribution transformer stations. Insulation supports or insulators are required in places where overhead lines are attached to metal towers. Insulators provide the necessary insulation



a) 17 kg b) 20 kg c) 16,8 kg

Slika 2. Potek sprememb ulivno-napajalnega sistema kape izolatorja, izhodiščno stanje (a); prva optimizacija (b), druga optimizacija (c)

Figure 2. The course of changes to the gating system of insulator cap; existing (a), first optimization (b), second optimization (c)

Slika 2 prikazuje potek optimizacije končnega ulivno-napajalnega sistema. Pri prvi optimizaciji smo s prestavitvijo lokacije napajalnikov uspešno odpravili krčilno poroznost v ulitku, ampak pri tem povečali bruto težo sistema s 17 kg na 20 kg. V drugem delu optimizacije smo zaradi težnje po dosegu večjega izplena taline optimizirali obliko napajalnikov na najmanjšo mero, ki še zagotavlja usmerjeno strjevanje. Pri tem smo bruto težo zmanjšali z 20 kg na 16,8 kg in tako povečali izplen taline za 16 %. Ob kapaciteti proizvodnje 200 izdelanih form na uro to pomeni prihranek 4800 kg taline na izmeno.

2 Eksperiment

Preiskovani ulitek kape izolatorja je izdelan iz bele temprane litine kakovosti EN-GJMW-550-04 (DIN EN 1562:2019), njegova neto teža je 2,6 kg. Zaradi same geometrije ulitka in želje, da se za izdelavo votlih delov uporabi eno jedro za več ulitkov, je bil obstoječi ulivno-napajalni sistem konstruiran, kot prikazuje slika 2 a). Izbrani so bili napajalniki cilindrične oblike, ki napajajo ulitek skozi ušesa kape izolatorja. Ta postavitev je ugodna, saj je tako omogočeno brušenje vratu napajalnika po ravni površini.

Litje začetnih vzorcev je bilo realizirano pri temperaturi 1420 °C in kemični sestavi, podani v Preglednici 1.

Tabela 1. Kemična sestava taline

Table 1. Chemical analysis of the melt

	C	Si	S	Mn	Cr
[mas. %]	2,83	1,00	0,04	0,85	0,08

Slika 1 b) prikazuje porušen ulitek v litem stanju, kjer je po celotnem preseku

between power lines and supports and prevent leakage of current into the ground.

Figure 2 shows the flow of optimization of the gating system. In the first optimization, by moving the location of the feeders, we successfully eliminated shrinkage porosity in the casting, but at the same time increased the gross weight of the system from 17 kg to 20 kg. In the second part of the optimization, due to the tendency to achieve better yield , we optimized the shape of the feeders to the smallest possible extent, which still ensures directional solidification. In doing so, we reduced the gross weight from 20 kg to 16,8 kg and thus increased the yield of melt by 16 %. With a production capacity of 200 molds per hour this amounts to 4800 kg less material needed per shift.

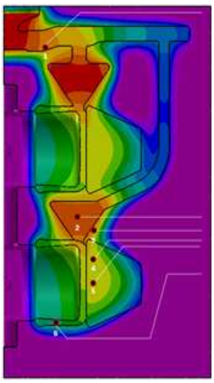
2 Experimental

The investigated insulator cap casting is made of white-heart malleable cast iron, quality EN-GJMW-550-04 (DIN EN 1562:2019) with a net weight of 2.6 kg. Due to the geometry of the casting and the desire to use one core for two castings for the production of a hollow inside part, the existing gating system was constructed as shown in Figure 2 a). Cylindrical-shaped feeders were chosen that feed the casting through the »ears« of the insulator cap. This arrangement is advantageous, as it enables the feeder neck to be round on a flat surface.

The casting of the initial samples was realized at a temperature of 1420 °C and the chemical composition is given in table 1.

Figure 1 b) shows casting in an as-cast state, where a crystalline shine characteristic of cementite is visible throughout the cross-section, which means that the casting has completely solidified "white" according to the metastable system Fe – Fe3C. During viden kristalni lesk, značilen za cementit, kar pomeni, da se je ulitek v celoti strdil »belo« po metastabilnem sistemu Fe – Fe3C. Z žarjenjem oz. tempranjem pa ledeburitni (evtektski) Fe3C razpade, pri čemer se ogljik odlaga v obliki kompaktnih delcev, imenovanih temprani ogljik.

Da bi bil izračun livarskih procesov kar najbolj natančen, so bili določeni robni pogoji, eksperimentalno opredeljeni z meritvami temperatur na posameznem mestu ulitka, napajalnika in v peščeni mešanici. Na osnovi eksperimentalno pridobljenih ohlajevalnih (litina) in segrevalnih (peščena mešanica) krivulj je bila izvedena ponastavitev koeficienta prenosa toplote v odvisnosti od temperature. Meritve temperature so bile izvedene na 6 različnih mestih, kot to prikazuje Slika 3. Podatke smo zajemali z analogno-digitalnim pretvornikom proizvajalca National Instruments tip NI9213 in programom Labview. Frekvenca meritev je bila 50 Hz. Uporabljeni so bili termočleni tipa K (Ni – Cr – Ni), oplaščeni z inoksom ali steklenimi vlakni. Plašč iz inoksa je bil uporabljen v primeru neposrednega stika s talino. Termoelementi, ki so bili v peščeni mešanici, pa so imeli plašč iz steklenih vlaken.

