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Nova generacija procesov formanja s svežim peskom in uporabo tehnologije zračenja za rahljanje

New Generation of Green Sand Molding Process Using Aeration Technology

Izvleček

Da bi se zmanjšala poraba surovin in energije, zahteve po izdelavi ulitkov s skoraj končno obliko postajajo vse večje. Za izdelavo visokokakovostne forme, ki bi zadovoljila takšne zahteve, se v svetu vse več uporablja postopek zapolnjevanja forme s peskom pri nizkotlačnem zračenju, kar omogoča enakomerno gostoto forme ob majhni porabi energije. Pri dejanskem ulivanju se je pokazalo, da ima tehnologija zračenja številne prednosti, kot so izvrstno zapolnjevanje s peskom, veliko trdnost in enakomerno gostoto forme, velike prihranke energije, majhno raven hrupa, manjšo obrabo modelov itn. Prispevek daje nekaj pomembnih informacij o postopku formanja s svežim peskom.

Abstract

Demands for near-net-shape iron castings become much stronger in order to save resource and energy consumption. In order to make a high quality mould to satisfy such demands, a moulding process using low air pressure “Aeration” sand filling, which can make the uniformly dense moulds with lower energy consumption, is becoming popular worldwide. In actual casting production, it has been proven that the aeration technology provides several advantages such as, excellent sand filling, high strength and uniformly dense mould, superior energy saving, low noise level, less pattern wear, etc. This study provides some valuable information for green sand moulding process.

1 Uvod

Svetovna livarska proizvodnja je leta 2012 presegla 100 milijonov ton. Nad 80 % proizvodnje se predstavljali izdelki iz železove litine, uliti v peščene forme. Tehnologija formanja s svežim peskom je pomembna v proizvodnji železovih ulitkov. Zahteve za izdelavo ulitkov s skoraj končno obliko so vse večje, da bi se zmanjšala poraba surovin in uporaba energije. Pri izdelavi visokokakovostne forme, ki bi zadovoljevala te zahteve, je bistvena izbira najbolj optimalnega procesa formanja s svežim peskom, s katerim se dobi

1 Introduction

World casting production in 2012 exceeded 100 million tons. Over 80 % of production was iron castings and made with sand moulds. Green sand moulding technology plays an important role in the iron casting production. Demands for near-net-shape iron castings become much stronger in order to save resource and energy consumption. In order to make a high quality mould to satisfy such demands, it is critical to choose the most optimum green sand moulding process which achieves making uniformly dense moulds with lower energy consumption [1-5].

enakomerno goste forme ob majhni uporabi energije[1-5].

V zadnjem času se v svetu vse več uporablja postopek zapolnjevanja forme ob nizkotlačnem zračenju peska, ki povzroča rahljanje in omogoča enakomerno goste forme pri majhni uporabi energije. Ta postopek formanja je sestavljen iz naslednjih dveh stopenj:

1) Zapolnjevanje forme z zračenim peskom: surovi zračeni pesek zapolnjuje okvir forme tekoče in gladko. Dodatno je nastajanje mostičkov, do katerega pogosto pride v nekaterih območjih zapletene geometrije modela in na ustju dolgih žepov, je zmanjšano na minimum.
2) Visokotlačno stiskanje: peščene forme se dokončno zgostijo z visokotlačnim stiskanjem. Glava za stiskanje po odsekih je pri formarskem stroju predhodno nastavljena glede na geometrijo modela. Po stiskanju se ustrezno zgladi še zadnja stran forme.

Pri dejanski izdelavi ulitkov se je tehnologija z zračenjem izkazala s številnimi prednostmi, kot so izvrstno zapolnjevanje forme, manj drobnega materiala [6-7], doseganje enakomerno goste trdne forme, veliki prihranki energije, malo hrupa, manjša obraba modelov itn.

Prispevek prikazuje analizo formarskega postopka s surovim peskom s poskusi in numerično simulacijo [3-5]. Matematični model zapolnjevanja forme z zračenim peskom, ki sloni na zveznem modelu dvofaznega toka, se je uporabil za formanje v dejanskem industrijskem merilu. Za stiskanje se je uporabila metoda končnih elementov. Z zelo občutljivo kamero in lastno izdelavo zaznavala za prisotnost peska smo prikazali, da zračeni pesek teče tekoče [11]. Ta študija daje nekatere zelo pomembne informacije za formarski proces s surovim peskom.

Recently, a moulding process using low air pressure "Aeration" sand filling1, which can make uniformly dense moulds with lower energy consumption, is becoming popular worldwide. This moulding process consists of the following two steps

1) Aeration sand filling: Green sand under aeration fills the flask smoothly and gently. Accordingly, the bridge-forming phenomenon, which often happens at some regions s. with complicated pattern geometry and at the entrance of a deep pocket, is minimized.
2) High pressure squeezing: Sand moulds are finally compacted by high pressure squeeze. The segment squeeze head is preset to contour the pattern geometry for flask tight moulding machine. Accordingly, the mould back is formed flat after squeezing.

In actual casting production, it has been proven that the aeration technology provides several advantages such as excellent sand filling, less friable [6-7] and uniformly dense strong mould, superior energy saving, low noise level, less pattern wear, etc.

