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SIAPRO d.o.o.
Postaja 9
5216 Most na Soči

Direktor: Franc JEZERŠEK

T: +386 5 3841 632
F: +386 5 3841 630
E: info@siapro.si

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T. Okuno[1], K. Somiya[1], Y. Takagi[1], K. Yano[1], S. Baba[2],
[1] Mie University, Faculty of Eng., Dept. of Mech. Eng., 1577 Kurimamachiya-cho, Tsu, Mie, Japan
[2] Flow Science Japan, Inc., Tokyo, Japan

Optimalna zasnova vzorcev vej na podlagi oblike izdelkov v tlačnem litju

Optimum Design of Branch Pattern Considering Product Shape for Die Casting Design

Povzetek

Tlačno litje je metoda, v katerem se staljena kovina vliva v tulec in z batom stisne v natančno kovinsko formo pri visoki hitrosti in pri visokem tlaku. Uporablja se za serijsko proizvodnjo visoko kakovostnih ulitkov s površinskim slojem v kratkem času. Tlačno litje nudi številne prednosti; med drugim omogoča izdelavo ulitkov zapletenih oblik ter dimenzijsko natančnost, prav tako pa zmanjšuje stroške materiala v primerjavi z litjem v peščene forme. Vendar pa je treba za zagotavljanje hitrega strjevanja tekoče kovine hitro napolniti kovinsko formo in bat vstaviti pri visoki hitrosti. Zato lahko zaradi vdora zraka nastajajo veliki zračni mehurčki. Gre za dejavnik, ki znatno poslabša mehanske lastnosti izdelka. Zato so potrebni ukrepi za spopadanje s to težavo.

Napori za preprečevanje nastanka takšnih napak so tradicionalno osnovani na optimalno zasnovanih dovajalnih sistemih, ustvarjenih skozi analizo CFD (computational fluid dynamics) za vdor zraka v dovajalnih sistemih. V tem laboratoriju pa nasprotno predlagamo neparametrično optimizacijsko metodo na podlagi krivulj. Krivulje, ki tvorijo zasnovo oblike razdelilnega kanala, se uporabljajo kot spremenljivke, ki preprečujejo vdor zraka v dovajalni sistem. Vendar pa se s proizvodnjo večjih in bolj zapletenih izdelkov poveča tudi potencial vdora zraka v izdelke. Zato je treba med zasnovo optimalne oblike razdelilnega kanala upoštevati tudi izdelek. V takšnem primeru je morda treba znatno spremeniti vedenje tekoče kovine v izdelku. To vključuje ne samo zunanjo obliko razdelilnega kanala, ampak je treba zagotoviti tudi optimalno zasnovo, vključno z vzorcem vej.

V tej raziskavi predlagamo novo metodo za optimizacijo, vključno z vzorci vej v oblikovanem prostoru. Ta metoda temelji na metodi kombinatorične optimizacije in neparametrične optimizacije. V optimizacijskem postopku najprej optimiziramo obliko razdelilnega kanala z vsemi vzorci vej. Nato optimiziramo obliko razdelilnega kanala ob upoštevanju izdelka kot začetno optimalno obliko, ki jo pridobimo kot rezultat. Predlagana metoda je torej optimizacija v dveh korakih.

Na koncu optimalno zasnujemo obliko razdelilnega kanala za izdelke enostavnih oblik, izdelane skozi metodo tlačnega litja, da bi preverili učinkovitost predlagane metode. Ugotovili smo, da je metoda v primerjavi s konvencionalnimi optimizacijskimi metodami učinkovitejša.

Ključne besede: tlačno litje, CFD, optimalna zasnova, razdelilni kanal, vzorec vej

Summary

Die casting is a method in which molten metal is poured into a sleeve and pressed with a plunger into a precise metal mold at high speed and high pressure. It is used to mass-produce superior casting of cast skin in a short time. Die casting has many advantages,

including allowing products with complicated shapes to be molded with dimensional accuracy, and reducing material cost compared to sand mold castings. However, in order to rapidly solidify the molten metal, it is necessary to fill the metal mold quickly and inject the plunger at a high speed. Therefore, internal defects such as air entrainment are generated by the blowhole. This is a factor that significantly reduces the mechanical properties of the product. Therefore, measures to address it are needed.

Efforts to prevent such defects from occurring have conventionally used optimally designed gating systems created by CFD (computational fluid dynamics) analysis for air entrainment in the gating system. In this laboratory, in contrast, we propose a nonparametric optimization method using curves. Curves that constitute the outline of the runner shape are used as variables to prevent air entrainment in the gating system. However, as products to be manufactured become larger and more complicated, potential for air entrainment in products also rises. Therefore, it is necessary to consider the product when determining the optimum design of the runner shape. In that case, it may be necessary to change the behavior of the molten metal in the product substantially. This includes not only the outer shape of the runner but also optimum design including branching patterns in design space is necessary.

In this research, we propose a new optimization method including branch patterns in the design space. This method uses both combinatorial optimization and the nonparametric optimization method. For the optimization procedure, we first optimize only the runner shape with all the branching patterns. Next, we optimize the runner shape considering the product as the initial optimum shape obtained as a result. Therefore, this proposed method is a two-stage optimization.

Finally, we optimally design the runner shape for simple shapes of products manufactured by the die casting method to verify the effectiveness of the proposed method. We find the method is superior compared to the conventional optimization method.

Key words: HPDC, CFD, Optimum Design, Runner, Branch Pattern

1 Uvod

Tlačno litje se uporablja za proizvodnjo industrijskih izdelkov, npr. avtomobilskih delov. Pri metodi tlačnega litja nastajajo napake, kot so zračni mehurčki, povzroča pa jih zrak, ki prehaja skozi staljeno kovino.