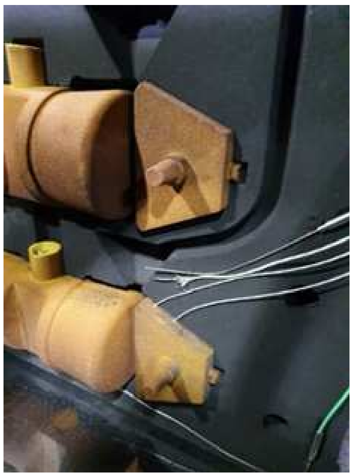


Slika 3. Postavitev termočlenov v peščeni formi

Figure 3. Placement of thermocouples in a sand mold

heat treatment - tempering, the ledeburite (eutectic) Fe3C breaks down, whereby the carbon is deposited in the form of compact particles called tempered carbon.

To make the calculation of the foundry processes as accurate as possible, boundary conditions were experimentally defined by temperature measurements at individual places of the casting, the feeder, and in the sand mixture. Based on the experimentally obtained cooling (casting) and heating (sand mixture) curves, the heat transfer coefficient was reset as a function of temperature. Temperature measurements were made at 6 different places, as shown in Figure 3. Data were collected with an analog-digital converter manufactured by National Instruments, type NI9213, and the Labview program. The measurement frequency was 50 Hz. Thermocouples type K (Ni – Cr – Ni) coated with stainless steel or fiberglass was used. A stainless steel jacket was used where there was direct contact with the melt. The thermocouples, which were in the sand mixture, had a fiberglass jacket.



Slika 4. Termočleni v peščeni formi

Figure 4. Thermocouples in a sand mould

3 Rezultati

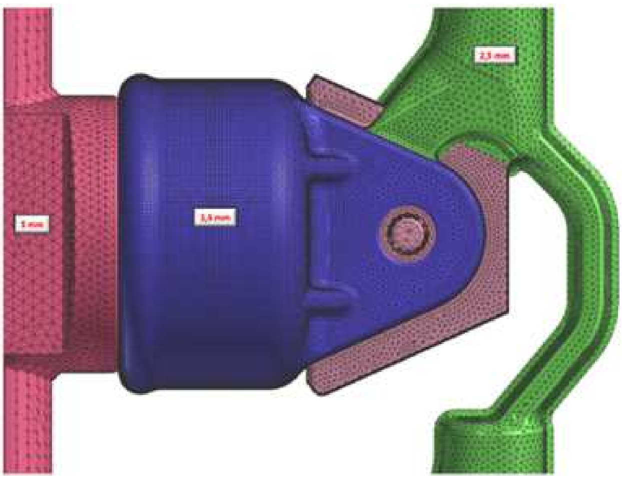
Na izrisanem 3-D modelu smo izvedli numerično simulacijo litja in strjevanja. Za geometrije ulitka in ulivno-napajalnega sistema, jeder in peščene forme smo izdelali površinsko mrežo, ki je sestavljena iz preprostih celic, s katerimi opišemo celotno geometrijo. Natančnost izdelave mreže in izračunane simulacije je odvisna od velikosti površinskih elementov. Izdelano površinsko mrežo predstavlja Slika 5. Na ulitku smo izbrali velikost površinskih elementov 1,5 mm, saj nas je zanimala prisotnost livarskih napak. Za ulivno-napajalni sistem smo nastavili velikost 2,5 mm in za jedra 5 mm. Peščeno formo smo razdelili na površinske elemente z velikostjo 12 mm. Poleg površinske mreže smo izračunali še volumsko mrežo. Skupno je tako bilo pripravljenih 5.270.162 volumskih elementov. Čas računanja je znašal 2 h 50 min.

Na Sliki 6 je prikazan posnetek simulacije strjevanja v trenutku, ko ulitek izgubi povezavo z napajalnikom. To območje v ulitku predstavlja zadnje strjevalno področje. Napajalnik ni zmožen zagotavljati zadostne količine taline skozi

3 Results

Numerical simulation of casting and solidification was carried out on the drawn 3-D model. For the geometries of the casting and gating system, cores, and sand form, a surface mesh grid was created, which consists of simple cells that describe the entire geometry. The accuracy of the mesh creation and the calculated simulation depends on the size of the surface elements. Figure 5 shows the produced surface mesh. The size of the surface elements on the casting was determined at 1.5 mm, as we were interested in the presence of casting defects here. A size of 2.5 mm was chosen for the gating system and 5 mm for the cores. The sand mold was divided into surface elements with a size of 12 mm. After the surface mesh was computed, the volume mesh was created. A total of 5,270,162 volume elements were thus prepared. The calculation time was 2 h 50 min.