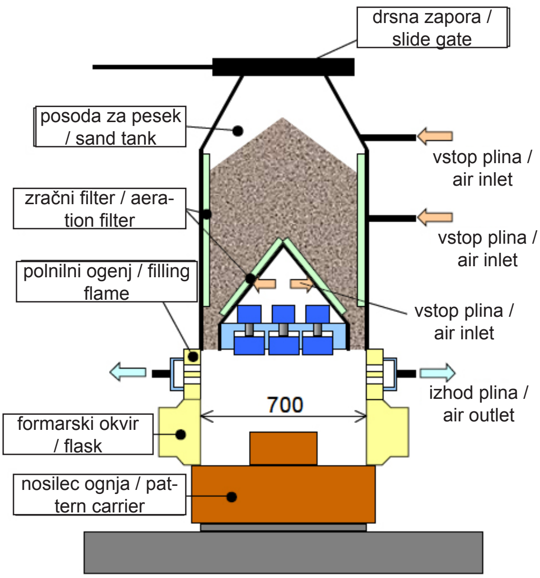
In this paper, the green sand moulding process was studied with experiments and numerical simulation [3-5]. A mathematical model of aeration sand filling based on two-phase flow continuous model was applied to actual production scale mould. Successively, a finite element method was applied for squeezing. It was clarified that the aerated sand flows smoothly by using a high speed video camera and a developed sand detecting sensor [11]. This study provides some valuable information for green sand moulding process.

2 Aerations and Filling

The sand filling density in small pocket is measured when mould is made with an

2 Zapolnjevanje forme z Zračenim peskom

Merili smo gostoto pri zapolnjevanju majhnega žepa, ko se je forma izdelovala na formarskem stroju med redno proizvodnjo1. Na sliki 1 je shematično prikazano industrijsko zapolnjevanje forme z zračenim peskom in visokotlačno stiskanje forme. Dimenzije formarskega okvirja so bile 700 mm x 900 mm x 300 mm (višina). Stisljivost svežega peska je bila 40 %.



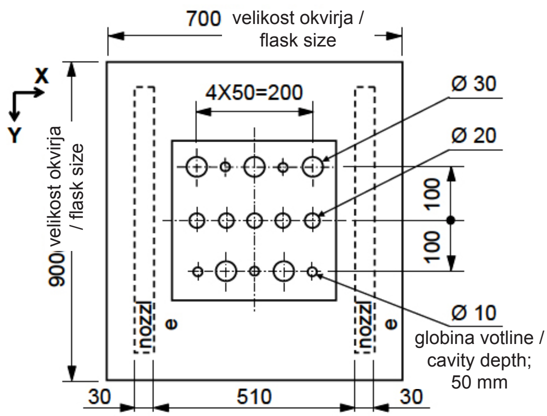
Slika 1. Shematičen prikaz industrijskega formarskega stroja za zračenje in stiskanje

Figure 1. Schematic illustration of production scale aeration / squeeze moulding machine

Skico eksperimentalne naprave za zapolnjevanje s peskom kaže slika 2. Tri različne oblike majhnih žepov smo namestili na model. Premeri majhnih žepov so bili 30 mm, 20 mm, 10 mm. Globina žepov je bila 50 mm. Zračilni kanali so bili postavljeni na dno vsakega žepa. Položaj šob prikazujejo črtkane črte. Šobe so nameščene vzdolž y-osi.