Dandanes so razdelilni in dovodni kanali zasnovani tako, da preprečujejo nastanek zračnih žepkov [1–3]. V tej raziskavi predlagamo novo metodo za optimizacijo, ki obsega vzorce vej v oblikovanem prostoru.

1 Introduction

The die casting method is used to produce industrial products such as automobile parts. In the die casting method, defects such as blow holes are generated by entraining air in the molten metal.

Runners and gates are now being specifically designed to prevent air entrapment [1-3]. In this research, we propose a new optimization method that includes branch patterns in the design space.

2 Predlog metode opredelitve oblike z uporabo matrike funkcij in vektorja realne vrednosti

Pri tej metodi smo uporabili kombinatorično optimizacijo kot tudi neparametrično optimizacijo. Uspelo nam je ustvariti novo metodo, ki opisuje vzorce vej kot tudi obris razdelilnega kanala. To pa omogoča iskanje novih rešitev za bolj prilagodljivo zasnovo v primerjavi s konvencionalnimi metodami.

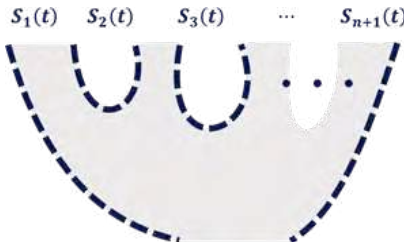
2.1 Izražanje posameznih vrednosti

V tem prispevku se za enoto, ki predstavlja povzetek lastnosti, namenjenih izražanju ene rešitve, uporablja izraz »posamezna vrednost«.

Pri optimizaciji razvejanih razdelilnih kanalov n se obstoj vsake posamezne veje ponazori z $1 \times n$ matrico $M = (m_1, m_2, \ldots, m_n)$ s številčno vrednostjo 0 ali 1. Številčna vrednost označuje prisotnost veje, 0 pa pomeni, da veje ni.

Pri neparametrični optimizaciji, ki je prikazana na Sl. 1, so posamezne vrednost prikazane s krivuljami n + 1.

S_1, S_2, ... , S_{n+1} so spremenljivke v pimeru razdelilnega kanala z n-vejami.



Sl. 1. Prikaz oblike predhodne metode

Fig. 1. Shape representation of previous method

Kot je prikazano na Sl. 2, bifurkacijo B_i predstavljata dve krivulji S_{Li} in S_{Ri}. Krivulje so izražene z $S_{L1}, S_{R1}, \ldots, S_{Ln}, S_{Rn}$ kar omogoča

2 Proposal of Shape Definition Method Using Function Matrix and Real Value Vector

In this study, we used both combinatorial optimization and the nonparametric optimization method. In this way, we propose a new method to represent branch patterns in addition to the outline of the runner shape. This makes it possible to search for solutions in a wider design space compared to the conventional method.

2.1 Individual Expression

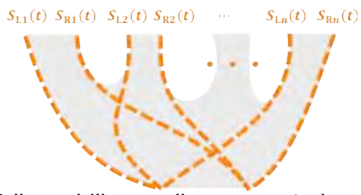
Firstly, in this paper, we express the unit that we summarized an attribute to express one solution in as “individual”.

When optimizing runners with n branches, the existence of each branch is represented using a $1 \times n$ matrix $M = (m_1, m_2, \ldots, m_n)$ with a numerical value of 0 or 1. Here, if the numerical value is 1, it means that there is a branch, and if it is 0, it means that there is no branch.

In the case of nonparametric optimization, as shown in Fig. 1, individuals are represented using n + 1 curves.

$S_1, S_2, \ldots, S_{n+1}$ as variables for a runner having n branches.

In this study, as shown in Fig. 2, the bifurcation B_i is represented by two curves S_{Li} and S_{Ri}. And a total of $2n$ curves are expressed by S_{L1}, S_{R1}, ... , S_{Ln}, S_{Rn} so that each branch can be expressed independently.



Sl. 2. Prikaz oblike predlagane metode

Fig. 2. Shape representation of proposed method

neodvisno izražanje vsake posamezne veje.

Z metodo sinteze se ustvari nova krivulja $S_\gamma(t)$ na podlagi dveh kontrolnih točk prvotnih dveh k-dimenzijskih krivulj $S_\alpha(t)$ in $S_\beta(t)$.

Najprej se krivulji $\acute{S}_\alpha(t)$ in $\acute{S}_\beta(t)$ ustvarita z razširitvijo ali zmanjšanjem prvotne krivulje na podlagi naslednje enačbe.

$$\begin{aligned}\acute{S}_\alpha(t) &= S_\alpha(2t_\alpha t)\\ \acute{S}_\beta(t) &= S_\beta(2t_\beta t)\end{aligned} \quad (1)$$

Tukaj $S_\alpha(t/2t_\alpha)$ in $S_\beta(t/2t_\beta)$ označujeta koordinate presečišča.

Če je k liho število, se nova krivulja opredeli z naslednjo enačbo.

$$\begin{aligned}S_\gamma(t) = {} & \acute{p}_{\alpha 0}(1-t)^k + \cdots + \acute{p}_{\alpha k_1}(1-t)^{k_2} t k_1 \\ & + \acute{p}_{\beta k_1}(1-t)^{k_1} t k_2 + \cdots + \acute{p}_{\beta 0} t^k\end{aligned} \quad (2)$$

Če je k sodo število, se nova krivulja opredeli z naslednjo enačbo.

$$\begin{aligned}S_\gamma(t) = {} & \acute{p}_{\alpha 0}(1-t)^k + \cdots + \acute{p}_{\alpha k_3}(1-t)^{k_5} t k_3 \\ & + \frac{\acute{p}_{\alpha k_4} + \acute{p}_{\beta k_4}}{2}(1-t)^{k_4} t k_4 \\ & + \acute{p}_{\beta k_3}(1-t)^{k_3} t k_5 + \cdots + \acute{p}_{\beta 0} t^k\end{aligned} \quad (3)$$

Tukaj vrednosti $\acute{p}_\alpha$ in $\acute{p}_\beta$ označujeta kontrolni točki $\acute{S}_\alpha(t)$ $\acute{S}_\beta(t)$ ter $k_1 = (k-1)/2$, $k_2 = (k+1)/2$, $k_3 = k/2-1$, $k_4 = k/2$, $k_3 = k/2+1$.

