

Vrednotenje 3D-tiskanih polimernih modelov, prevlečenih z nanofluidi, za postopek hitrega precizijskega litja

Evaluation of 3D Printed Polymer Patterns Coated with Nanofluids for the Rapid Investment Casting Process

Povzetek

V postopku hitrega precizijskega litja polimerni modeli nadomestijo običajne voščene modele, ki se v krajšem času izdelajo na strojih za 3D-tiskanje. Iz 3D-natisnjene vzorca se nato izdelata keramično školjko, ki se nato uporabi za litje kovinskega kosa. Ta postopek se pogosto uporablja za izdelavo prototipov in majhne serijske proizvodnje, saj omogoča hitro izdelavo kompleksnih kovinskih delov brez potrebe po orodju. Čeprav je trdnost polimernega modela ustrezna, se med taljenjem v primerjavi z voščenimi modeli bolj razširijo, kar bi porušilo keramično školjko. Poleg tega hrapavost površine polimernega vzorca nikoli ni tako fina kot pri voščnem modelu.

V tem delu so bili 3D-modeli natisnjeni z uporabo stroja za nanašanje staljenega materiala (Fused Deposition Modelling – FDM) (model: Ultimaker), pri čemer sta surovini akrilonitril butadien stiren (ABS) in polilaktična kislina (PLA). Po izvedbi velikega števila poskusov je bilo ugotovljeno, da ima model iz polilaktične kisline boljše lastnosti. Pri razvoju 3D-tiskanih modelov so bili upoštevani različni vzorci polnil, med katerimi je bilo ugotovljeno, da imata giroidni in kubični vzorec polnila večjo tlačno trdnost v primerjavi z drugimi vzorci polnil.

Poleg tega je hrapavost površine polimernega modela vedno slabša od hrapavosti voščene modela. Zato smo poskušali povečati hrapavost površine polimernih modelov z ustvarjanjem tanke prevleke okoli 3D-natisnjenih polimernih modelov z uporabo nano tekočin, ki vsebujejo nano delce, kot so cinkov oksid (ZnO), titanov dioksid (TiO₂) in grafenov oksid (GO). Ugotovljeno je bilo, da lahko ti nanofluidi ustvarijo enakomerno tanko plast okoli polimernih modelov in znatno izboljšajo njihovo površinsko hrapavost. S premazovanjem z nanofluidi se je izboljšala tudi trdnost polimernih modelov.

Ključne besede: postopek hitrega precizijskega litja, 3D-natisnjeni vzorci, giroidno in kubično polnilo, nanoprevleka, hrapavost površine

Abstract

In the rapid investment casting process, polymer patterns replace conventional wax patterns, which are produced on 3D printing machines within a shorter period. The 3D printed pattern is used to create a ceramic mould, which is then used to cast the metal part. This process is often used for prototyping and low-volume production runs, as it enables the rapid production of complex metal parts without requiring tooling. Although the strength of the polymer pattern is already good, they undergo a larger expansion during melting compared to wax patterns, which break the ceramic shell. Further, the surface roughness of a polymer pattern is not as fine as that of a wax pattern.

In the present work, 3D-printed patterns were developed using a Fused Deposition Modelling (FDM) machine (Make: Ultimaker), with Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) as the raw materials. After conducting a significant number of experiments, it was found that PLA offers better characteristics to the pattern. Different infill patterns were considered while developing the 3D printed patterns, of which gyroid and cubic infill patterns were found to have better compressive strength, compared to the other infill patterns.

Furthermore, the surface roughness of a polymer pattern is always inferior to that of a wax pattern. Hence, an attempt was made to enhance the surface roughness of the polymer patterns by creating a thin coating around the 3D-printed polymer patterns, using nanofluids containing nanoparticles such as Zinc Oxide (ZnO), Titanium Dioxide (TiO₂), Graphene Oxide (GO). It was found that these nanofluids could create a uniform thin film around the polymer patterns, significantly improving their surface roughness. The strength of the polymer patterns was also increased with the coating by using Nano fluids.

