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Uporaba sol-gel tehnologije v livarskih premazih

Applicaton of Sol-Gel Technology in Foundry Coatings

Izvleček

Sloj premaza na peščeni formi ali jedru ustvarja visoko temperaturno bariero med talino in formo ter s tem preprečuje reakcije med njima. To posredno vpliva tudi na izboljšanje površine ulitkov. Temeljne zahteve ognjevzdržnih premazov so: zagotavljanje ustrezne poroznosti, visoke ognjevzdržnosti ter preprečevanje fizikalno-kemijskih reakcij med talino in premazom (penetracija, mazanje, raztapljanje). Optimizacijo sestave premaza, ki bi čim bolj izpolnil vse zgoraj omenjene zahteve, je možno doseči z dodajanjem sol-gel komponente. Uporaba sol-gel postopka v proizvodnji livarskih premazov je nova tehnologija. Dodatek sol-gel komponente izboljša površino ulitkov in reološke lastnosti premaza; pri tem pa ima pomembno vlogo razmerje sóla glede na ostale komponente. Dodana sol-gel komponenta zmanjša viskoznost premaza, kar pa izboljša mazljivost in s tem posledično omogoča boljšo površino ulitka. Namen raziskave je bil raziskati učinek uporabe sol-gel komponente kot dodatka k premazu na vodni osnovi s cirkonskim polnilom.

Preučevali smo vpliv treh kemijsko različnih sol-gel komponent iter različnih masnih razmerij med osnovnim premazom in sol-gel komponento na površino ulitkov. Rezultati kažejo, da uporaba sol-gel komponente izboljša površinsko kakovost ulitkov.

Ključne besede: vodni premaz s cirkonskim polnilom, premaz s sol-gel komponento, površina ulitka, globina penetracije premaza

Abstract

The mould or core coating creates a high thermal integrity barrier between the metal and the mould in the reduction of the thermal shock experienced by the sand system. The basic requirements for refractory coatings are to ensure adequate porosity and high refractoriness, and to prevent the physicochemical reaction at the metal-coating interface (lubrication, solution, penetration). Optimization of the composite coatings to fulfil all the above-mentioned requirements can be achieved by adding the sol-gel component. The use of the sol-gel process in the production of foundry coatings has been a new technology. The addition of sol-gel components significantly improves the surface of castings and its rheological properties; where an important role also has the ratio of sol relative to other components. The added sol-gel component reduces the viscosity of the coating, which improves its lubricity and consequently enables a better casting surface. The purpose of this research was to investigate the effect of using the sol-gel component as an additive to the water-based coating with a zircon filler.

We studied the influence of three chemically different sol-gel components and the influence of various mass ratios between the basic coating and the sol-gel component on

the casting surfaces. The results indicate that the use of the sol-gel component significantly improves the quality of casting surfaces.
Key words: water-based coating with zirconium filler, coating with added sol-gel component, surface of casting, coating penetration depth

1 Uvod

Premazi za forme in jedra so nujni pomožni materiali v proizvodnji ulitkov. Osnovna naloga livarskih premazov je zagotavljanje učinkovite ognjevzdržne pregrade med peščeno formo ali jedrom in talino pri procesu litja in strjevanja. To zagotavlja gladko in čisto površino ulitkov, pri čemer ne nastajajo napake pripečenega peska ali napake zaradi penetracije kovine v formo (grudice, vdolbinice ali hrapava površina). Uporaba visokokakovostnih premazov bistveno vpliva na zmanjšanje dragih postopkov čiščenja orodja in nadaljnjega obdelovanja ulitka, kar posledično vpliva tudi na zmanjšanje proizvodnih stroškov v livarni. [1 - 4]

Premaz je sestavljen iz več komponent, pri čemer je njegova uporaba oziroma sestava odvisna od uporabe litine (barvna kovina, jeklo, siva litina), kemijskih lastnosti (pH – kisel, bazičen, nevtralen) in materiala forme ali jedra. Za jeklene litine se v premazih največkrat uporablja ognjevzdržno polnilo na osnovi cirkona, kromita, sintermagnezita, olivina in drugih keramičnih materialov z visoko temperaturo taljenja. [1 - 4]

Raziskave so pokazale, da je večina današnjih premazov odvisna od namena uporabe, zato lahko vsebujejo preko dvajset različnih komponent. Da premaz zagotavlja določene lastnosti mora vsebovati naslednje štiri glavne komponente in druge dodatke[1 - 4]:

- ognjevzdržno polnilo,
- tekoči nosilec,
- suspenzijsko sredstvo in

1 Introduction

Coatings for moulds and cores are essential auxiliary materials in the production of castings. The basic task of foundry coatings is to provide an effective refractory barrier between the sand form or the core and the melt during the casting and solidification process. This ensures a smooth and clean surface of castings, without sand burn on, pick-ups and other surface defects (metal penetration, veining, erosion). The use of high-quality coatings significantly influences the cost of cleaning procedures of the tool and further processing of the casting, which consequently also influences the reduction of production costs in the foundry. [1 - 4]

The coating consists of several components, and its use or composition depends on the use of cast iron (non-ferrous metal, steel, gray cast iron), chemical properties (pH - acid, basic, neutral) and material of the mould or core. For steel castings the most commonly used refractory filler is based on zircon, chromite, sintermagnesite, olivine and other ceramic powders with high melting temperature. For other castings it is not necessary to use such a high refractory filler as the casting does not reach such high temperatures. [1 - 4]

Researches have shown that most of today's coatings depend on the purpose of the application, so they can contain over twenty different components. To provide certain properties, the coating must include the following four main components and other additives [1 - 4]:

- Refractory filler

- vezivo.