Optimizacija je izvedena z uporabo posamezne vrednosti kot je pojasnjeno zgoraj.

2.2 Ustvarjanje začetnih posameznih vrednosti

V tej optimizaciji se začetne posamezne vrednosti ustvarijo na način, ki zagotavlja enakomerne vzorce vej. Prav tako se krivulje $S_{L1}, S_{R1}, \ldots, S_{Ln}, S_{Rn}$ ustvarijo naključne sekundarne Bézierove krivulje.

The synthesis method generates a new curve $S_\gamma(t)$ using the control points of the original two k-dimensional curves, $S_\alpha(t)$ and $S_\beta(t)$.

First, curves $\acute{S}_\alpha(t)$ and $\acute{S}_\beta(t)$ are generated by extending or reducing the original curve using the following equation.

$$\begin{aligned}\acute{S}_\alpha(t) &= S_\alpha(2t_\alpha t)\\ \acute{S}_\beta(t) &= S_\beta(2t_\beta t)\end{aligned} \quad (1)$$

Here, $S_\alpha(t/2t_\alpha)$ and $S_\beta(t/2t_\beta)$ indicate the coordinates at the intersection.

Then, if k is an odd number, a new curve is defined by the following equation.

$$\begin{aligned}S_\gamma(t) = {} & \acute{p}_{\alpha 0}(1-t)^k + \cdots + \acute{p}_{\alpha k_1}(1-t)^{k_2} t k_1 \\ & + \acute{p}_{\beta k_1}(1-t)^{k_1} t k_2 + \cdots + \acute{p}_{\beta 0} t^k\end{aligned} \quad (2)$$

If k is an even number, a new curve is defined by the following equation.

$$\begin{aligned}S_\gamma(t) = {} & \acute{p}_{\alpha 0}(1-t)^k + \cdots + \acute{p}_{\alpha k_3}(1-t)^{k_5} t k_3 \\ & + \frac{\acute{p}_{\alpha k_4} + \acute{p}_{\beta k_4}}{2}(1-t)^{k_4} t k_4 \\ & + \acute{p}_{\beta k_3}(1-t)^{k_3} t k_5 + \cdots + \acute{p}_{\beta 0} t^k\end{aligned} \quad (3)$$

Here, $\acute{p}_\alpha$ and $\acute{p}_\beta$ indicate control points of $\acute{S}_\alpha(t)$ $\acute{S}_\beta(t)$, respectively, and $k_1 = (k-1)/2$, $k_2 = (k+1)/2$, $k_3 = k/2-1$, $k_4 = k/2$, $k_3 = k/2+1$.

Optimization is performed by using the individual expression explained above.

2.2 Generation of Initial Individuals

In this optimization, initial individuals are generated so that branch patterns exist uniformly. Also, curves $S_{L1}, S_{R1}, \ldots, S_{Ln}, S_{Rn}$ are generated as random secondary Bezier curves.

2.3 Križanje

Križanje se v tej optimizaciji izvaja z dvema glavnima posameznima vrednostma. Matrica M_c predstavlja vzorec vej podrejene posamezne vrednosti, ustvarjene na podlagi naslednje enačbe za matrici M_p in M_q, ki predstavljata vzorec vej glavne posamezne vrednosti.

$$m_{ci} = \begin{cases} m_{pi} (= m_{qi}) & (m_{pi} = m_{qi}) \\ m_{pi} \text{ or } m_{qi} & (m_{pi} \neq m_{qi}) \end{cases} \quad (4)$$

Tako m_{pi} kot m_{qi} sta izbrani z verjetnostjo 1/2. Križanje zagotovi lastnosti obeh glavnih posameznih vrednosti, kadar so njune lastnosti enake, če pa se lastnosti razlikujejo, se zagotovi samo ena. Krivulja križanja je enaka kot pri neparametrični optimizaciji v povezavi s konvencionalno metodo.

V tem prispevku smo matrico M uporabili za vsako obliko vzorca vej, da bi poenostavili razlago, poimenovali pa smo jo oblika $m_1\, m_2 \ldots m_n$.

3 Preprosta optimizacija oblike razdelilnega kanala

3.1 Opredelitev težave v povezavi z optimizacijo

Optimizacija oblike razdelilnega kanala je temeljila na rezultatih analize CFD (computational fluid dynamics). Da bi ocenili napake zaradi vdora zraka v izdelku, je bila opredeljena naslednja enačba, ki je namenjena modeliranju optimizacijskega problema.

$$\text{Minimize } J = \frac{1}{|n_{\text{cell}}|} \sum_{i \in n_{\text{cell}}} E_{\text{air,i}} \quad (5)$$

2.3 Crossover Method

Crossover in this optimization is performed for two parent individuals. A matrix M_c representing the branch pattern of a child individual is generated by using the following equation for the matrices M_p and M_q representing the branch pattern of a parent individual.

$$m_{ci} = \begin{cases} m_{pi} (= m_{qi}) & (m_{pi} = m_{qi}) \\ m_{pi} \text{ or } m_{qi} & (m_{pi} \neq m_{qi}) \end{cases} \quad (4)$$

Both m_{pi} or m_{qi} are selected with a probability of 1/2. This crossover method inherits the features of the parent individuals if they have the same features and inherits only one of them if they have different features. The curve crossover method is the same as the nonparametric optimization of the conventional method.