Figure 6 shows a snapshot of the solidification simulation at the moment when the casting loses its connection with the feeder. This area in the casting thus represents the last solidification area, and since the feeder is not able to provide enough melt throughout the entire solidification time and thus compensate for shrinkage, a high probability of shrinkage porosity can be expected here. The reason for this is that the feeder is designed in such a way that it feeds the casting through the "ears". In doing so, it places a heavy thermal load on the smaller



Slika 5. Površinska mreža

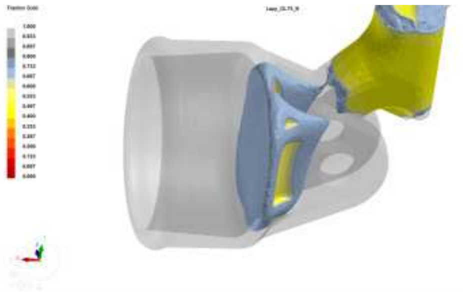
Figure 5. Surface mesh

celoten čas strjevanja in tako kompenzirati krčenja, zato je tukaj pričakovati veliko verjetnost pojava krčilne poroznosti. Vzrok za to je, da je napajalnik konstruiran na način, da napaja ulitek skozi »ušesa«. Pri tem močno toplotno obremeni manjše jedro (Slika 7) in ta del ulitka se zato ohlaja počasneje. Posledično ima tukaj ulitek tudi največji termalni modul. Ker se ohlaja počasneje, je čas do temperature solidus na tem delu okoli 270 s, medtem ko se vrat napajalnika strdi po 220 s.

Slika 9 prikazuje izračun toplotnega modula za ulitek kape izolatorja. Opaziti je, da je modul na sredini ulitka največji, in sicer okoli 0,52 cm, medtem ko je najmanjši modul ulitka 0,28 cm. Modul

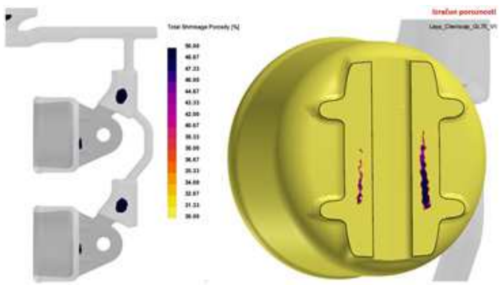
core (Figure 7) and this part of the casting, therefore, cools more slowly. As a result, the casting here also has the highest thermal modulus. Because it cools more slowly, the time to solidus temperature is around 270 s, while the neck of the feeder solidifies after 220 s.

Figure 9 shows the thermal modulus calculation for an insulator cap casting. It can be seen that the module in the middle of the casting is the largest, namely around 0,52 cm, while the smallest module of the casting is 0,28 cm. The modulus of the feeder's neck varies between 0,44 cm and 0,47 cm, which is not sufficient because the modulus of the feeder's neck should be greater than the highest modulus of the



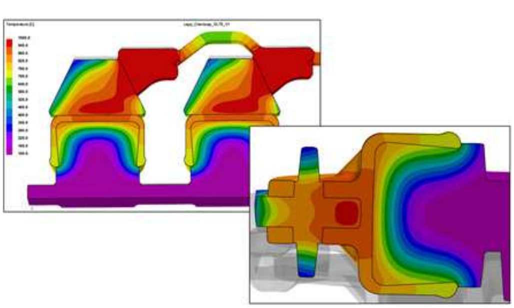
Slika 6. Izračun strjevanja

Figure 6. Calculation of solidification



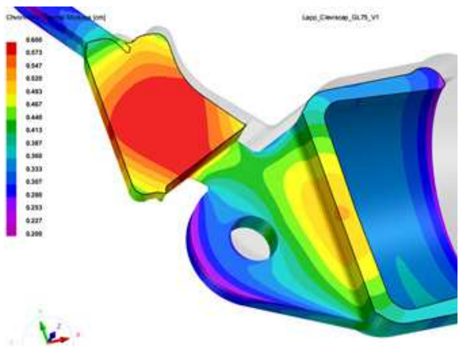
Slika 7. Izračun krčilne poroznosti

Figure 7. Calculation of total shrinkage porosity



Slika 8. Temperaturno polje na koncu strjevanja

Figure 8. Temperature field at the end of solidification



Slika 9. Izračun toplotnega modula ulitka

Figure 9. Calculation of thermal modulus

vratu napajalnika se giblje med 0,44 cm in 0,47 cm, kar pa ni zadostno, saj bi moral biti modul vratu napajalnika večji od najvišjega modula ulitka, da bi dosegli usmerjeno strjevanje iz ulitka skozi vrat napajalnika v napajalnik. To merilo imenujemo merilo modulov, kjer je MU modul ulitka, MV modul vratu napajalnika in MN modul napajalnika.

$$M_U < M_V < M_N \quad (2)$$

Nov ulivno-napajalni sistem je bil zasnovan na način, da smo ohranili postavitev ulitkov na modelni plošči. Tako smo se izognili popravilu orodja za izdelavo jeder in orodja za vlaganje jeder v peščeno formo. Napajalnike smo postavili na del ulitka, ki ga je simulacijska programska oprema ProCAST izračunala kot tistega z največjim termalnim modulom in kot območje, ki se strdi zadnje. Napajalnike smo prav tako povečali, da bi dovajali dovolj taline v ulitek, tako da je njihov modul večji kot modul ulitka, katerega napajajo.