Premaz se na formo ali jedro nanaša na različne načine, in sicer s čopičem ali krpico, potapljanjem, pršenjem ali polivanjem. Izbira metode nanosa je odvisna od obsega proizvodnje, ekonomičnosti postopka, velikosti in kompleksnosti forme ali jedra itd. [1 - 4]

Dodatek sol-gel komponente v premaz naj bi izboljšal reološke lastnosti in površino ulitka. Z izboljšanjem reoloških lastnosti se posledično izboljšajo tudi mazljivost, nanašanje in oprijemljivost na peščene forme ali jedra. Poleg tega pa mora premaz zagotavljati tudi visokotemperaturno bariero med talino in peščeno formo ter preprečevati reakcije med kovinsko talino in materialom forme. S tem zmanjšamo površinske napake na končnih izdelkih. Poudariti moramo, da področje uporabe sol-gel komponente v premazih še ni dovolj raziskano, sklepa pa se, da bi lahko dosegli boljše funkcionalne lastnosti, kar bi prišlo prav proizvajalcem premazov kot tudi uporabnikom le-teh. [5 - 9]

Sól je zmes majhnih delcev dveh (ali več) snovi, ki je navidezno homogena, in jo imenujemo disperzni sistem. Snov, ki je v zmesi v manjši množini, je dispergirana faza; le-ta je porazdeljena v disperznem mediju. Velikost delcev trdne dispergirane faze je med 1-100 nm. Nanometrski koloidni delci sola nastanejo s hidrolizo molekul prekuzorja, ki nato kondenzirajo. Pri določenih pogojih se koloidni delci lahko povežejo v tridimenzionalno neurejeno in po celotnem volumnu razvejano mrežo – pri čemer se tvori gel. Ločimo dva osnovna postopka sol-gel sinteze: anorganski (koloidni) in organski (polimerni oz. alkoksidni). Po koloidni poti gel nastane z aglomeracijo gostih koloidnih delcev, pri polimerni pa s polimerizacijo polimernih verig. [5 - 9]

- Binder agent
- Suspension agent
- Liquid carrier

Coatings can be applied to the mould or core in different ways. They can be applied as brushing and swabbing, spraying, dip coating and flow coating. The selection of the application method depends on the range of production, the economy of the process, the size and complexity of the mould or core, etc. [1 - 4]

The addition of the sol-gel component to the coating should improve the rheological properties and surface of the casting, and consequently it should improve lubrication, application and adhesion to sand moulds or cores. In addition, the coating must also provide a high temperature barrier between the melt and the sand mould and prevent the reactions between the melt and the mould material. With this we reduce the surface defects on finished castings. It should be emphasized that the field of the sol-gel component in the coatings has not yet been sufficiently studied, and it is concluded that it would be possible to achieve better functional properties, which would benefit both the coating manufacturers and the users of these coatings. [5 - 9]

Sól is a mixture of small particles of two (or more) substances that are seemingly homogeneous – a so called dispersion system. A substance in the mixture in a smaller amount is a dispersed phase; it is distributed in a dispersive medium. The particle size of the solid dispersed phase is between 1-100 nm. The nanometer colloidal particles of the sól are formed by hydrolysis of the precursor molecules, which are then condensed. Under certain conditions, the colloidal particles can be linked to a three-dimensional, unregulated and brunched network through the entire volume - forming a gel. We distinguish two basic processes of sol-gel synthesis: inorganic (colloidal) and

2 Eksperimentalno delo

Kot osnovni premaz smo uporabljali vodni premaz s cirkonskim polnilom (Aquadur ZP), v katerega smo dodajali različne vrste in količine sól komponent. Okvirna sestava premaza Aquadura ZP je naslednja:

- 83 mas. % ognjevzdržnega polnila (cirkon, Al-silikati),
- 2 mas. % organskega veziva in
- 15 mas. % vode.

Sintetizirani smo tri različne sól komponente:

- Sól 1 (na osnovi HCl),
- Sól 2 (na osnovi TEOS-a),
- Sól 3 (na osnovi H_2SO_4).

V premaz smo dodajali 10 in 25 mas. % sól komponente, v nekaterih primerih pa smo dodatno pripravili še premaze s 15 in 20 mas. % sól komponente.

Pred pripravo merilnih celic smo pripravili termoelemente, ki smo jih kasneje vstavili v merilno celico, s pomočjo katerih smo med postopkom vlivanja in strjevanja merili temperature. Merilne celice smo premazali s čopičem in jih pripravili za sušenje v peči. Pred samim sušenjem v merilno celico vstavimo termoelement, kot je prikazano na Sliki 1, ter jih sestavimo skupaj. V peč (Slika 2) jih damo z namenom izločevanja tekočega nosilca iz premaza – s tem se na formi ustvari samo trden sloj premaza. Po sušenju so bile merilne celice pripravljene na ulivanje (Slika 3).