In this paper, we use the matrix M for each branch pattern shape to simplify the explanation and call it Shape $m_1\, m_2 \ldots m_n$.

3. Optimization of Runner Shape by Simple Shape

3.1 Optimization Problem Definition

Optimization of the runner shape was based on the results of computational fluid dynamics (CFD) simulation analysis. In order to evaluate air entrainment defects in the product, the following equation was defined to model the optimization problem.

$$\text{Minimize } J = \frac{1}{|n_{\text{cell}}|} \sum_{i \in n_{\text{cell}}} E_{\text{air,i}} \quad (5)$$

Here, E_{air} is the entrained-air volume ratio in each mesh cell in the CFD simulator, n_{cell} is the set of mesh cells in the product section in Fig. 1, excluding

E_{zrak} je volumsko razmerje ujetega zraka v vsaki celici mreže v simulatorju CFD, n_{celica} je nabor celic v mreži v predelu produkta na Sl. 1, razen delov izravnalnega kanala, kot so preliv in oddušniki. Manjša kot je vrednost funkcije *J*, manj napak zaradi vdora zraka bo imel izdelek. Ta težava v povezavi z optimizacijo se reši z uporabo predlagane metode, osnovane na genetskem algoritmu (GA). Za potrditev učinkovitosti predlagane metode prav tako uporabljamo tudi konvencionalno metodo.

3.2 Nastavitev simulacije CFD

Mreža celic v simulatorju CFD je bila nastavljena na enotno velikost 3 mm. Poleg tega je bila analiza izvedena ob upoštevanju težnosti, površinske napetosti, viskoznosti in prevajanja toplote. Taljena kovina je bila aluminijeva zlitina ADC 12, ki se pogosto uporablja v tlačnem litju.

V tej študiji smo za simulacijo CFD uporabili programsko opremo FLOW-3D, ki jo proizvaja podjetje Flow Science Co. Ltd., namenjeno splošnim analizam CFD [4].

3.3 Rezultati optimizacije in analiza

Posamezni graf raztrosa v okviru optimizacije za predlagano metodo je prikazan na Sl. 3.

S Sl. 3 je razvidno, da sta obliki 100 in 010 povezani z razmeroma slabimi ocenjenimi vrednostmi, obliki 101 in 111 pa z razmeroma dobrimi ocenjenimi vrednostmi. Prav tako je očitno, da je mogoče v primeru zožitve vzorca vej na ena znotraj vzorca poiskati boljšo rešitev.

Nadalje, povprečna vrednost volumskega razmerja ujetega zraka v produktu, ki je ocenjena vrednost J v težavi v povezavi z optimizacijo, je bila primerjana

the exhaust system such as overflow and vent. The smaller the function value *J*, the fewer the air entrainment defects in the product. This optimization problem is solved using the proposed method based on a genetic algorithm (GA). We also use the conventional method to confirm the effectiveness of the proposed method.

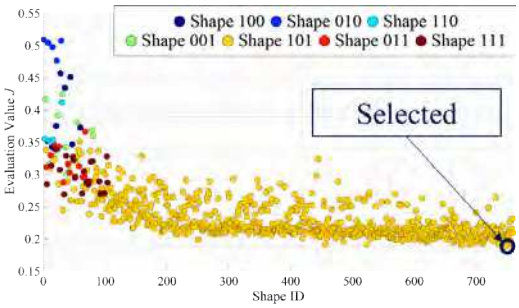
3.2 Setting of CFD Simulation

The mesh cell in the CFD simulator was uniformly set at 3 mm. In addition, analysis was made in consideration of gravity, surface tension, viscosity and heat conduction. The molten metal was assumed to be aluminum alloy ADC 12, which is commonly used in die casting.

In this study, FLOW-3D, a general-purpose CFD software manufactured by Flow Science Co., Ltd., was used for CFD simulation [4].

3.3 Optimization result and analysis

The individual scatter map in the optimization of the proposed method is shown in Fig. 3.



Sl. 3. Graf raztrosa ocenjenih posameznih vrednosti, ki izhajajo iz predlagane metode

Fig. 3. Scatter diagram of the evaluation values of individuals derived in proposed method

From Fig. 3, it can be seen that Shape 100 and Shape 010 show relatively poor

za vsako zasnovo dovajalnega sistema. Rezultati so prikazani v Preglednici 1.

Oblika, ki izhaja iz predlagane metoda, je povezana z dobro vrednostjo, kot je očitno iz rezultatov. Če povzamemo, izboljšati je mogoče pretok taljene kovine v proizvodnem delu ter izvesti takšno zasnovo dovajalnega sistema, ki zmanjšuje možnost nastanka napak zaradi vdora zraka.

4. Sklepi

V tej študiji smo predlagali novo metodo za optimizacijo, ki obsega vzorce vej v oblikovanem prostoru v okviru metode tlačnega litja. Predlagana metoda združuje kombinatorno optimizacijo z opredelitvijo novega izraza krivulje na podlagi uporabe vektorja z realno vrednostjo kot neparametrično metodo optimizacije.

Optimalno smo zasnovali obliko razdelilnega kanala za izdelke enostavnih oblik, izdelane skozi metodo tlačnega litja, da bi preverili učinkovitost predlagane metode. Ugotovili smo, da je metoda v primerjavi s konvencionalnimi optimizacijskimi metodami učinkovitejša.

evaluation values, and Shape 101 and Shape 111 show relatively good values. Also, it can be seen that after the branch pattern is narrowed down to one, a better solution is searched for in the pattern.

Also, the average value of the entrained-air volume ratio in the product, which is the evaluation value J in the optimization problem, was compared in each gating system design. The results are shown in Table 1.