Rezultati meritev temperatur v ulitku, jedru in peščeni mešanici so podani na Sliki 10 in Sliki 11. S termočlenom 1 smo izmerili maksimalno temperaturo 1419 °C, ki smo jo potrdili tudi s sondo za merjenje temperature na vlivnem avtomatu. S spreminjanjem temperature skozi čas lahko spremljamo ohlajanje taline do konca formarske linije, kjer se ulitki ločijo od peščene mešanice. Takrat smo termočlene odklopili in ulitke pobrali iz forme. Proga, na kateri se ulitki ohlajajo v peščeni mešanici, preden padejo v hladilni boben in se od peščene mešanice ločijo, je dolga 12 m. To pot ulitki dosežejo po 12 minutah, temperatura po tem času znaša 818 °C. To pomeni, da je hitrost ohlajanja okoli 50 °C/min.

Termočlen T2 je bil lociran v sredini napajalnika spodnjega ulitka (zaradi poteka dovodnega kanala termočlenov nismo mogli postaviti v zgornji ulitek). Za okoli 30 s je termočlen izgubil povezavo, vendar se je ta nato vrnila. Opazimo, da temperatura

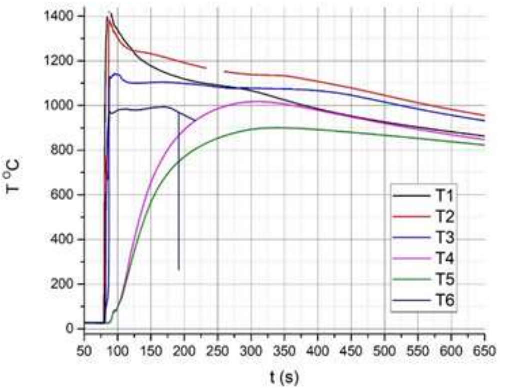
casting to achieve directional solidification from the casting through the feeder's neck into the feeder. This is called the modulus criterion, where MU is the modulus of the casting, MV is the modulus of the feeder neck, and MN, is the modulus of the feeder.

$$M_U < M_V < M_N \quad (2)$$

The new gating system was designed in such a way as to preserve the placement of the castings on the model plate, as this avoided the repair of the core-making tool and the core setter. We placed the feeders on the part of the casting that ProCAST calculated as having the highest thermal modulus and as the area that solidifies last. We have also enlarged the feeders to feed enough melt into the casting so that their modulus is greater than the modulus of the casting they feed.

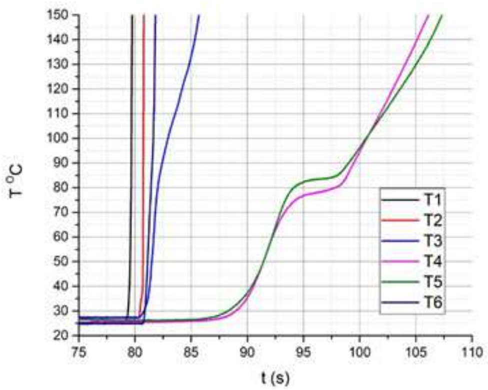
The results of temperature measurements in the casting, core and sand mixture are given in Figures 11 and Figure 12. With thermocouple 1, the maximum temperature was measured at 1419 °C, which was also confirmed with the temperature measuring probe on the pouring machine. By changing the temperature over time, we can monitor the cooling of the melt to the end of the cooling line, where the castings are separated from the sand mixture. At that time, we disconnected the thermocouples and collected the castings from the mold. The line on which the castings are cooled in the sand mixture before falling into the cooling drum and separating from it is 12 m long. The castings reach this path after 12 min, the temperature after this time is 818 °C. This gives us a cooling rate of around 50 °C/min.

Thermocouple T2 was located in the middle of the feeder of the lower casting (due to the flow of the runners, we could not place the thermocouples in the upper casting). For about 30 s, the thermocouple



Slika 10. Rezultati meritev temperatur

Figure 10. Results of temperature measurements



Slika 11. Povečano območje T4 in T5

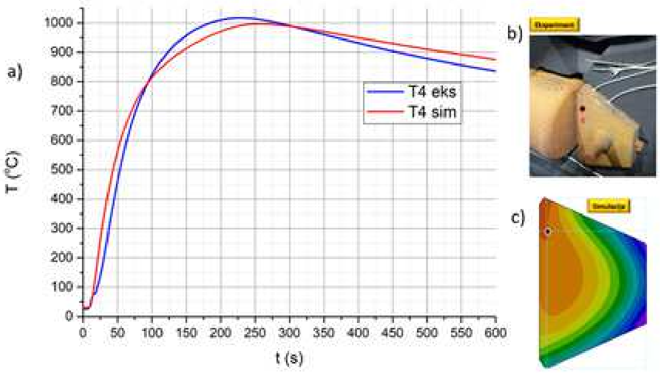
Figure 11. Enlarged view, showing T4 and T5

pada počasneje kot v termočlenu T1. To ni presenetljivo, saj je volumen napajalnika veliko večji kot volumen razdelilnega kanala, zato se ta ohlaja počasneje. Maksimalna dosežena temperatura je znašala 1385 °C, in sicer okoli 6 s po začetku litja, kar se natančno sklada z izračunom litja. Toliko časa je talina potrebovala za pot od livne čaše do spodnjega napajalnika.