Med postopkom sušenja merilnih celic smo v indukcijski peči že talili sivo litino, ki smo jo kasneje ulili v pripravljene merilne celice. Za taljenje sive litine smo potrebovali od 30 do 45 minut. Temperatura taline pred ulivanjem je bila okoli 1300 ˚C. Za ulivanje sive litine smo se odločili, ker je sorazmerno preprosta za uporabo, ima dobre livne sposobnosti, dobro trdnost in je cenovno dostopna. Pri ulivanju sive litine smo

organic (polymeric or alkoxide) pathways. With colloidal path, the gel is formed by agglomeration of dense colloidal particles, and by polymeric path the gel is formed by polymerization of polymer chains. [5 - 9]

2 Experimental Work

As a primer we used water based coating with zircon filler Aquadur ZP), into which various types and quantities (10 wt. % and 25 wt. %) of sól components were added. The rough composition of the Aquadur ZP coating is as follows:

- 83 wt. % refractory filler (zircon, Al-silicates)
- 2 wt. % organic binder
- 15 wt. % water.

We have synthesized three different sól components:

- Sól 1 (based on HCl)
- Sól 2 (based on TEOS)
- Sól 3 (based on H_2SO_4)

Before preparing the measuring cells, we had prepared thermoelements, which were later inserted into the measuring cell. With those elements we measured the temperature during the casting process. The application that we used to coat the measuring cells was brushing (figure 1). After brushing the moulds were prepared for drying in the furnace. Before the measuring cells were placed in a furnace (figure 2), where our intention was to remove the liquid carrier from the coating and only create a hard layer on the form, we had inserted the thermoelement into the measuring cell and composed it. After drying, the measuring cells were ready for casting (figure 3).

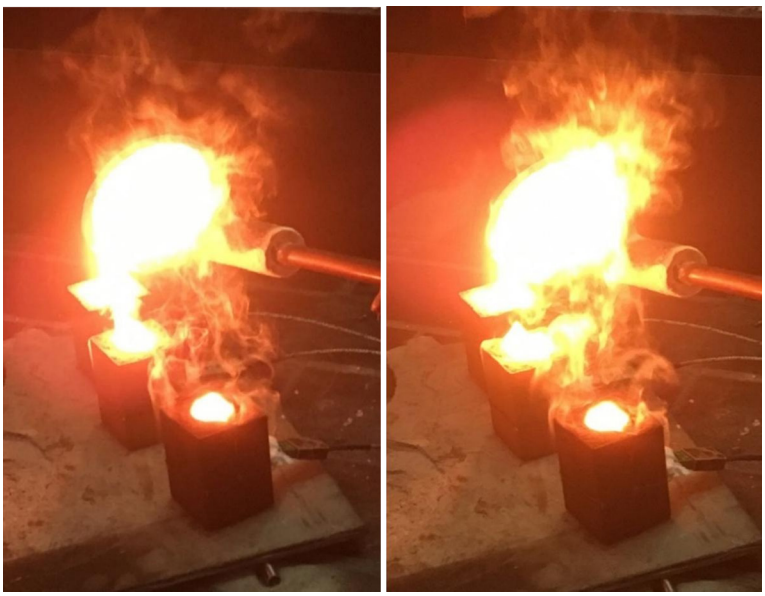
During the drying process of the measuring cells, the grey cast iron was melted in the induction furnace, which was later casted into the prepared measuring cells. We needed 30 to 45 minutes to cast

Sl. 1. Premazana celica z vstavljenim termoelementom, pred sušenjem

Fig. 1. Coated measuring cell with inserted thermoelement, before drying

Sl. 2. Sušenje merilnih celic v peči

Fig. 2. Drying of the measuring cells in the furnace



Sl. 3. Postopek vlivanja sive litine v peščene celice

Fig. 3. The casting process of grey cast iron into sand cells

termoelemente tipa K zaščitili s kvarčnimi zaščitnimi cevkami.

Za razumevanje obnašanja premazov na peščeni formi ali jedru je bila potrebna dosledna karakterizacija. Karakterizacijo

grey cast iron. The melt temperature before casting was about 1300 ° C. We decided to cast cast iron because it is relatively easy to use, has good casting properties, good strength and is affordable. When casting

premazov smo opravili z naslednjimi postopki:

- pregled površine z optičnim mikroskopom,
- globina penetracije premaza,
- mazljivost in nanos premaza,
- viskoznost in gostota premaza.

3 Rezultati in diskusija

3.1 Površina ulitkov

Osnovni premaz Aquadur ZP je v obliki paste. Tak premaz se težko nanaša, zato smo ga pred nanosom na površino forme morali redčiti z destilirano vodo. V našem primeru smo premaz redčili s 7,5 mas. % vode, da smo formo s čopičem lažje premazali. Po redčenju je bil premaz še vedno gost in se je težko nanašal. Poleg tega, da ta premaz ni bil tako mazljiv, je zaradi velike gostote puščal sledi premazovanja s čopičem (sliki 4 in 5).

Sól komponenta je v tekočem stanju preden gelira, zato po dodatku le-te v premaz ni potrebno dodatno redčenje premaza z destilirano vodo. Ko smo v premaz dodali sól komponento, smo ga s tem že razredčili. Mazljivost premaza je bila nato odvisna od vrste in količine sól komponente, ki smo jo primešali v premaz. Premazi s sól komponento na osnovi TEOS-a so bili težje mazljivi kot premazi s sól komponento na osnovi HCl ali H_2SO_4.