Preglednica 1. Ocenjena vrednost optimizirane oblike

Table 1. Evaluation value of the optimized shape

Ocenjena vrednost / Evaluation value	Predhodna metoda / Previous method	Predlagana metoda / Proposed method
J	0,2565	0,1885

As is shown from this result, the shape derived by the proposed method shows a good value. In sum, it is possible to improve the flow of the molten metal in the product part and to realize a gating system design that can reduce the occurrence of air entrainment defects.

4. Conclusions

In this study, we proposed a new optimization method that includes the branch pattern in the design space in the die casting method. The proposed method is a method combining combinatorial optimization by defining a new curve expression using a real-valued vector as a nonparametric optimization method.

We optimally design the runner shape for simple shapes of products manufactured by the die casting method to verify the effectiveness of the proposed method. We find the method is superior compared to the conventional optimization method.

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Augustín Sládek, Marek Bruna
KTI, SjF, ŽU Žilina, Univerzitná 1, 010 26 Žilina, Slovakia

Nove vrste uporabe na področju tehnološki priprav na področju proizvodnje z investicijskim litjem

New Applications in Technological Preparations for Investment Casting Production

Izvleček

Dandanes se v livarnah računalniška podpora v okviru ustvarjanja tehnične dokumentacije ne uporablja v zadostni meri. Namesto računalniškega dokumentiranja se uporabljajo klasične metode ustvarjanja tehnične dokumentacije, računalniška podpora pa se uporablja zgolj v majhni meri. Področje livarske tehnologije ni primerno za uporabo konvencionalnih sistemov CAPP na podlagi skupinske tehnologije, ker delujejo skozi enostavno reprezentativno izbiro iz zbirke podatkov glede na lastnosti. V tem prispevku predstavljamo rešitev za povezavo sistemov in možnost uporabe sočasnega inženirstva. V našem oddelku smo zasnovali sistem, ki deluje kot orodje za ustvarjanje tehnološke dokumentacije in namen katerega je učinkovito izkoriščati skupinsko tehnologijo.

Ključne besede: aluminijeve zlitine, reoksidacija, dovajalni sistem, numerična simulacija, bifilm

Abstract

Nowadays, foundries do not sufficiently utilize computer support during the creation of technical documentation. Instead of computer documentation is used classical method for designing technological documentation and the use of computer support is only discrete. For the area of casting technology is not appropriate to use conventional CAPP systems with use of group technology because they work with a simple representative selection from the database according to the characteristics. The submitted article shows a solution for systems interconnection and the possibilities of using the concurrent engineering. In our department was designed system serving as the creation tools for technological documentation, whose role is to effectively benefit from group technology.

Key words: Aluminium alloys, reoxidation, gating system, numerical simulation, bifilm

1 Uvod

Kakovostne zahteve na inženirskem področju postajajo vedno strožje. Merili kakovosti v livarnah sta natančnost rezultatov in časovno obdobje, potrebno za uspešno izvedbo rešitve.

Skozi uporabo računalnikov v proizvodnji lahko skrajšamo čas, potreben za razvoj in proizvodnjo. CAx so računalniški

1 Introduction

Quality requirements in engineering works is constantly escalating. Quality criteria in foundries are - the accuracy of the results and time horizon needed for implementing a successful solution.

By use of computers in engineering production we can achieve shortening of the time for development and production. CA

sistemi, zasnovani za podporo dejavnosti v vseh proizvodnih fazah, npr. pri zasnovi komponent, načrtovanju proizvodnje, dejanski proizvodnji in montaži, skladiščenju in transportu.

Faza snovanja tehnične dokumentacije je povezana z večjim številom rutinskih dejavnosti, ki obsegajo kalkulacije, iskanje, združevanje in razvrščanje podatkov, ki vključujejo manjšo mero miselne dejavnosti. To pomeni, da je večina dokumentacije pripravljene na podlagi znanih in natančnih algoritmov (osnovo predstavljajo že znana tehnološka pravila in dejstva, pridobljena skozi natančne metode in na podlagi številnih let izkušenj). Izbira ustrezne tehnologije temelji na različnih podatkov, ki omogočajo izdelavo proizvodnih skic kot tudi specifične proizvodne pogoje. Rezultati odločitve so pripravljeni na podlagi konkretnega zaporedja ukazov, rezultat katerega je najučinkovitejša metoda za proizvodnjo delov pod specifičnimi pogoji.

2 Tehnična priprava proizvodnje (TPP)

Napredovanje avtomatizacije na inženirskem področju je vedno izrazitejša ne samo v povezavi s pripravami (zmanjšanje obsega dela v okviru tehnoloških priprav, zmanjšanje števila inženirjev), ampak tudi v povezavi s proizvodnjo (zmanjšanje stroškov, zvišanje produktivnosti dela). Avtomatizacija inženirskih izračunov predvideva uporabo dodelanih metod, ki zagotavljajo zanesljive rezultate.

Razlike med viri avtomatizacije na inženirskem področju so ogromne. Ti viri pokrivajo celoten spekter inženirskih dejavnosti, ki so potrebne za zasnovo, načrtovanje in izdelavo – tehnološke naloge.

Na Sl. 1 je prikazan poenostavljen model priprav na proizvodnjo s podporno

systems are computer systems designed to support activities at all stages of production, i.e. design of components, production planning, actual production and assembly, warehousing and shipping.