Termočlena T4 in T5 sta merila temperaturo v peščenem jedru. Izmerjene temperature termočlena T4 so višje, ker je termočlen bližje napajalniku kot termočlen T5. Iz grafa je razvidno, kako se temperatura v jedru povečuje, ko toplota prehaja iz ulitka

lost connection, but then it came back. We notice that the temperature drops more slowly than in thermocouple T1. This is not surprising, because the volume of the feeder is much larger than the volume of the runner, so it cools more slowly. The maximum temperature reached was 1385 °C, about 6 s after the start of casting, which is exactly in line with the casting calculation. That's how long the melt needed to travel from the pouring basin to the lower feeder.

Thermocouples T4 and T5 measured the temperature in the sand core. The measured temperatures at T4 are higher because the thermocouple is closer to



Slika 12. Primerjava segrevalnih krivulj eksperimenta in simulacije v peščenem jedru (a), pozicija termoelementa T4 (b), mesto določitve izračunane segrevalne krivulje (c)

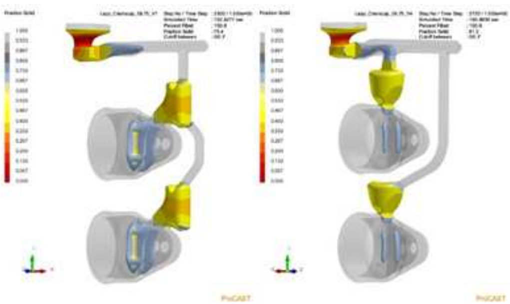
Figure 12. Comparison of the heating curves of the experiment and simulation in the sand core (a), the position of the thermocouple T4 (b), the location of the calculated heating curve (c)

na jedro. Opazna pa je tudi sprememba na krivulji T4 in T5, in sicer pri temperaturi okoli 80 °C, kar je skladno s temperaturo vžiga fenolne smole v jedru Croning.

Slika 12 prikazuje primerjavo med eksperimentalno določeno in izračunano segrevalno krivuljo v peščenem jedru ter položaj termoelementa T4 v peščeni formi in na virtualnem jedru. Opazimo, da je izračunana segrevalna krivulja bolj zvezna, saj ne upošteva vseh pogojev, kot je npr.

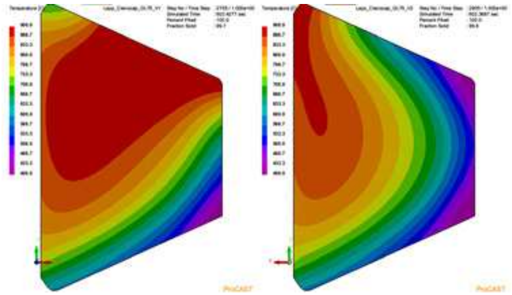
the feeder than the T5 thermocouple. The graph shows how the temperature in the core increases as heat passes from the casting to the core. A change in the T4 and T5 curve is also noticeable at a temperature of around 80 °C, which would correspond to the ignition temperature of the phenolic resin in the Croning core.

Figure 12 shows a comparison between the experimentally determined and calculated heating curve in the sand



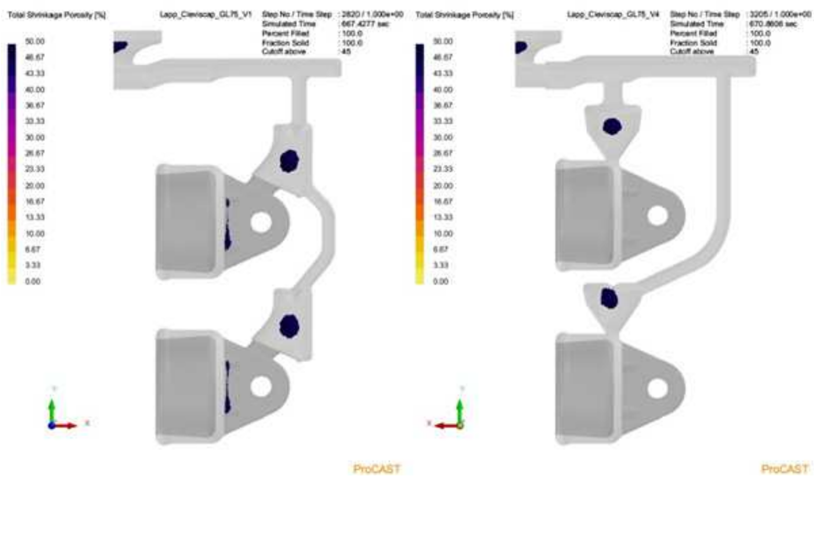
Slika 13. Izračun strjevanja za verzijo 1 (a) in verzijo 3 (b)

Figure 13. Calculation of solidification for version 1 (a) and version 3 (b)



Slika 14. Temperaturno polje jedra 10 min od začetka litja za verzijo 1 (levo) in verzijo 3 (desno)

Figure 14. Temperature field of the sand core 10 min after casting for version 1 (left) and version 3 (right)



Slika 15. Izračun krčilne poroznosti za verzijo 1 (levo) in verzijo 3 (desno)

Figure 15. Calculation of total shrinkage porosity for version 1 (left) and version 3 (right)

vžig fenolne smole, kar pa je zaznano na eksperimentalno določeni krivulji. Zaradi manjših razlik med eksperimentom in izračunom smo v programu ProCAST nekoliko spremenili določene parametre jedra Croning (gostota, prevodnost), da smo se čim bolj približali realnemu stanju.