Pri ulitkih, kjer smo uporabili premaz z dodano komponento sól 1 (na osnovi HCl), smo dobili najboljše rezultate površine ulitka. Površina je bila v primerjavi z ulitki brez sól komponente bolj gladka in z manj napakami pripečenega peska. Na površino ulitka v veliki meri vpliva količina dodane sól komponente, saj smo v primeru, kjer smo v premaz dodali 25 mas. % sól komponente (Slika 7), dobili nekoliko boljše rezultate kot

cast iron, K-type thermoelements are protected with quartz protective tubes.

In order to understand the behaviour of coatings on sand mould or core, a consistent characterization was required. The parameters that we used for characterization of our foundry coating are listed below:

- Examination of the surface with an optical microscope
- Depth of penetration of the coating
- Lubrication and application of the coating
- Viscosity and density of the coating

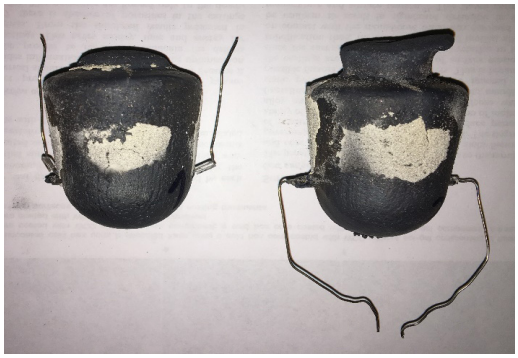
3 Results and Discussion

3.1 Surface of the Castings

The basic coating Aquadur ZP is in paste form. Coatings in the form of paste are difficult to apply, so they have to be diluted with distilled water before being applied to the surface of the mould. In our case, the coating was diluted with 7.5 wt. % of water – the brushing was easier. After diluting, the coating was still dense and difficult to apply. Furthermore, it was less applicable, due to its high density, and the traces of brush on it could there be seen. (figure 4 and 5).

The sól component is in liquid state before it comes to the gel. After the addition of sól to the coating, there is no need to dilute it with distilled water. It was diluted by the addition of the sól component to the coating. The application of the coating was then dependent on the type and quantity of the sól component that was added to the coating. Coatings based on TEOS were harder to apply than coatings based on HCl or H_2SO_4.

For castings, where the coating with the added sól 1 component (based on HCl) was used, we obtained the best results on the casting surfaces. The surface was smoother

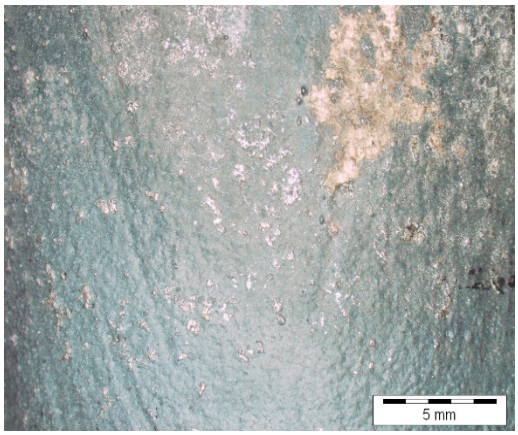


Sl. 4. Ulitek brez sól komponente takoj po odstranitvi iz merilne celice

Fig. 4. Casting where we used coating without the sól component immediately after removal from the measuring cell

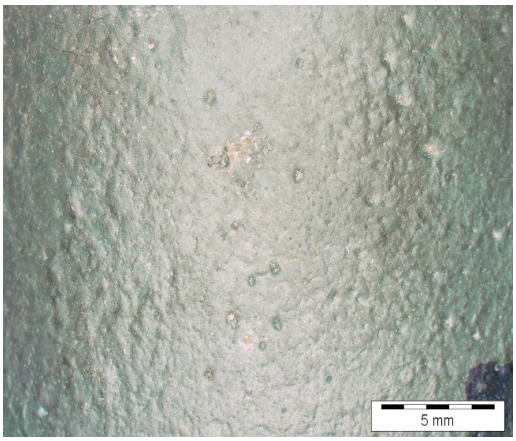
Sl. 5. Ulitek brez sól komponente, očiščen

Fig. 5. Casting where we used coating without sól component, cleaned



Sl. 6. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S1 – 10

Fig. 6. Casting surface (10x magnification), where coating S1 - 10 was used



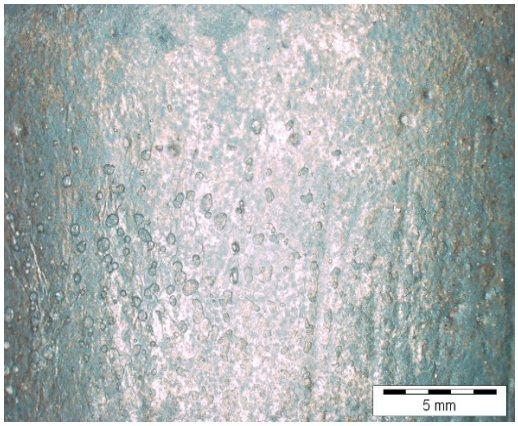
Sl. 7. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S1 – 25

Fig. 7. Casting surface (10x magnification), where coating S1 - 25 was used

pri premazu, kjer smo dodali 10 mas. % sól komponente (Slika 6).