Keywords: rapid investment casting process, 3D printed patterns, gyroid and cubic infill, nano fluid coating, surface roughness

1 Uvod

Pri hitrem precizijskem litju (Rapid Investment Casting – RIC) se voščeni model nadomesti s 3D-natisnjenim modelom, kar omogoča kompleksnejše oblike in hitrejšo izdelavo. Iz 3D-natisnjenega modela se nato izdelata keramično školjko, ki se nato uporabi za litje kovinskega kosa. Ta postopek se pogosto uporablja za izdelavo prototipov in majhne serijske proizvodnje, saj omogoča hitro izdelavo kompleksnih kovinskih delov brez potrebe po orodju. Čeprav je trdnost polimernega modela ustrezna, se med taljenjem v primerjavi z voščeni modeli bolj razširijo, kar bi porušilo keramično školjko. Poleg tega je hrapavost površine polimernega modela vedno slabša od hrapavosti voščene modela. Zato je bilo v tem delu opravljenih nekaj raziskav za premagovanje teh izzivov.

2 Eksperimentalno delo

Sprva so bili polimerni modeli razviti v skladu z geometrijo, prikazano na Sliki 1, z

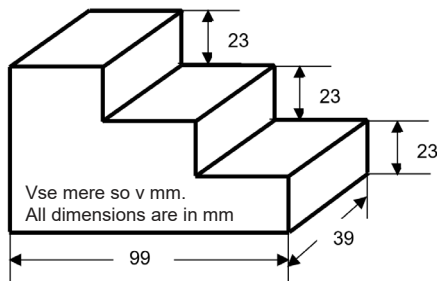
1 Introduction

In the Rapid Investment Casting (RIC), the wax pattern is replaced with a 3D-printed pattern, which allows far more complex shapes and faster production times. The 3D printed pattern is used to create a ceramic mould, which is then used to cast the metal part. This process is often used for prototyping and low-volume production runs, as it allows for rapidly producing complex metal parts without needing tooling. Although the strength of the polymer pattern is good, they undergo larger expansion during melting compared to wax patterns, which break the ceramic shell. Furthermore, the surface roughness of a polymer pattern is always inferior to that of a wax pattern. Hence, in the present work, some investigations were conducted to overcome these challenges.

2 Experimental Work

Initially, polymer patterns were developed as per the geometry shown in Fig 1, using

uporabo 3-D tiskalnika Ultimaker s fuzijskim nanašanjem (Fused Deposition Modelling – FDM).



Slika 1. Dimenzije vzorca.

Fig 1. Dimensions of the pattern.

Surovina, ki se uporablja pri FDM, je trdna v obliki filameta, ki vstopa v grelni komoro. To komoro obdaja spiralni grelnik, ki vzdržuje temperaturo na zahtevani ravni. Na vходу v to je par koles, ki filament potiskata v komoro. Na izhodu je pritrjena šoba ustreznega premera. Premera šob sta različna, in sicer 0,4 mm in 0,8 mm.

Polimerni modeli (ob uporabi PLA in ABS) so bili razviti s FDM, pri čemer so se spreminjali parametri, kot so višina plasti, širina linije, širina polnilne linije, širina stenske linije, širina zgornje in spodnje linije, hitrost tiskanja, hitrost polnjenja, hitrost stene in hitrost zgornje in spodnje linije. Hlajenje in podpora sta ustrezno izbrana.

a Fused Deposition Modelling (FDM) machine (Make: Ultimaker).

The raw material used in FDM is solid in the form of a wire roll. This chamber is surrounded by a heating coil, which maintains the temperature of the chamber at the required level. At the entry of this chamber is a pair of wheels through which the raw material wire passes into the chamber. At the exit, a nozzle of appropriate diameter is fixed. The nozzle diameters are varied at 0.4 mm and 0.8 mm.

Polymer patterns (using the materials PLA and ABS) were developed using FDM, varying the parameters such as layer height, line width, infill line width, wall line width, top-bottom line width, print speed, infill speed, wall speed, and top-bottom travel speed. Cooling and support have been selected appropriately.

The ceramic slurry was prepared by mixing aluminium silicate with the binder (Ethyl silicate), along with some wetting agents and anti-foaming agents. The ingredients and the process parameters of the ceramic slurry are shown in Table 1.

The ceramic shells developed are shown in Fig 2. These shells were fired inside an oven, and the polymer pattern material was removed from the ceramic shell. Molten metal (AA6061 alloy) was melted to about 750 °C and poured into the dried ceramic shell, and the casting was taken out after solidification.

Preglednica 1. Procesni parametri izdelave keramične školjke.