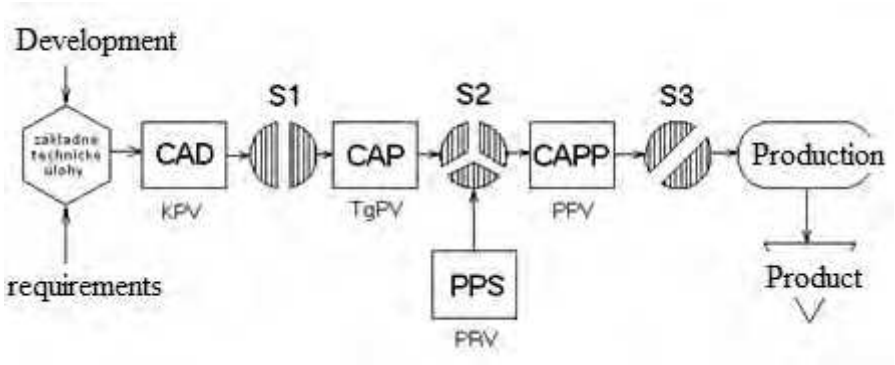
During the creation of technical documentation, is found a large number of routine activities and the calculations, searching, grouping, sorting data, and much smaller amount of intellectual activity. It means that most of the documentation is build up on the basis of known and precise algorithms (based on pre-known technological rules and regularities obtained by exact methods and many years of practice). Selection of right technology is based on the various data that can provide manufacturing drawings, as well as the specific conditions of production. Results of the decision are built to a certain sequence of commands that should guarantee the most beneficial method of producing parts under its specific conditions.

2 Technical Preparation of Production (TPP)

Progressivity of automation in engineering works is striking not only in sphere of preparation (reduction in labor content within technological preparation, reducing the number of engineering staff), but of course also in the sphere of production (cost reduction, increase labor productivity). By automatization of engineering calculations it needs to be included sophisticated methods to achieve correct results.

Variation of automation resources for engineering sphere is very wide. It covers the entire spectrum of engineering activities required for design, planning and construction - technological tasks.

Fig. 1 shows the simplified model of production preparation with the support of



Sl. 1. Skica priprav na proizvodnjo

Fig. 1. Scheme of production preparation

računalniško tehnologijo; na modelu so označene točke sodelovanja (S1, S2, S3) v okviru posameznih modulov (priprava na zasnovo proizvodnje – KPV, tehnološka priprava proizvodnje – TgPV, proizvodnja na podlagi projektnih priprav – PPV, načrtovanje in kontrola proizvodnje – RDP), ki temeljijo temeljnem načelu CIM (Computer Integrated Manufacturing – računalniško podprta proizvodnja).

Takšna integracija je pomanjkljiva na področju nerezalnih tehnologij. Sistemi CA se uporabljajo zgolj v omejenem obsegu. Izjemo predstavlja integracija CAD in simulacijskih programov.

computer technology, where are marked mutual cooperation nodes (S1, S2, S3) of individual modules (design production preparation - KPV, technological preparation of production - TgPV, project preparation manufacturing - PPV, production planning and control - RDP), which is based on the basic philosophy of CIM (Computer Integrated Manufacturing - Computer Aided Manufacturing).

In the non-cutting technologies such integration is lacking. There are only a discreet use of˝CA systems. An exception is the integration of CAD and simulation programs.

2.1 Sistemi CAD

Računalniško vodeni sistemi podpirajo inženirska dela, povezana s pripravo proizvodnje. V podjetjih, v katerih se osredotočajo na proizvodnjo sestavnih delov skozi nerezalne tehnologije, se običajno uporabljajo konvencionalni sistemi CAD, takšni sistemi pa se uporabljajo tudi v obratih, kjer proizvajajo strojno obdelane dele.

Obstaja veliko število sistemov CAD. Vzrok za umestitev teh sistemov

2.1 CAD Systems

Computer aided systems supporting engineering design works for the production preparation. In companies focused to produce components by non-cutting technologies are generally used conventional CAD systems which are used also by companies for focused on production of machined parts.

There is a large number of CAD systems. The reason for placing these systems into production is their direct support by the

v proizvodnjo je dejstvo, da jih podpira neposredno livarska simulacijska programska oprema (Unigraphic → MAGMAsoft, PRO / Engineer → WinCast) ali pa je mogoča njihova neposredna uporaba v praksi (CATIA). Vsi ti sistemi so v celoti asociativni, sprememba v vsaki razvojni stopnji pa vodi do spremembe vseh povezanih podatkov in parametrov.

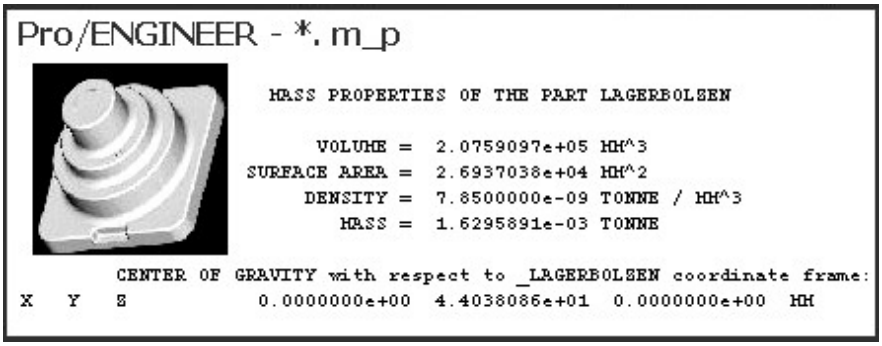
Sisteme CAD je mogoče uporabljati na tudi manj ustaljene načine, npr. znotraj sistema AutoCAD se nahaja posebno okolje za programeranje VisualLIST, ki omogoča enostavno delo s programskim jezikom AutoLISP, ki je namenjen avtomatizaciji nalog opredeljene tehnične zasnove na podlagi preprostih funkcij (izračun dovajalnega sistema, napajalnikov itd.). Za opisovanje kompleksnosti oblike je mogoče uporabiti tudi posebne datoteke, ki jih ustvarijo sistemi CAD (npr. *. Mpr, *. M_p - Sl. 2.), in sicer ustvarijo klasifikacijo tehnologije skupine, ki se shrani v zbirko podatkov o ulitkih za nadaljnjo uporabo v zasnovi tehnoloških procesov.