Na Sliki 13 lahko vidimo primerjavo izračuna strjevanja za verzijo 1 in verzijo 3 približno 150 s po začetku litja. Pri verziji 3 s spremenjenim položajem napajalnikov se ulitek strjuje enakomerno v napajalnik in ne izgubi povezave z njim. Prav tako se mesto največjega termalnega modula prestavi na območje pod napajalnikom. Zaradi tega se zmanjša tudi pregrevanje manjšega jedra (Slika 14). Tako smo dobili usmerjeno strjevanje, ki je najučinkovitejši ukrep za odpravo krčilne poroznosti. Pri usmerjenem strjevanju ni bistvena preprečitev nastanka lunkerja, pač pa njegov prenos na neškodljivo mesto, to je v napajalnik (Slika 15).

4 Zaključek

Pri gravitacijskem litju v peščene forme je zasnova ulivno-napajalnega sistema izjemno pomembna, saj njegova geometrija neposredno vpliva na kakovost ulitkov in količino izmeta. Ključni cilj ulivnega sistema je zagotoviti nemoten pretok taline iz livne čaše v livno votlino celoten čas litja in strjevanja.

V članku je bila opisana sprememba postavitve in geometrije napajalnikov za ulitek kape izolatorja. Na obstoječem ulivno-napajalnem sistemu je bilo po litju zaznati povečan delež livarskih napak, predvsem kot posledica krčilne poroznosti. V sklopu optimizacije so bili napajalniki prestavljeni na mesto, kjer so računalniški izračuni določili najvišji termalni modul in ga prepoznali kot območje, ki se strdi zadnje.

core and the position of the thermocouple T4 in the sand mold and on the virtual core. We notice that the calculated heating curve is more uniform as it does not take into account all conditions such as e.g. ignition of the phenolic resin, which is detected on the experimentally determined curve. Due to minor differences between the experiment and the calculation, we slightly changed certain parameters of the Croning core (density, conductivity) in the ProCAST program to get as close as possible to the real situation.

In Figure 13 we can see a comparison of the solidification calculation for version 1 and version 3 approximately 150 s after the start of casting. In version 3 with a changed position of the feeder, the casting solidifies evenly in the direction of the feeder and does not lose its connection with it. Also, the location of the largest thermal module is moved to the area under the feeder. This is also registered on the temperature field calculation of the sand core (Figure 14). Based on the applied changes, directional solidification was obtained, which is the most effective measure to eliminate shrinkage porosity. It is not essential to prevent the formation of a shrinkage defect, but rather to transfer it to a harmless place, i.e., to the feeder (Figure 15).

4 Conclusions

In gravity casting in sand molds, the design of the gating system is extremely important, as its geometry directly affects the quality of the castings and the amount of scrap. The key goal of the gating system is to ensure a smooth flow of melt from the pouring cup to the casting cavity throughout the casting and solidification period.

The article described a change in the layout and geometry of the feeders for

Rezultati teh izračunov so bili potrjeni s stanjem po litju v proizvodnji.

insulator cap casting. On the existing gating system, an increased proportion of casting defects was detected after casting, mainly as a result of shrinkage porosity. As part of the optimization, the feeders were moved to the place where the simulation showed the highest thermal modulus and recognized as the area that solidifies last. The results of these calculations were confirmed with the results after casting in production.

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AKTUALNO / CURRENT

62nd IFC in Portoroz - Slovenia 30 years membership in WFO

Dr. Carsten Kuhlgatz announced "Young researchers scientist Award 2023"

Dr. Carsten Kuhlgatz, President of the World Foundry Organization, thanked Mirjam Jan-Blazic and her team for the excellent organization and execution of the 62nd IFC in Portoroz. Knowing that Ms. Jan-Blazic organizes this conference with only two other team members, everyone can only have high regard for this achievement. The leaders of the World Foundry organization (WFO) hope that we will be able to participate in many more conferences in Portoroz.

30 years of membership in WFO

On behalf of the Executive Committee and the team of General Secretaries, Kuhlgatz thanked the Slovenian Foundry Society for its 30 years of membership in the WFO. The Slovenian Foundry Association is a very active member in the WFO. A highlight of the cooperation was the World Technical Forum, which took place in 2019 in combination with the 59th IFC in Portoroz.

The conferences, which are mainly organized by the member associations, provide an excellent forum for foundry professionals from all over the world with the opportunity for exchange of experience, presentation of new technologies and networking. This is also the main task of the WFO and the WFO Working Groups. In many cases, the new technologies are developed by young scientists and experts.