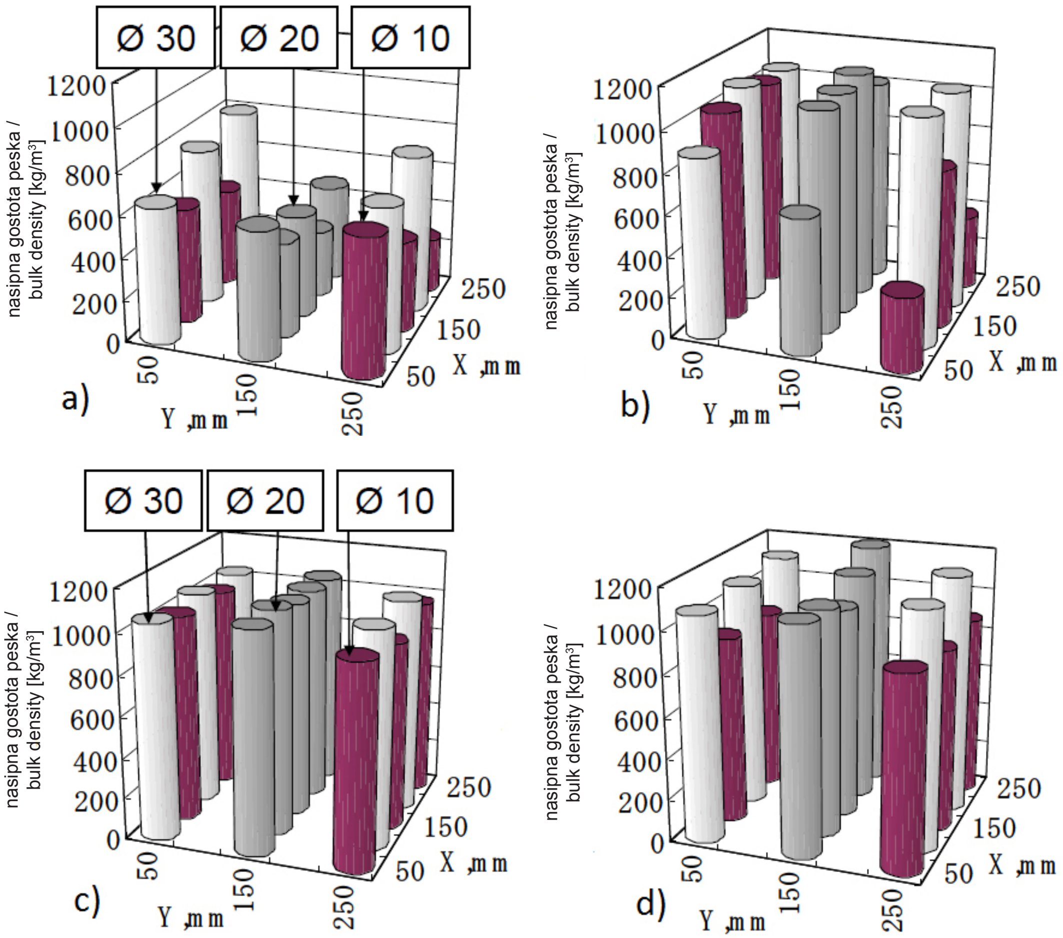
actual production moulding machine1. The schematic illustration of production scale aeration sand filling / high pressure squeezing moulding machine is shown in Fig. 1. The Flask size is 700mm x 900mm x 300mm (height). The compactability of the green sand is 40%. The layout of the test pattern for sand filling experiment is shown in Fig. 2. Three different types of small pockets are placed on the pattern. The diameters of small pocket are 30, 20, and 10mm respectively. The depth of the small pockets is 50mm. Vents are installed at the bottom of each pocket. The position of the nozzle is shown with dotted lines. The nozzles are arranged along Y-axis.

The weights of the sand filled in each pocket with 3 different filling methods, i.e., gravitational free fall from a louver hopper, conventional high-pressure blowing, and low-pressure aeration, are measured and the bulk densities are calculated. Experimental results of sand filling for small pockets in cases of free fall, blow filling, and aeration filling (of 0.1 and 0.15 MPa) are shown in Figure 3.



Slika 2. Zasnova preskusne naprave za polnjenje s peskom

Figure 2. The layout of the test pattern for sand filling experiment



Slika 3. Eksperimentalni rezultati polnjenja majhnih žepov s peskom; a) prosti pad, b) pihanje: 0,3 MPa, c) zračenja 0,1 MPa, d) zračenje 0,15 MPa

Figure 3. Experimental results of sand filling for small pockets; a) free fall, b) blow: 0.3 MPa, c) aeration: 0.1 MPa, d) aeration: 0.15MPa

Mase peska, ki je zapolnil vsak žep s tremi načini zapolnjevanja: s težnostnim prostim padanjem peska iz lijaka z zaporo, s standardnim visokotlačnim pihanjem in z nizkotlačnim zračenjem, smo merili ter nato izračunali gostote peska.

Eksperimentalne rezultate polnjenja majhnih žepov s peskom s prostim padom, pihanjem in zračenjem (z 0,1 in 0,15 MPa) kaže slika 3.

Regarding to the gravitational free falling by louver hopper shown in Fig.3-A), even in the case of the largest pocket of 30mm diameter, the average density achieved is 730 kg/m3, and the density becomes lower as the diameter becomes smaller.

Regarding to the high pressure blow filling shown in Fig. 3-B), the bulk densities are generally higher than those obtained with free falling from louver hopper, by the

Pri polnjenju s prostim težnostnim padanjem iz bunkerja z zasunom (Slika 3-A) je bila celo pri največjem žepu s premerom 30 mm dosežena povprečna gostota 730 kg/m^3: gostota peska se je zmanjševala z zmanjševanjem premera žepa.

Pri polnjenju s pihanjem pri velikih tlakih (slika 3-B) je bila v splošnem gostota peska večja kot pri polnjenju s prostim padom iz bunkerja zaradi vpliva zračnega toka na delce peska. Gostote so bile večje pri večjih žepih. Pri žepu s premerom 30 mm so dosegle celo 1040 kg/m^3. Vendar pa gostote v žepih premera 10 mm in 20 mm niso bile zadostne.

Pri polnjenju z nizkotlačnim zračenjem (sliki 3-C in 3-D) pa so bile dosežene gostote v splošnem kljub nižjemu tlaku kot pihanju višje kot pri pihanju. Razume se, da zmanjšanje odpora zaradi trenja v območju zračilnega filtra prispeva, da se dosežejo višje gostote. V primeru polnjenja z zračenjem namreč teče formarski pesek tekoče, ne da bi nastajali mostički.

Pri tlaku zračenja 0,1 MPa (slika 3-C) je bila dosežena gostota v žepu premera 10 mm 950 kg/m^3, v žepih premera 20 mm in 30 mm pa je presegla raven 1000 kg/m^3.