Vendar pa je treba pomniti, da kompleksnost oblike ni vedno neposredno sorazmerna s kompleksnostjo proizvodnje in da je v vseh okoliščinah ni mogoče natančno opisati.

foundry simulation programs (Unigraphic → MAGMAsoft, PRO / Engineer → WinCast), or their practical use (CATIA). All of these systems are fully associative and change at each stage of development results in a change of all related data and parameters.

It is possible to use CAD systems also in a less conventional manner, for example. Within the AutoCAD's system is located in a special programming environment Visual LISP enabling comfortable working with Auto LISP programming language where possible using simple functions to automate tasks solved in a listed technical design (calculation of gating system, risers, etc.). You can also use special files created by CAD systems (eg *. Mpr, *. M_p - Fig.2.) to describe the shape complexity in creating the classifications of group technology then saving to the castings database for further use in the design of the technological process.

It should be noted, however, that the shape complexity is not always directly proportional to the complexity of the production and it cannot be in all situations exactly describable.



Sl. 2. Prikaz informacij v povezavi z maso in površino

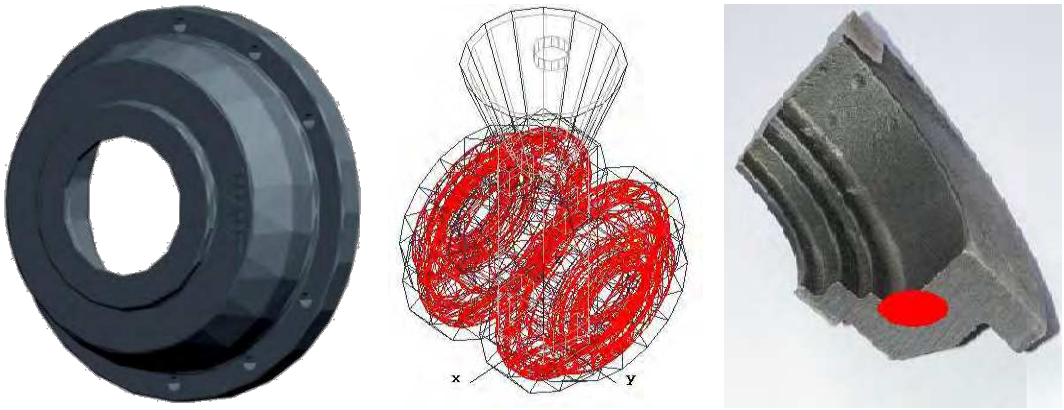
Fig. 2. Listing information related to the mass and surface

2.2 Sistemi CAE

To so sistemi, ki podpirajo virtualizacijo tehnoloških procesov (računalniške simulacije). V računalniški simulaciji se prikažejo pojavi, ki potečejo v dovajalnem sistemu in v formi med polnjenjem s staljeno kovino in med strjevanjem. To omogoča spremljanje ne samo polnjenja forme, ampak tudi strjevanje in ohlajanje celotnega sistema. Uporaba računalniške simulacije je ključnega pomena za časa in stroškov, potrebnih za razvoj novih proizvodnih tehnologij, izboljšanje tehnoloških, kakovostnih in cenovnih parametrov livarske proizvodnje kot tudi znatno znižanje finančnih potreb v povezavi z upravljanjem dobav kot tudi izobraževanjem livarskih delavcev, ki lahko globlje spoznajo pojave, ki potekajo v formi med litjem in med strjevanjem. Računalniške simulacije litja zagotavljajo skoraj vse informacije, potrebne za optimizacijo dovajalnih sistemov kot tudi celotnega postopka litja in strjevanja. Optimizacija dovajalnih sistemov z računalniško simulacijo temelji na primerjavi različic dovajalnih sistemov. Primerjava zajema stroške, prednosti,

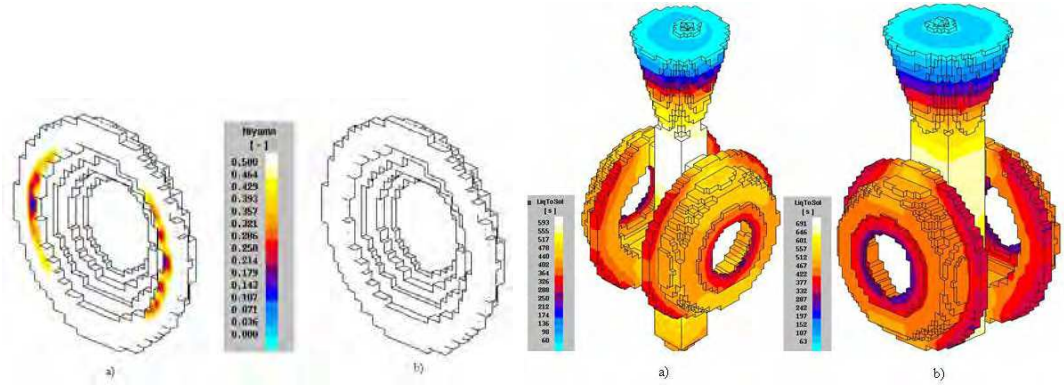
2.2 CAE Systems

These are systems that support virtualization of technology processes (computer simulation). In a computer simulation there are visible phenomena taking place in the gating system and the casting mold during filling by molten metal and during its solidification. I tis possible to monitor not only the filling of the mold, but also solidification and cooling of the whole system. The advantages of using computer simulation is essential to reduce the time and financial costs for the development of new product technologies, increasing the technical, quality and price parameters of foundry production with a substantial reduction on financial demands - supply management and also with education of foundry workers so they can deeper understand of the phenomena that take place in mold during the pouring and solidification. Computer simulation of casting gives almost all the information needed to optimize the gating system and the whole process of casting and solidification. Gating system optimization using computer simulation is based on a comparison of different variants