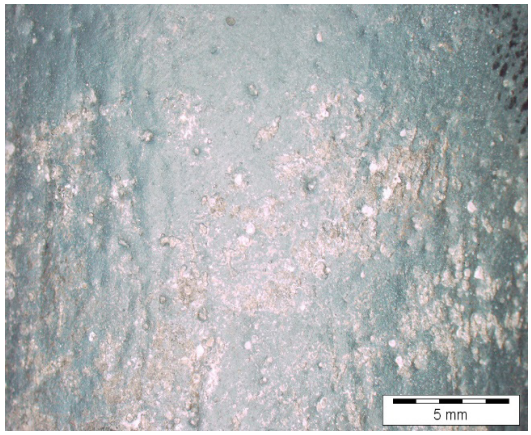
Pri premazih z dodano komponento sól 2 so na površini ulitka vidne nekakšne črtice, ki so posledica slabe mazljivosti premaza. Slabo mazljivost premaza lahko pripišemo nestabilnosti sóla 2, saj

in comparison to the castings without the sól component and with fewer defects of sand-burn on it. The casting surface is largely influenced by the amount of the added sól component. Results with coatings where we added 25 wt.% of the sól component (figure 7) were slightly better in comparison



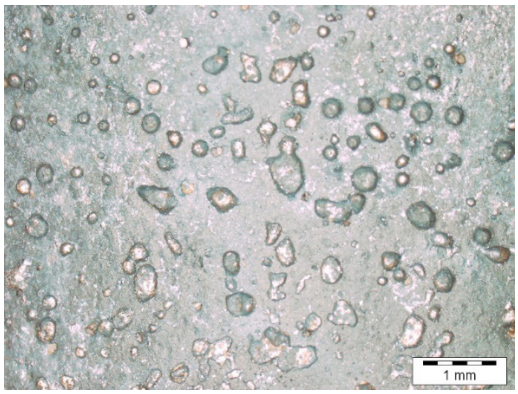
Sl. 8. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S2 – 10

Fig. 8. Casting surface (10x magnification), where coating S2 - 10 was used



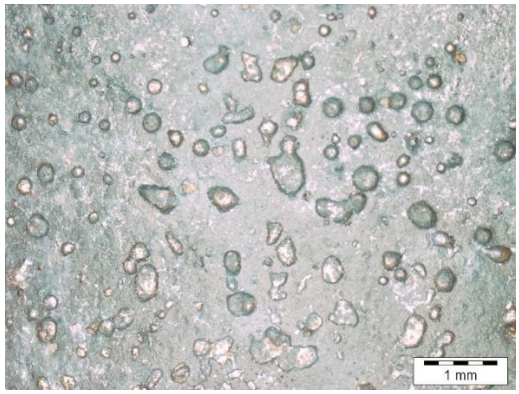
Sl. 9. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S2 – 25

Fig. 9. Casting surface (10x magnification), where coating S2 - 25 was used



Sl. 10. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S3 – 10

Fig. 10. Casting surface (10x magnification), where coating S3 - 10 was used



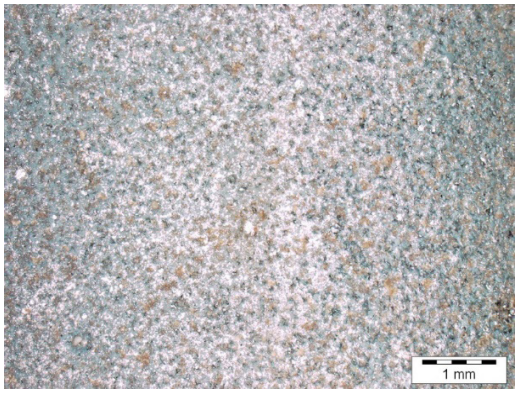
Sl. 11. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S3 – 25

Fig. 11. Casting surface (10x magnification), where coating S3 - 25 was used

je le-ta v času nanosa najverjetneje že geliral. Ob primerjavi površin, kjer je bil uporabljen premaz z 10 mas. % (Slika 8) in premaz s 25 mas. % (Slika 9) dodane sól 2 komponente, vidimo, da ni bistvene razlike na površini, kar pomeni, da pri uporabi sól komponente na osnovi TEOS-a količina dodanega sóla nima bistvenega

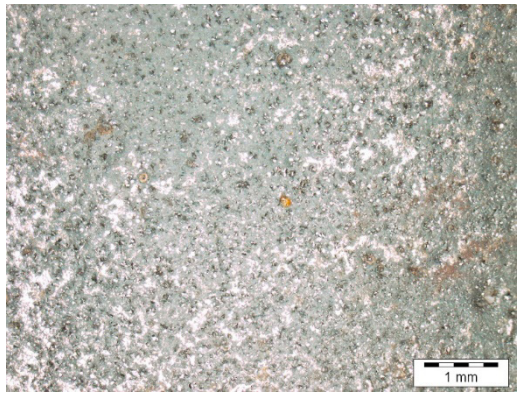
to the coatings where we added 10 wt. % of the sól component (figure 6).