Young scientists and professionals conference

What could be more obvious than to organize a conference only for young scientists and professionals from all over the world. These young scientists and professionals are our future. However, WFO will not want to hold this conference in person, but rather in the world-wide-web. For the first time the WFO will use a digital conference platform to organize, execute and follow up this special event. We will develop a webpage for the call of papers, the registration of the attendees and the execution of the conference. The young scientist has to send a video of their presentation. This video will be available at the conference platform for a special period in March or April 2023. Everybody who is registered can watch this video at any time. This will ensure that the presentations can be viewed conveniently on any continent and in any time zone. There will be a chat function for questions. Spontaneous discussion sessions can also be initiated via video or chat. A jury will ensure that the presentations meet a certain quality standard. The jury will evaluate the presentations and select the 3 best of them.

Dr. Kuhlgatz Carsten with the president of the Slovenian Foundrymen Society, MSc. Mirjam Jan-Blažić, on Foundrymen's night

Young scientists Award 2023 at GIFA - GMTN 2023 in Duesseldorf

The best 3 presenter's will be invited to the GIFA 2023 in Düsseldorf. They have to explain their results and developments at the Meeting Point of the GIFA. There they will receive awarded prizes.

But without the help of all responsible Persons in the member associations we will not be successful in getting enough presentations. So please support us and promote this special event in your member associations, universities, research institutes and companies. Kuhlgatz is convinced that this format will be a complete success. Subsequently, this platform can be used by all member associations to organize and hold events on behalf of the WFO for a small fee.

About Dr. Carsten Kuhlgatz

Dr. Carsten Kuhlgatz is president of the World foundry Organization 2022 and 2023. He was president of Hüttenes-Albertus for 20 years and most recently the CEO of the global HA Group. Today he is shareholder and president of the holding Albertuswerke GmbH. One of their affiliates is Hüttenes-Albertus und die HA-Group.

Dr. Kuhlgatz Carsten

Editor's comment:
Presented in this article are Dr. Carsten Kuhlgatz's valuable thoughts, which he gave in his speech on Foundrymen's night on 15th September 2022.

AKTUALNO / CURRENT

62. IFC Portorož 2022

Tradicionalna vsakoletna septembrska livarska konferenca z livarsko razstavo v Portorožu, 62. po vrsti, ki jo organizira Društvo livarjev Slovenije skupaj z soorganizatorji: Naravoslovno tehniška fakulteta Univerze v Ljubljani in Fakulteta za strojništvo Univerze v Mariboru, je potekala letos v času od 14. - 16. septembra. Za razliko od prejšnjih dveh konferenc, ki sta bili organizirani tudi v letih 2020 in 2021, t.j. v letih pandemije korona virusa, je letošnja konferenca potekala brez omejitev in v nadvse sproščenem vzdušju. Na vsakem koraku se je čutilo veliko zadovoljstvo s tem, da so zopet možni socialni strokovni kontakti v živo.

Pogled na plenarno dvorano

Udeleženci konference in razstave so se na predvečer konference srečali na že tradicionalnem pozdravno-spoznavnem srečanju v Piranu, katerega se zmeraj udeleži tudi predstavnik županstva Občine Piran. Letos je pozdravne besede udeležencem namenila podžupanja Občine Piran, ga. Manuela Rojec.

Na konferenci so bili prisotni ugledni predstavniki znanstvenih in gospodarskih subjektov iz tujine in Slovenije s področja livarske znanosti in stroke ter predstavniki nacionalnih livarskih združenj in društev. Generalna ocena pa je tudi ta, da konferenca ohranja sloves ene od največjih livarskih konferenc v tem delu Evrope. Letošnja udeležba z več kot 290 udeleženci iz 23 držav, vključno s Slovenijo, to potrjuje. Na konferenci je bilo predstavljeno preko 40 predavanj, od tega 11 kot plenarna, tri plakatna, ostala pa so bila porazdeljena v sekcije: Lito železo in livarska tehnologija, Neželezove zlitine in Sekundarna oprema in

Prizorišče pred razstavnimi dvoranami

tehnologije za livarstvo. Predavanja so zajela zelo široko problematiko: različne in nove livarske tehnologije ter nove livne materiale, digitalizacijo procesov v industriji 4.0, uporabo industrijskih robotov in novih rešitev za talilne peči in čiščenje ulitkov.

Predsednica Društva livarjev Slovenije in predsednica organizacijskega odbora 62. IFC Portorož 2022, mag. Mirjam Jan-Blažić, je na otvoritvi konference in razstave v otvoritvenem govoru podala ugotovitev, da so po pandemiji v ospredje prišle bistveno hitreje nekatere nove teme in rešitve na področjih digitalizacije, krožnega gospodarstva in širše trajnostnega razvoja v luči prehoda na zeleno in brezogljično družbo. Poudarila je, da se po dveh kriznih letih in tudi zaradi vojne v Ukrajini v livarstvu ter celotnem gospodarstvu vse evropske države srečujejo z zelo resnimi problemi in zahtevnimi izzivi, ki se nanašajo na enormno rast cen energentov in preskrbo ter rast cen surovin. Gre za probleme, ki že marsikje vplivajo na zmanjšanje livarske proizvodnje in tudi že ogrožajo obstoj nekaterih podjetij. Zato so udeleženci bili edini, da je za ohranjanje proizvodnje ter delovnih mest, potrebna takojšnja državna pomoč vlad in enotni ter hitri ukrepi tudi na nivoju Evropske Unije in dosleden znan program vladne pomoči že letos tudi za celo naslednje leto.