Na drugi strani pa je bila pri zračilnem tlaku 0,15 MPa (slika 3-D) dosežena gostota v žepu s premerom 10 mm 980 kg/m^3, kar je manj kot pri zračilnem tlaku 0,1 MPa. To pomeni, da nastopajo energijske izgube pri visokotlačnem pihanju delcev svežega peska, ki imajo nasproten učinek pri polnjenju majhnega žepa. Pri naših eksperimentalnih razmerah je dal zračilni tlak 0,1 MPa najboljše rezultate.

3. Računalniška simulacija polnjenje z zračenim peskom

Da bi analizirali obnašanje formarskega peska med formanjem smo pripravili

effect of airflow acting on sand particles. The bulk densities are higher in larger size of pocket. In the 30mm diameter pocket, the bulk density reaches as high as 1,040 kg/m^3. However, the bulk densities obtained in 10mm and 20mm diameter pockets are not sufficient.

Regarding to the low pressure aeration filling shown in Fig. 3-C) and D), although, the aeration pressure is much lower than blow filling, the obtained bulk density is generally higher than that of blow filling. It is considered that the decrease of friction resistance at the aeration filter area contributed to achieving higher bulk density. Namely, in the case of aeration filling, moulding sand flows smoothly without bridge-forming.

In the case of 0.1MPa aeration pressure shown in Fig. 3-C), the bulk density of the 10mm diameter pocket reaches about 950 kg/m^3, and that of 20 and 30mm diameter pockets exceed the level of 1,000 kg/m^3. On the other hand, in the case of 0.15MPa aeration pressure shown in Fig. 3-D), the bulk density of the 10mm diameter pocket is about 890 kg/m^3, which is lower than that of 0.1MPa aeration pressure.

Therefore, high pressure blowing of green sand particles has an energy loss and an opposite effect for filling into the small pocket. In this experimental condition, the case of 0.1MPa aeration pressure brings the best result.

3. Comuputer Simulation Aeration Sand Filling

In order to analyze the behaviour of moulding sand during moulding, a computer simulation is performed for aeration sand filling. In the mathematical model [3] for aeration filling processes, the Euler two-phase flow model has been taken as the računalniško simulacijo zapolnjevanja forme z zračenim peskom. V matematičnem modelu polnjenja z zračenim peskom [3] se je uporabil Eulerjev dvofazni model toka kot osnova. V tem modelu sta plinska in trdna faza vzeti kot zvezni fazi, tj. vzeti sta bili kot tok zraka in tok peska.

V osnovnih enačbah matematičnega modela so bile enačbe kontinuuma in enačbe gibalne količine za plinsko ter trdno fazo obravnavane ločeno. Vzeto je bilo, da so vsi delci peska enaki in da sta njihovi značilnosti povprečni premer ter povprečna gostota. Za opis trkov med posameznimi delci se je uporabil značilni kinetičnoteoretični model večfaznega toka, ki ga je postavil Gidaspow [8]. Enačbe ravnovesja mas in gibalnih količin plinske ter trdne faze so se izračunale po metodi končnih razlik. V teh enačbah so odvisne spremenljivke delež prostornine plina, delež prostornine trdne faze, gostota plina, hitrostni vektorji toka plina in toka peska.

Enačba zveznosti plinske faze je:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g) + \nabla \cdot (\alpha_g \rho_g V_g) = 0 , \quad (1)$$

enačba gibalne količine plinske faze:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g V_g) + \nabla \cdot (\alpha_g \rho_g V_g V_g) = \beta(V_g - V_s) + \nabla \cdot \tau_g . \quad (2)$$

Težnostna sila zraka se zanemari, ker je zelo majhna v primerjavi z napetostjo zraka. Enačba zveznosti trdne faze je:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g) + \nabla \cdot (\alpha_g \rho_g V_g) = 0, \quad (3)$$

in enačba gibalne količine trdne faze:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g V_g) + \nabla \cdot (\alpha_g \rho_g V_g V_g) = \beta(V_g - V_s) + \nabla \cdot \tau_g \quad (4)$$

kjer je α_g prostorninski delež plinske faze in α_s prostorninski delež trdne faze. Zato je $\alpha_g + \alpha_s = 1$. β je koeficient zračnega upora,

basis of design. In this model, both gas phase and solid phase have been assumed as continuum, i.e., they have been treated as air flow and sand flow respectively. In the governing equations of mathematical model, the continuity equations and momentum equations of gas phase and solid phase have been treated separately. All of the sand particles are considered to be identical and characterized by a mean diameter and a mean density. To describe the collision between different sand particles, a typical kinetic theory model for multiphase flow is built based on the Gidaspow [8]. The mass and momentum balance equations for the gas phase and solid phase are solved by FDM (Finite Difference Method). In these equations, the dependent variables are the gas volume fraction, the solid volume fraction, the gas density, the velocity vectors of the gas and sand flow.