In the coatings with the added sól 2 component, there are some visible traces on the casting surface due to the low lubricity of the coating. The poor lubricity of the coating can be attributed to the instability of the sól 2 component, which has already gelated at



Sl. 12. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S3 – 10

Fig. 12. Casting surface (10x magnification), where coating S4 - 10 was used



Sl. 13. Površina ulitka (10x povečava), kjer je bil uporabljen premaz S3 – 25

Fig. 13. Casting surface (10x magnification), where coating S4 - 25 was used

pomena. Na obeh površinah so vidne sledi pripečenega peska, kar povzroča napake na površini, prav tako so na obeh ulitkih vidne sledi premazovanja merilne celice s čopičem. Četudi površina na ulitkih ni tako gladka in enakomerna, je vseeno boljša, kot površina kjer smo uporabili premaz brez dodane sól komponente. Dodatek sól komponente v premaz torej vsekakor vpliva na izboljšanje površine ulitka, vendar pa je pri tem odvisno, kateri sól smo v premazu uporabili.

Pri tretjem ulivanju smo uporabili premaze z dodano komponento sól 3. Površina ulitkov je boljša kot pri premazu s komponento sól 2, vendar še vedno slabša kot pri premazih s komponento sól 1. Vsekakor je tudi ta premaz (z dodano komponento sól 3) še vedno vidno boljši od premaza brez dodane sól komponente.

Na površini ni večjih napak. Čeprav površina ni tako gladka, je bilo tukaj zelo malo napak pripečenega peska. Na površini ulitka so se v obeh primerih, tako pri 10 mas. % (slika 10) kot tudi pri 25 mas. % (Slika 11) dodane sól komponente, pojavili mehurčki. Pojav mehurjenja lahko pripišemo preveliki

the time of application. When comparing surfaces, where a coating with 10 wt. % (figure 8) and a coating with 25 wt. % (figure 9) added sól 2 component was used, we see that there is no significant difference in the surface area, which means that when using sól component based on TEOS, the amount of added sól is not that important. On both surfaces there are visible errors of sand-burn on and the traces of brushing, visible due to the same reason – sól 2 has already gelated at the time of application. Even if the casting surface is not so smooth and even, it is still better than the surface where the coating without the added sól component was used. The addition of the sól component to the coating therefore certainly influences the improvement of the casting surface, but it depends on the type and the quantity of sól used in the coating.

In the cases where we used coatings with the added sól 3 component, the casting surface is better than in the coating with the sól 2 component, but still worse than in the coatings with the sól 1 component. By all means, this coating (with added sól

poroznosti premaza, kar pomeni, da je bil premaz prepusten za talino. Lahko pa so mehurji tudi posledica reakcij na meji med formo/premazom/talino.

Najboljše rezultate glede površine ulitkov smo dobili pri uporabi premaza z dodano komponento sól 1. Iz tega razloga smo se odločili, da premaze s to komponento ponovno pripravimo in jih še enkrat preizkusimo ter nekoliko bolj podrobno raziščemo - premaze z dodano komponento sól 4 (identičen komponenti sól 1).

Iz površine je razvidno (Sliki 12 in 13), da nam komponenta sól 4 v premazu daje bolj gladko površino, glede na premaz, kjer nismo uporabili sól komponente. Prav tako je površina ulitka, kjer smo imeli v premazu 25 mas. % sóla, najbolj gladka, z najmanj napakami.

3.2 Penetracija premaza v formo

Penetracija je bila odvisna od vrste, količine in časa uporabe premaza (razvidno v Tabeli 1). Naša predpostavka je bila, da bo penetracija najgloblja pri premazih s 25 mas. % dodane sól komponente, vendar v vseh primerih ni bilo tako. Pri premazih z dodano komponento sól 2 je penetracija pri 25 mas. % dodane sól komponente nižja kot pri premazu z 10 mas. % sól komponente, kar ponovno lahko pripišemo nestabilnemu sólu, ki je bil dodan v premaz. Lahko sklepamo, da je premaz z dodano komponento sól 2 v času našega nanašanja že geliral. V ostalih primerih je bila penetracija premazov s 25 mas. % dodane sól komponente globlja kot pri premazih z 10 mas. % dodane sól komponente.

Poleg količine dodane sól komponente pa je na penetracijo vplival tudi čas med izdelavo in uporabo premaza, saj se penetraciji kjer smo uporabili identičen 3 component) is still visibly better than the coating without the added sól component.

There are no major defects on the surface. Although the surface is not that smooth, here there were very few mistakes due to the sandburn . With both coatings – either with 10 wt. % (figure 10) and 25wt. % (figure 11) sól 3 component, there were blisters on the casting surface. The blistering effect can be attributed to the excessive porosity of the coating, which means that the coating was too permeable to the melt. However, blisters may also be due to reactions at the border between form / coating / melt.

The best results on the casting surface were obtained when using the coating with the added sól 1 component. Due to this reason, we decided to re-prepare the coatings with this component, test them again and examine in more detail – those were coatings with the added sól 4 component (identical to the sól 1 component).

If we compare the casting surface (Figs. 12 and 13) with added sól component to the coating and the one without it, we can see that the added sól component produces a smoother surface. Here we gained the similar results as before – casting surface was smoother with coatings where a higher amount of sól component (25 wt. %) was used and there were also fewer defects on the surface.