Manuela Rojec, podžupanja občine Piran, in Mirjam Jan Blažić, predsednica Društva livarjev Slovenije

Vsa posredovana predavanja na konferenci bodo s strani predsednika programsko znanstvenega odbora, zasl. prof. dr. Alojza Križmana, predstavljena s kratkimi izvlečki oz. komentarji v ločenem prispevku, ki bo objavljen v 4. št. Livarskega vestnika decembra 2022.

Na letošnji livarski razstavi v Portorožu je sodelovalo 48 razstavljavcev (od tega 21 iz tujine in 27 iz Slovenije), ki so po večini dobavitelji različnih materialov, opreme ali znanja za livarsko industrijo. Na straneh 188 – 191 te izdaje LV objavljamo fotografije razstavnih prostorov vseh razstavljavcev.

Predsednica Organizacijskega odbora
62. IFC Portorož 2022,
Mag. Mirjam Jan-Blažić

AKTUALNO / CURRENT

Društvo livarjev Slovenije ima novega častnega člana

Občni zbor Društva livarjev Slovenije (v nadaljevanju Društvo) je na svoji izredni seji dne 31. 08. 2022, na predlog Izvršnega odbora Društva, sprejel naslednji sklep:

Za častnega člana Društva livarje Slovenije se imenuje dolgoletni stanovski kolega iz poljskega združenja livarjev - STOP iz Krakowa, mag. Tadeusz Franaszek. Listina častnega člana mu je slovesno vročena s strani predsednice Društva in predsednice Organizacijskega odbora IFC, mag. Mirjam Jan-Blažić in predsednika Programsko-znanstvenega odbora IFC, zasl. prof. dr. Alojza Križmana, na otvoritvi 62. IFC Portorož 2022.

Mag. Tadeusz Franaszek že od 70 let prejšnjega stoletja ohranja tesne stike z Društvom livarjev Slovenije. V obdobju več kot 30 let je pogosti udeleženec mednarodne livarske konference v Portorožu, pri čemer je bil skupaj s pokojnim profesorjem Jozefom Suchyjem z Univerze v Krakowu glavni promotor in ambasador povezovanja in sodelovanja. Nenehno je skrbel za ohranjanje in rast sodelovanja z Univerzo v Krakowu ter udeležbo poljskih znanstvenikov kot predavateljev na mednarodni livarski konferenci v Portorožu.

V zadnjem desetletju je spodbujal tudi udeležbo predstavnikov poljske livarske industrije za sodelovanje na tem osrednjem vsakoletnem livarskem dogodku Društva. Življenjepis mag. Tadeusza Franaszeka izpričuje njegovo dolgoletno predanost livarstvu na širokem delovnem področju: Inštitutsko delo, konstruktorsko in projektantsko delo na področju livarskih strojev in opreme, delo na različnih projektih uvajanja novih tehnologij v obstoječih poljskih livarnah kot tudi v tujini ter prevzemanje vodstvenih in najvišjih vodilnih funkcij. Posebno dejaven je bil tudi po vseh področjih nekdanje Jugoslavije, kjer je denimo poskrbel za zagon livarn v Slavonski Požegi na Hrvaškem, RTB Bor in 14. oktober Kruševac v Srbiji, v podjetju Novi život Zenica v BIH ter celo v Sloveniji v Livarni Titan, Kamnik.

Od leta 2007 do danes je glavni urednik poljske livarske revije PRZEGLAD ODLEWNICTWA. Od leta 1951 je član poljskega združenja livarjev STOP in do današnjih dni je dolgoletni član njegovega vodstva. Od 2011 do danes pa je predsednik ZG STOP.

Mag. Mirjam Jan-Blažić

AKTUALNO / CURRENT

Galerija slik vseh sponzorjev-razstavljavcev na 62. IFC Portorož 2022

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AKTUALNO / CURRENT

Pregled livarskih prireditev v letu 2022 / 2023

Datum dogodka	Ime dogodka	Mesto in država
05. – 07. 10. 2022	Evropska konferenca tlačnega litja cinka	Koblenz, Nemčija
06. – 07. 10. 2022	Randhofenski dan lahkih kovin	Salzburg, Avstrija
16. - 20. 10. 2022	74. svetovni livarski kongres in generalna skupščina WFO	Busan, J. Korea
27. - 28. 10. 2022	Ledebur-Kolokvium	Freiberg, Nemčija
12. - 16. 06. 2023	Mednarodni sejem metalurgije in livarstva (GIFA)	Duesseldorf, Nemčija

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SREBRNA POKROVITELJA 62. IFC PORTOROŽ 2022

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