Continuity equation of the gas phase:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g) + \nabla \cdot (\alpha_g \rho_g V_g) = 0 , \quad (1)$$

momentum equation of the gas phase:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g V_g) + \nabla \cdot (\alpha_g \rho_g V_g V_g) = \beta(V_g - V_s) + \nabla \cdot \tau_g \quad (2)$$

The gravity force of air is neglected because it is very small compared with the stress of air. Continuity equation of the solid phase:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g) + \nabla \cdot (\alpha_g \rho_g V_g) = 0, \quad (3)$$

momentum equation of the solid phase:

$$\frac{\partial}{\partial t}(\alpha_g \rho_g V_g) + \nabla \cdot (\alpha_g \rho_g V_g V_g) = \beta(V_g - V_s) + \nabla \cdot \tau_g \quad (4)$$

where, α_g is the volume fraction of gas phase, α_s is the volume fraction of solid phase, namely, $\alpha_g + \alpha_s = 1$. β is the drag coefficient, τ_g is the stress tensor of gas flow which is expressed by Sinclair's model [9],

τ_g napetostni tenzor plinskega toka, ki ga podaja Sinclairov model [9], τ_s napetostni tenzor trdne faze, ki ga podaja Millerjev model [10].

4. Stiskanje

Za simulacijo stiskanja se je uporabila trgovska računalniška oprema, ki sloni na metodi končnih elementov. Model nelinearnega elastičnega materiala se je uporabil za simulacijo stiskalnega formanja [4-5]. Sočasno obstajajo tri vrste nelinearnosti pri standardnem procesu stiskanja.

1) Mehanska odzivna nelinearnost: krivulje deformacija-napetost [4] smo dobili s poskusi s štirimi svežimi peski z različnimi gostotami. Kaže, da napetost narašča eksponentno z deformacijo in da se lahko pri procesu stiskanja doseže jo velike deformacije, 30-40%.
2) Strukturna nelinearnost: formarski pesek je sestavljen iz posameznih kremenovih zrn, pokritih s plastjo bentonit/voda, ter prazninami med njimi, zapolnjenimi z zrakom. Za takšen material sta kot notranjega trenja in kohezija dva glavna faktorja, ki se navadno uporabita kot značilnosti materiala. Če na ta material delujejo zunanje sile, se zrak iz praznin med delci iztisne. Zato je deformacija formarskega peska plastična.
3) Kontaktna nelinearnost: zunanje trenje, ki obstaja med peskom in okvirjem forme, močno vpliva na učinek zgoščevanja.

5 Razmere pri simulaciji

Naredili smo računalniško simulacijo in poskuse formanja brez okvirja. Slika 4-A kaže geometrijski model te študije.

τ_s is the stress tensor of solid phase which is expressed by Miller's model [10].

4. Squeeze

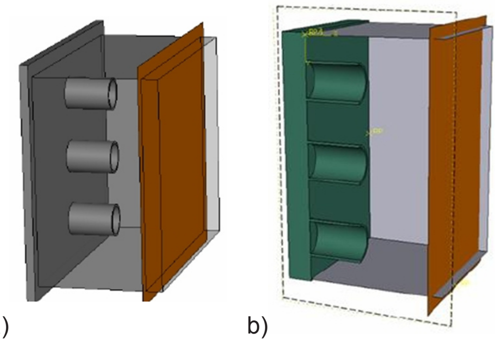
In the squeeze moulding simulation, commercial software, which is based on FEM (Finite Element Method), is applied. The nonlinear elastic material model is used for squeeze moulding simulation [4-5]. There are three types of nonlinearity existing simultaneously in a normal compaction process.

1) Mechanical response nonlinearity: The strain-stress curves [4] are obtained experimentally for four green sands with different density. It seems that the stress increases exponentially with strain, and a large deformation of 30%-40% can be obtained upon the completion of a compact process.
2) Structural nonlinearity: Moulding sand is composed of discrete silica sand grains covered with bentonite/water layer and air voids. For such material, the internal friction angle and cohesion are two major factors, which are usually used to represent the features of material. When subject to an external force, the air voids existing among moulding sand are squeezed out. Consequently, the deformation of mould sand is plastic.
3) Contact nonlinearity: External friction which exists between sand and flask influences the compaction effect significantly.

5 Simulation Condition

Computer simulation and experiment are performed for flask-less moulding process. Figure 4-A) shows geometrical model for the present study. The dimension of the

Dimenzije okvirja so bile 608 mm x 510 mm x 260 mm. Modelna plošča je imela tri rokave z notranjim premerom 70 mm in višino 110 mm. Na dnu rokavov so bili zračilni kanali. Smer toka peska je bila skoraj navpična na odprtino rokava. Glede na simetričnost modela se je samo ena polovica forme uporabila, da se skrajša čas računanja in zmanjša velikost pomnilnika. Slika 4-B kaže simetrično polovico za simulacijo.



a) b)

Slika 4. Geometrijski model procesa stiskanja, a) integriran geometrijski model, b) simetrična polovica

Figure 4. Geometrical model of squeezing process; a) Integrated geometrical model b) Symmetrical half part

6 Rezultati simulacije

Rezultate simulacije in eksperimentalne rezultate zapolnjevanja forme z zračenim peskom prikazuje slika 5. V našem primeru je bilo zelo težko popolnoma zapolniti vodoravni rokav. Vendar formarski pesek teče tekoče v tri rokave zaradi učinka nizkotlačnega zračenja. Izračunano obnašanje je zelo podobno eksperimentalnemu.