3.2 Depth of Penetration of the Coating

Penetration depended on the type, quantity and the time of use of the coating (table 1). Our assumption was that the penetration would be deepest in coatings with 25 wt. % of added sól component. We can confirm this assumption in all cases but in the cases where coatings with added sól 2 component were used. For coatings with added sól 2

Sl. 14. Prikaz merjenja penetracije z optičnim mikroskopom

Fig. 14. Penetration measurement with optical microscope

premaz (premazi z dodano komponento sól 1 in premazi z dodano komponento sól 4) bistveno razlikujeta. Tukaj razliko v penetraciji lahko pripišemo času uporabe premaza, saj smo premaze z dodano komponento sól 4 nanesli isti dan, kot smo jih pripravili, medtem ko smo premaze z dodano komponento sól 1 uporabili v 4 – 5 dneh, po tem, ko smo jih pripravili. Slika 14 prikazuje merjenje globine penetracije.

component, penetration with 25 wt. % added sól 2 component is lower than with coating with 10 wt.% added sól 2 component, which can again be attributed to an unstable sól 2 added to the coating. We can conclude that the coating with the added sól 2 component had already been gelled during our application. In other cases, penetration of the coatings with 25 wt. % of added sól component was deeper than in the coatings with 10 wt. % added sól component. Figure 14 shows the measurement of penetration depth.

The penetration was also influenced by the time of use – time between the preparation and the application of the coating. We can confirm that as we compare coatings with added sól 1 and sól 4 (which are identical). Coatings with added sól 4 component have considerably deeper penetration in comparison to the coatings with added sól 1 component. This is due to the time of use – coatings with sól 4 component were used the same day as we prepared them, while coatings with added sól 1 component were used four or five days after we prepared them.

Tabela 1. Povprečna globina penetracije za posamezne premaze glede na vrsto in količino dodane sól komponente

Table 1. Average penetration depth for individual coatings according to the type and quantity of added sól components

Uporabljen sól v premazu / Used sól in coating		
ZP (brez sóla) / ZP (without sól)	170,05	
	10 % dodane sól komponente / 10 % added sól component (µm)	25 % dodane sól komponente / 25 % added sól component (µm)
Sól 1	133,73	164,52
Sól 2	135,82	130,22
Sól 3	127,29	288,25
Sól 4	528,33	569,18

3.3 Viskoznost in gostota

Viskoznost in gostota sta bili izmerjeni za premaze z dodano komponento sól 4. Oba parametra zavisita od količine dodane sól komponente, kar lahko razberemo iz tabel 2 in 3. Tako gostota kot viskoznost sta najnižji pri premazih z največ dodane sól komponente in obratno najvišji pri premazih z najmanj dodane sól komponente. Gostoto smo lahko izmerili vsem premazom ne glede na količino dodane sól komponente, medtem ko viskoznosti ni bilo možno izmeriti pri premazih z 10 mas. % in brez dodane sól komponente, saj sta bila preveč viskozna, da bi tekla skozi iztočni viskozimeter. Podatki merjenja gostote in viskoznosti so podani v tabeli.

Tabela 3. Viskoznost premazov glede na količino dodane sól komponente

Table 3. Viscosity of coatings according to the quantity of added sól components

Premaz / Coating	Viskoznost / Viscosity (s)
ZP	Nismo mogli izmeriti / non measurable
S4 – 10	Nismo mogli izmeriti / non measurable
S4 – 15	31,5
S4 – 20	16,0
S4 - 25	12,5

4 Zaključek

Znano je, da sól znatno vpliva na izboljšanje površine ulitka in na penetracijo premaza v formo. Z dobljenimi rezultati smo prišli do sledečih zaključkov:

- površine ulitkov so v primerjavi s premazom brez sól komponente v vseh primerih boljše, bolj homogene in z manj napakami pripečenega peska, ne

3.3 Viscosity and Density

The viscosity and density were measured for coatings with added sól 4 component. Both parameters depend on the amount of added sól component. Both the density and the viscosity are the lowest in coatings with the highest added sól component and vice versa - the highest in coatings with the least added sól component. The density was measured for all coatings regardless of the amount of added sól component, while the viscosity could not be measured for coatings with 10 wt. % and without added sól component, because they were too viscous to flow through the viscometer. Data of density and viscosity measurement are given in the table.

Tabela 2. Gostota premazov glede na količino dodane sól komponente

Table 2. Density of coatings according to the quantity of added sól components

Premaz / Coating	Gostota / Density (g/ml)
ZP	2,77
S4 – 10	2,35
S4 – 15	2,21
S4 – 20	2,10
S4 - 25	1,97

4 Conclusion

It is known that sól component significantly affects the improvement of the surface of the casting and the penetration of the coating into the mold. With the results we obtained the following conclusions:

- The surface of the castings is better, more homogeneous and with fewer defects of sand-burn compared with the coating without sól component, regardless of the type and quantity of

glede na to, katero vrsto in količino sóla smo uporabili. Najboljše rezultate glede površine smo dobili pri premazih, kjer smo uporabili sól 1 in sól 4 (ki imata enako sestavo) na osnovi HCl. Poleg vrste dodane sól komponente je odvisna tudi količina le-te, in sicer smo najboljše rezultate, kot je bilo pričakovano, dobili, kjer smo dodali največ sól komponente. Industrijsko bolj uporabni bi bili premazi z manj dodane sól komponente, ki so prav tako pokazali dovolj dobre rezultate in so primerni za testiranje v livarni;