Table 1. Process parameters of ceramic shell building.

| Sloj / Coat | Vrsta suspenzije / Slurry type | Posip / Stucco | Čas namakanja / Dip time (s) | Čas odtekanja / Drain type (s) | Čas sušenja / Dry time (h) |
|-------------|--------------------------------|------------------------|------------------------------|--------------------------------|----------------------------|
| 1 | Primarno / Primary | Circon / Zircon 80/120 | 30 | 60 | 24 |
| 2-5 | Sekundarno / Secondary | Circon / Zircon 16/30 | 30 | 60 | 4 |
| 6 | Zunanji / Outer | Ni na voljo / N/A | 30 | 60 | 24 |

Keramična suspenzija je bila pripravljena z mešanjem aluminijevega silikata z vezivom (etilsilikat) ter nekaterimi sredstvi za boljše omočenje in sredstvi za preprečevanje penjenja. Sestavine in procesni parametri keramične suspenzije so prikazani v Preglednici 1.

Izdelane keramične školjke so prikazane na Sliki 2. Te školjke so bile žgane v peči in polimerni model je bil odstranjen iz keramične školjke. Staljena kovina (zlitina AA6061) je bila segreta na približno 750 °C in ulita v posušeno keramično školjko, po strjevanju pa je bil ulitek odstranjen.

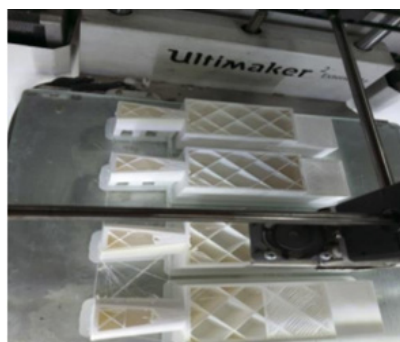


Slika 2. Keramične školjke med sušenjem.

Fig 2. Ceramic shells during drying.

3 Vpliv zapolnitve vzorca

Težave pri trdnem modelu so iskoristek materiala in nastanek razpok v keramični školjki zaradi prevelikega toplotnega raztezanja polimera med taljenjem. Zato so bili votli modeli sprva natisnjeni z 90 % zapolnitvijo, postopoma pa se je zapolnitev zmanjšala na 10 %. Ugotovljeno je bilo, da so vzorci primerni za livarske zahteve tudi pri 10 % zapolnitvi, ne da bi pri tem ogrozili dejavnike, kot so trdnost, površinska obdelava itd. Na Sliki 3 so prikazane različne zapolnitve votlih vzorcev.



Slika 3. Notranjost vzorcev, uporabljenih v tej študiji.

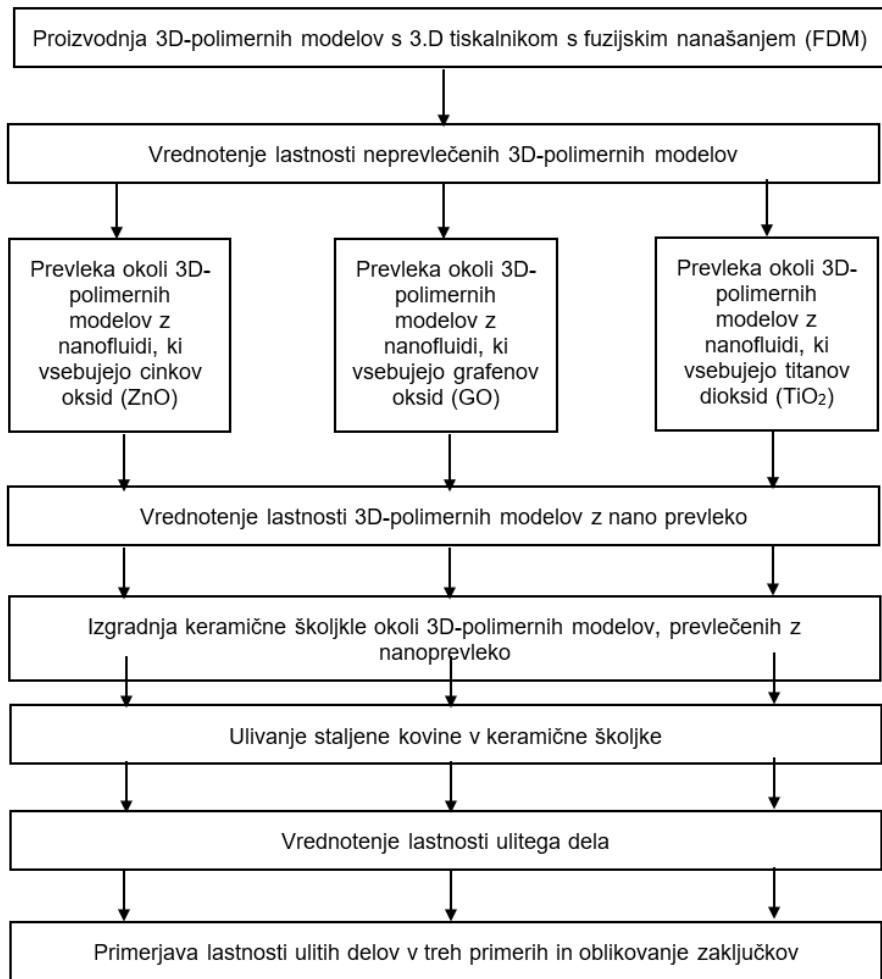
Fig 3. Pattern interiors used in the present study.