Pred simulacijo stiskanja je treba rezultate simulacije zapolnjevanja forme z zračenim peskom prenesti v geometrijski model stiskanja, kar se lahko razdeli na 5 delov glede na gostoto. Po tem se lahko

flask is 608mm×510mm×260mm. Pattern plate has three sleeves with inner diameter of 70mm and height of 110 mm.

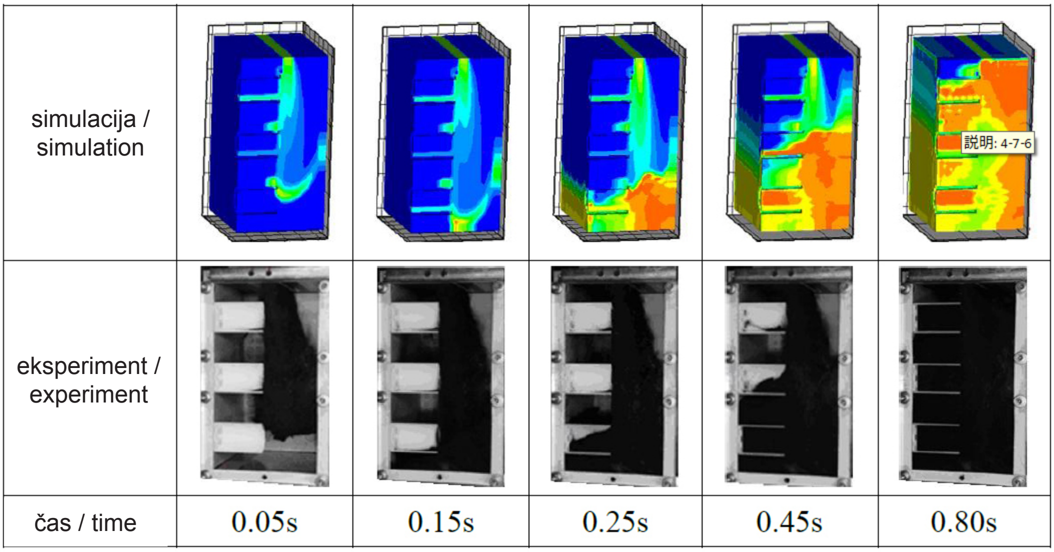
There are vents at the bottom of the sleeve. The direction of sand flow is nearly perpendicular to the opening of the sleeve. For the symmetrical feature of the model, only one half of the mould is calculated to decrease calculation time and memory size. Figure 4-B) shows a symmetrical half part for simulation.

6 Simulation Results

The simulation and experimental results for aeration sand filling is shown in Fig. 5. In this case, it is quite difficult to fill the horizontal sleeve completely. However, moulding sand flows smoothly into the three sleeves by the effect of low pressure aeration. The calculated behaviour is very similar to experimental one.

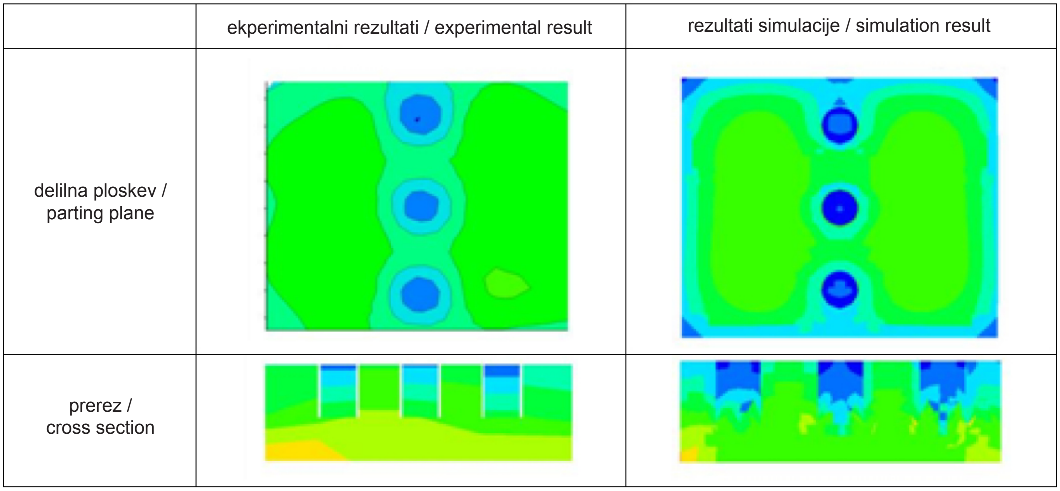
Before squeeze simulation, the simulation results of aeration sand filling should be transferred to squeezing geometrical model which can be divided into 5 parts according to bulk density. After that, the squeeze simulation can be done with Finite Element Method. The simulation results of squeeze are converted according to the relationship between calculated stress field and mould strength field [4].