- nanašanje in mazljivost premazov sta bila odvisna od vrste in količine dodane sól komponente. Kot smo predpostavili, so se premazi, kjer je bilo dodane več sól komponente, mazali lažje kot tisti, kjer je bilo dodane manj sól komponente oziroma je sploh ni bilo. Hipoteza je bila potrjena v vseh primerih, razen pri sólu 2 (na osnovi TEOS-a), kjer je bilo mazanje izredno težko, saj je bil premaz izredno viskozen, ker je verjetno že prišlo do geliranja, preden smo premaz nanesli na površino;
- penetracija je bila odvisna od vrste, količine in časa uporabe premaza. Naša predpostavka je bila, da bo penetracija najgloblja pri premazih s 25 mas. % dodane sól komponente, vendar v vseh primerih ni bilo tako. Pri premazih z dodano komponento sól 2 je penetracija pri 25 mas. % dodane sól komponente nižja kot pri premazu z 10 mas. % sól komponente. V ostalih primerih je bila penetracija premazov s 25 mas. % dodane sól komponente globlja kot pri premazih z 10 mas. % dodane sól komponente. Poleg količine dodane sól komponente pa je na penetracijo vplival tudi čas med izdelavo in uporabo premaza, kar se je zgodilo pri premazih s komponento sól

the sól used. The best surface results were obtained in coatings where sól 1 and sól 4 (having the same composition) based on HCl were used. In addition to the type of added sól component, the amount of the component depends on it. The best results, as expected, were obtained when a higher amount of sól component was added. Industrial coatings would be more cohesive with less added sól components, which also showed good results, and are suitable for testing in the foundry.

- The application and lubrication of the coatings depend on the type and quantity of the added sól component. As we have assumed, coatings, where higher amount of sól component was added, were lubricated more easily than those where fewer sól component was added. The hypothesis was confirmed in all cases, except in case with added sól 2 component (based on TEOS), where the lubrication was extremely difficult, since the coating was extremely viscous, as it was likely that gelation had already occurred before the coating was applied to the surface.
- Penetration depends on the type, quantity and the time of use of the coating. Our assumption was that the penetration would be deepest where we used coatings with 25 wt. % added sól component, but in all cases this was not true. For coatings with added sól 2 component, penetration where we used coating with 25 wt. % added sól component is lower than in coating with 10 wt. % sól component. In other cases, penetration of coatings with 25 wt. % added sól component was deeper than in coatings with 10 wt. % added sól component. In addition to the amount of added sól component, the penetration

1 in premazih s komponento sól 4;
- viskoznost in gostota premazov zavisita od količine dodane sól komponente. Tako gostota kot viskoznost sta najnižji pri premazih z največ dodane sól komponente in obratno najvišji pri premazih z najmanj dodane sól komponente. Gostoto smo lahko izmerili vsem premazom ne glede na količino dodane sól komponente, medtem ko viskoznosti ni bilo možno izmeriti pri premazih z 10 mas. % in brez dodane sól komponente, saj sta bila preveč viskozna, da bi tekla skozi iztočni viskozimeter.

also depends on the time of use – time between preparation and application.
- Viscosity and density of coatings depend on the amount of added sól component. Both the density and the viscosity are the lowest in coatings with the highest added sól component and vice versa the highest in coatings with the least added sól component. The density can be measured for all coatings regardless of the amount of added sól component, while the viscosity could not be measured for coatings with 10 wt. % and without the added sól component as they were too viscous to flow through the viscometer.

Viri / Literature

[1] AĆIMOVIĆ-PAVLOVIĆ, Z., PRSTIĆ, A., ANDRIĆ, L., MILOŠEVIĆ, V., MILIĆEVIĆ, S.: Ceramic Coating for Cast House Application, Ceramic Coatings - Applications in Engineering, Prof. Feng Shi (Ed.), 2012ISBN: 978-953-51-0083-6, InTech, dostopno na svetovnem spletu: http://www.intechopen.com/books/ceramic-coatingsapplications-in-engineering/ceramic-coatings-for-application-in-foundry [Navedeno: 15.03.2018].
[2] NWAOGU, U.C., TIEDJE, N.S.: Foundry Coating Tehnology: A Review. Materials Science and Application, 2011, 2, 1143-1160
[3] BROWN, J. R.: Foseco Ferrous Foundryman's Handbook, Pergamon Press, Oxford, 2000.
[4] AĆIMOVIĆ-PAVLOVIĆ, Z. A.: Zaštitni premazi u livarstvu. Monografija, Beograd, 2009.
[5] NWAOGU, U. C., TIEDJE, N. S. New Sol-Gel Coatings to Improve Casting Quality. DTU Mechanical Engineering, 2011.
[6] PIERRE, A. C. Introduction to sol-gel processing. New York: Springer Science + Business Media 1998
[7] ZARZYCKI, J.: Past and Present of Sol-Gel Science and Technoogy, Journal of Sol-Gel Science and Technology, 8, 17-22 (1997)
[8] BRINKER, C.J., SCHERER, G. W.: Sol-gel Sciencs, Academic Press, New York, 1990
[9] SCHUBERT, U., HÜSING, N.: Synthesis of Inorganic Materials, Wiley, 2. izdaja, Weinheim, 2005)