4 Vpliv premaza z nanofluidi

3D-natisnjeni polimerni modeli imajo v primerjavi z voščenimi modeli neustrezno obdelano površino. Zato smo poskušali izboljšati hrapavost površine polimernih modeliv z ustvarjanjem tanke prevleke z nanofluidi. Za tanko prevleko okoli polimernih modelov so bile uporabljeni trije različni nanofluidi, ki so vsebovali cinkov oksid (ZnO), grafenov oksid (GO) in titanov dioksid (TiO₂). Ultrazvočni sistem za nanašanje z brizganjem je bil uporabljen

3 Influence of Pattern Infill

The problems with the solid pattern are the wastage of material and cracking of the ceramic shell due to excessive thermal expansion of the polymer while melting. Hence, hollow patterns were printed initially at 90 % infill, and gradually the infill was reduced to 10 %. Even at 10 % infill, the patterns were found to be suitable for foundry requirements without compromising factors like strength, surface finish, etc. The different hollow pattern interiors are shown in Fig 3.



Slika 4.
Diagram poteka dela.

za naprševanje nanofluida na polimerne modele. Opravljenih je bilo več poskusov s spreminjanjem parametrov pršenja.

Hrapavost površine neprevlečenih 3D-polimernih modelov je bila ocenjena z optičnim profilometrom. Geometrijska toleranca modelov je bila ocenjena z uporabo koordinatnega merilnega stroja. Trdoto 3D-polimernih modelov smo izmerili z instrumentom za merjenje mikro trdote. Diagram poteka z zaporedjem preiskav, izvedenih v tem delu, je prikazan na Sliki 4.

4 Influence of Coating with Nano Fluids

The 3D printed polymer patterns have an inadequate surface finish compared to the wax patterns. Hence, an attempt was made to improve the surface roughness of the polymer patterns by creating a thin coating with nanofluids. Three different Nano fluids containing Zinc Oxide (ZnO), Graphene Oxide (GO), and Titanium Dioxide (TiO₂) were used to give a thin coating around the polymer patterns. An Ultrasonic Spray Coater was used to spray the nano fluid