Figure 6 shows the simulation and experimental mould strength distribution after squeezing. The experimental results are measured using actual production scale flask-less moulding machine. The simulation results are very similar to the experimental one. However, the experimental value at the corner is higher than the simulation one because the actual flask has tapered corner.



Slika 5. Rezultati simulacije in poskusov zapolnjevanja forme z zračenim peskom

Figure 5. Simulation and experimental results for aeration sand filling process



Slika 6. Simulacijska in eksperimentalna porazdelitev trdnosti po stiskanju

Figure 6. Simulation and experimental strength distribution after squeezing

simulacija stiskanja naredi po metodi končnih elementov. Rezultati simulacije stiskanja se lahko pretvorijo v skladu z odnosom med izračunanim napetostnim poljem in trdnostnim poljem forme [4].

7 Analyze of Sand Filling with Sand Detection Sensor [11]

It is essential to know sand filling behaviour and bulk density after sand filling. Generally, Slika 6 prikazuje simulacijsko in eksperimentalno porazdelitev trdnosti forme po stiskanju. Eksperimentalni rezultati so bili merjeni med industrijskim procesom formanja. Simulacijski rezultati so zelo podobni eksperimentalnim. Vendar so dobljene eksperimentalne vrednosti v vogalih večje od simulacijskih, ker ima dejanski formarski okvir vogale z naklonom.

7 Analiza zapolnjevanja s peskom z zaznavalom za zaznavanje peska [11]

Zelo pomembno je poznati obnašanje peska pri zapolnjevanju forme ter njegovo gostoto po zapolnjevanju. V splošnem ni možno meriti gostote peska v formi med zapolnjevanjem. Zato smo razvili zaznavalo za pesek, da bi lahko ugotavljali obnašanje peska med zapolnjevanjem.

8 Zaznavalo za zaznavanje peska med zapolnjevanjem

Namen razvitja zaznavala za zaznavanje peska je bil vedeti, kdaj surovi pesek doseže modelno ploščo, posebno pri globokem žepu. Standardna tehnologija za zaznavanje peska meri tlak stika peska. Obnašanje surovega peska med stiskanjem se je ugotavljalo z zaznavalom, ki so ga razvili J. Bast in sodelavci [12]. Tlak ob stiku peska med zapolnjevanjem forme z zračenim peskom je namreč premajhen, da bi ugotovili njegov tlak s tem zaznavalom. Poleg tega zaznavalo tlaka ne meri samo tlak ob stiku peska, ampak tudi zračni tlak. Pred kratkim je bilo razvito novo zaznavalo za zaznavanje peska na osnovi električne tehnologije, s katerim je mogoče ugotavljati stik peska pri zapolnjevanju forme z zračenim peskom.

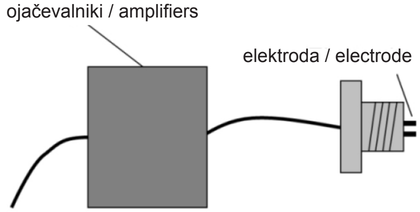
Slika 7 shematično prikazuje razvito zaznavalo za pesek, ki je sestavljeno iz

it is impossible to measure the bulk density inside mould during sand filling. Therefore, a sand sensor has been developed in order to detect the sand filling behaviour.

8 Sand Detection Sensor for Sand Filling

Purpose of developing sand detection sensor is to know when green sand arrives at pattern plate, especially, in the deep pocket. A conventional technology for sand detection is measuring sand contact pressure. The green sand behaviour during squeeze has been evaluated by a sensor developed by J. Bast et al. [12]. However, the sand contact pressure during aeration sand filling is too weak to detect the pressure with this sensor. Furthermore, the pressure sensor measures not only sand contact pressure but also air pressure. Recently, a new sand detection sensor has been developed by electrical technology to detect sand contacting during aeration sand filling.

Figure 7 shows schematic illustration of developed sand detection sensor which consists of electrodes and amplifiers. When sand particles enter between electrodes, the electric circuit is closed. The voltage is amplified because the conductivity of the green sand is extremely low.



Slika 7. Shematičen prikaz razvitega zaznavala za zaznavanje peska

Figure 7. Schematic illustration of developed sand detection sensor

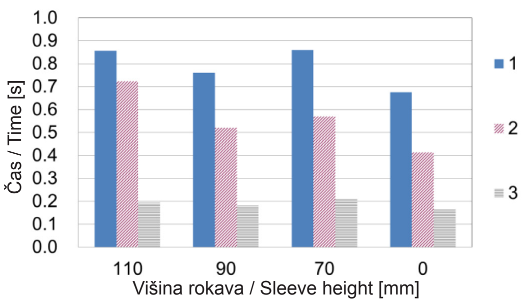
elektrod in ojačevalnikov. Ko zrno peska pride med elektrodi, se električni tokokrog zapre. Napetost se ojači, ker je prevodnost surovega peska izredno majhna.

9 Eksperimentalne razmere

Razvito zaznavalo se je preverjalo na dejanskem formarskem stroju. Velikost okvirja je bila 508 mm x 610 mm. Uporabili smo ploščat model in model rokava za vrednotenje obnašanja peska pri zapolnjevanju. Model rokava je imel v sredini tri rokave. Notranji premer rokavov je bil 70 mm, višine pa 70, 90 in 110 mm. Model rokava je shematično prikazan na sliki 8. Zračilni tlak med zapolnjevanjem s peskom je bil 0,1 MPa. Stisljivost surovega peska je bila nastavljena na 35 %.

10 Eksperimentalni rezultati

Slika 9 daje primerjavo časov, ko pesek pride na dno vsakega, različno visokega rokava. Višine rokavov so bile 110, 90 in 70 mm. Višina rokava 0 mm na sliki 9 pomeni, da je bil uporabljen ploščat model pri poskusu zapolnjevanja s peskom.

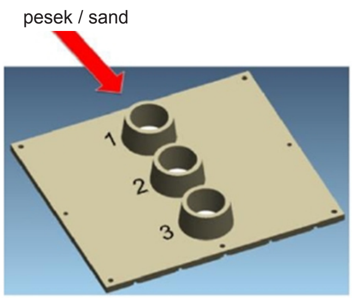


Slika 9. Primerjava časov, ko pride pesek na dno rokava, v odvisnosti od višine

Figure 9. Comparison of sand arrival times at the bottom of sleeves in each sleeve height

9 Experimental conditions

Actual production scale moulding machine is used to verify this developed sensor. The flask size is 508 x 610 mm. Flat pattern and sleeve pattern are used to evaluate the sand filling behaviour. The sleeve pattern has three sleeves along the center. Inner diameter of sleeve is 70 mm. Heights of sleeve are 70, 90 and 110 mm. Schematic illustration of sleeve pattern is shown in Fig. 8. Aeration pressure during sand filling is 0.1 MPa. The green sand is adjusted to 35 % compactability.



Slika 8. Shematični prikaz preskusnega modela s tremi rokavi

Figure 8. Schematic illustration of test pattern with sleeves

10 Experimental Results

Figure 9 shows comparison of sand arrival times at the bottom of sleeves in each sleeve height. Sleeve heights are 110, 90 and 70mm. Sleeve height 0 mm in Fig. 9 means that flat pattern is used for sand filling experiment. The sand filling behavior observed by video camera is shown in Fig.5. The sand arrival times at the bottom of lower sleeve (No.3) are about 0.2 s. in all conditions. Then, the green sand arrives at the bottom of middle sleeve (No. 2) between 0.4 and 0.7 s. Finally, the sand filling is finished less than 1.0 s. in all conditions.

Obnašanje peska med zapolnjevanjem smo zasledovali z video kamero, kar je prikazano na sliki 5. Čas, da je prišel pesek na dno nižjega rokava (št. 3) je bil pri vseh razmerah 0,2 s. Na dno srednjega rokava (št. 2) je pesek prispel v 0,4 s do 0,7 s. V vseh primerih je bilo zapolnjevanje s peskom končano v manj kot 1,0 s. Zato na obnašanje zračenega peska oblika modela ne vpliva veliko. Surovi pesek namreč teče zelo tekoče pri zapolnjevanju z zračenim peskom.

11 Sklepi

Tehnologijo zapolnjevanja forme z zračenim peskom smo vrednotili pri formanju s surovim peskom z vidika, kako pesek zapolnjuje formo. Prišli smo do naslednjih ugotovitev:

1) Proces zapolnjevanja z zračenim peskom smo matematično numerično simulirali na osnovi teorije dvofaznega toka v kombinaciji s kinetično teorijo. Rezultati simulacije so se ujemali z eksperimentalnimi rezultati. Proces zaključnega stiskanja smo računali z metodo končnih elementov. Tudi trdnost forme smo numerično simulirali in rezultate simulacije primerjali z eksperimentalnimi rezultati. S poskusi in simulacijo smo ugotovili, da je zapolnjevanje forme z zračenim peskom učinkovito za majhne žepe in omogoča doseči veliko trdnost forme ter enakomerno gostoto peska, poleg tega pa še manjšo porabo zraka.
2) Zaznavalo za zaznavanje peska, razvito na osnovi električne tehnologije, lahko vrednoti obnašanje peska pri zapolnjevanju. Na obnašanje zračenega peska pri zapolnjevanju forme oblika modela ne vpliva veliko. Surovi pesek namreč teče tekoče pri nizkotlačnem zračenju.

Therefore, the behaviour of aeration sand filling is not much affected by pattern shape. Namely, the green sand flows very smoothly by aeration sand filling.

11 Conclusion

Aeration sand filling technology in green sand moulding process is evaluated from the view of sand filling process. The results are summarized as follows.

1) Aeration sand filling is numerically simulated with the two-phase flow theory and the mathematical model is built with kinetic theory. The calculated behaviour of aeration sand filling is in agreement with the experimental results. The final squeeze compaction process is calculated with Finite Element Method. The mould strength can be numerically simulated. The results of simulation are compared with the experimental results. Through these experiment and simulation, aeration sand filling is effective for small pocket and can make high strength and uniform density mould by lower air consumption.
2) The sand detection sensor, which is developed using electrical technology, can evaluate sand filling behaviour. The behaviour of aeration sand filling is not much affected by pattern shape. Namely, the green sand flows very smoothly by low pressure aeration.

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