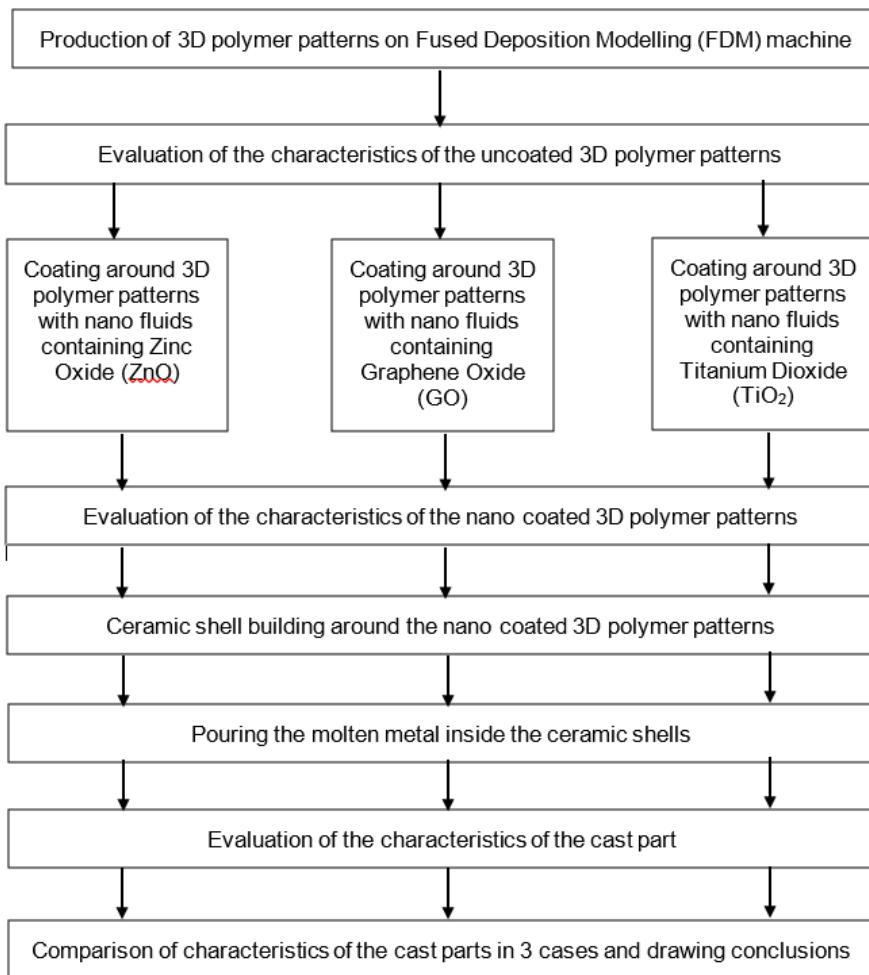


Fig 4. The flow diagram of the present work.

5. Zaključki

- Ugotovljeno je bilo, da se hrapavost površine polimernega modela znatno izboljša po nanosu premaza okoli 3D-natisnjene polimernega modela, kar posledično izboljša hrapavost površine končnega ulitka.
- Med vsemi uporabljenimi nanofluidi se je nanofluid, ki vsebuje titanov dioksid (TiO₂), izkazal za najučinkovitejšega pri izboljšanju hrapavosti površine in trdnosti polimernega modela.

around the polymer patterns. Several experiments were conducted by varying spray parameters.

The surface roughness of the uncoated 3D polymer patterns was evaluated by an optical profilometer. The geometrical tolerance of the patterns was evaluated using a Coordinate Measuring Machine. The hardness of the 3D polymer patterns was measured using a micro-hardness tester. The flowchart with the sequence of investigations carried out in the present work is shown in Fig 4.

- Čeprav lahko nanofluid, ki vsebuje grafenov oksid (GO), izboljša tudi hrapavost površine polimernega vzorca, ne more bistveno izboljšati trdnosti modela.
- Nanofluid, ki vsebuje cinkov oksid (ZnO), lahko zmerno vpliva na izboljšanje hrapavosti površine in trdnosti polimernega modela.
- Z zmanjšanjem zaponitve 3-D natisnjene modela bi lahko zmanjšali tudi debelino keramične školjke z zmanjšanjem števila prevlek okoli modela, kar bi optimiziralo trdnost in stabilnost keramične školjke.
- Pri izdelavi 3D-tiskanih modelov so bili upoštevani različni vzorci zapolnitve, med katerimi je bilo ugotovljeno, da imata giroidni in kubični vzorec zaponitve večjo tlačno trdnost v primerjavi z drugimi vzorci.

5. Conclusions

- It has become apparent, that there is a significant improvement in the surface roughness of the polymer pattern after a coating is applied around the 3D printed polymer pattern, which in turn improves the surface roughness of the final cast part.
- Among all the Nano fluids used, the Nano fluid containing Titanium Dioxide (TiO₂) was found to be most effective in improving the surface roughness and strength of the polymer pattern.
- Though the Nano fluid containing Graphene Oxide (GO) could also improve the surface roughness of the polymer pattern, it could not improve the strength of the pattern significantly.
- The Nano fluid containing Zinc Oxide (ZnO) could show a moderate influence in improving the surface roughness as well as the strength of the polymer pattern.
- By reducing the infill of the pattern material, the thickness of the ceramic shell could also be reduced by reducing the number of coatings around the pattern, which in turn would optimize the strength and stability of the ceramic shell.
- Different infill patterns were considered while developing the 3D printed patterns, out of which Gyroid and cubic infill patterns were found to have better compressive strength, compared to the other infill patterns.

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