Sl. 3. Lit pokrov: a) 3D-model, b) model oboda, c) mikro porozna površina

Fig. 3. Casted cover: a) 3D model, b) model of the shell, c) the area of micro porosity



Sl. 4. Rezultati izračunov simulacije: a) začetna zasnova, b) spremenjena zasnova

Fig. 4. Results of the simulation calculation: a) initial design, b) modified design

pretok kovine, metalurško strukturo itd. Na Sl. 3 je prikazan lit pokrov iz ogljikovega jekla. V prvotno predlagani strukturi je presečna mikro poroznost, ki so jo potrdili simulacijski izračuni. S spremembo dimenzij dovajalnega sistema se zagotovijo boljši pogoji v povezavi z mikro poroznostjo, kar je bilo potrjeno tudi s simulacijskimi izračuni. Na Sl. 4 so prikazani rezultati izračunov simulacije z namenom optimizacije.

2.3 Sistemi CAPP

To so sistemi, ki temeljijo na načelu klasifikacije komponent na podlagi vrste kot tudi tehnologije, ki se uporablja za sistematično proizvodnjo.

Proizvodna oprema v nekem podjetju določa razpon proizvedenih delov; z njo se proizvajajo komponente, ki jih je mogoče razvrstiti v skupine podobnih delov. Razvrščanje delov je mogoče izvesti na podlagi različnih meril (npr. z vidika geometrije, materiala, tehnologije itd.). Vsaka skupina ima svojega predstavnika kot tudi ustrezen tehnološki proces.

of gating systems. Comparing takes into account price, advantages, flow of metal, metallurgical structure, etc... At figure 3 is presented cast lid made of carbon steel. In the originally proposed structure is a cross-sectional micro porosity, which was confirmed by the simulation calculations. By changing the dimensions of the gating system was achieved better micro porosity conditions, which was also confirmed by simulation calculations. Figure 4 presents the results of simulation calculations of the optimization.

2.3 CAPP systems

These are systems based on the principle of classifying objects of type and group technology in which it is processed methodical process solutions.

Manufacturing equipment available in a company determine the spectrum of the produced parts, is likely to produce components that can be classified into groups, in which components are similar. Sorting of parts can be carried out according to different criteria (in terms of geometry, material, technology, etc...). Each group has

Sistemi CAPP omogočajo izboljšanje učinkovitosti in tehnološke pripravljenosti skozi:

- standardizacijo tehnologij,
- uporaba dedovanja in podobnosti delov v proizvodni tehnologiji,
- računalniško pomoč pri pripravi zasnove seznama materialov za proizvodnjo.

Sistem SYSKLASS spada med najbolj znane sisteme CAPP na Slovaškem in Češkem. Sistem omogoča izvedbo dejavnosti od zasnove in razvoja komponent v sklopu oblikovalskih in tehnoloških priprav pa vse do izbire optimalnih orodij. Sistem ASEPO (zbirka avtomatiziranih tehnoloških postopkov) je modularni integrirani sistem, ki deluje na podlagi grafične podpore ter uporablja podatke iz zbirk tehnoloških podatkov in znanja. Sirius TPV je del integriranega informacijskega sistema SAFIT, zasnovanega za upravljanje proizvodnje. Zaradi kompleksnosti je primeren za uporabo pri proizvodnji majhnih serij.

2.4 Sistemi GCAPP

Generativni sistemi CAPP (GCAPP) so mnogo bolj kompleksni od sistemov CAPP in delujejo po načelu skupinske tehnologije. Priprava na načrtovanje tehnološkega procesa je za inženirje zahtevna naloga. Inženir oblikuje »dober« proizvodni postopek na podlagi lastnih miselnih procesov. Te človeške miselne procese pa je zelo težko prevesti v algoritmi. Računalniški sistem bi lahko tehnološki proces oblikoval in sestavil na podoben način, vendar bi bilo treba podrobno opisati vse dejavnosti, ki jih mora izvesti inženir. Še posebej zahtevna je implementacija takšnih sistemov s strani programerjev. V primerjavi z drugačno različico sistemov, imenovanih its representative and the corresponding technological process.

CAPP systems implemented to increase the level of efficiency and technological preparation of production by:

- use technological standardization,
- use of inheritance and similarity of parts of their production technology,
- allow computer aiding to the preparation of design through manufacturing Bills of materials.

Among the most famous CAPP system in Slovakia and the Czech Republic belongs SYSKLASS. This system implements activities from design development components through design and technological preparation, as well as choosing the optimal tools. The system ASEPO (compilation of Automation of technological procedures) is a modular integrated system working with graphical support and exploiting technological database and knowledge. Sirius TPV is a part of an integrated information system SAFÍR designed to manage production. Due to its complexity it is suitable for use in a small batch production.

2.4 GCAPP Systems

Generative CAPP systems (GCAPP) are much more complex than CAPP systems operating on the principle of group technology. The preparation of the technological process planning is a challenging engineering task. Engineer design “good” production process by his own thoughts. These human thought processes are very difficult to put into algorithms. The computerized system could similarly design and compile technological process, but it is necessary to thoroughly describe all activities undertaken by

CAPP, pa uporaba teh sistemov ni prav močno razširjena. Zaradi kompleksnosti in obsežnosti se običajno uporabljajo za eno vrsto dela. Generativni sistemi CAPP, ki temeljijo na analizi podatkov CAD, pa so zmožni oblikovanja tehnoloških procesov.

2.5 Informacijski sistemi

Edini informacijski sistem, primeren za sisteme v livarnah, se imenuje OPTI. Osredotoča se predvsem na načrtovanje, upravljanje in izračun stroškov v podjetjih, njegova uporaba v zasnovi in podpori zasnove tehnologij pa je razmeroma omejena. Analitski sistem temelji na dveh osnovnih virih:

- Sklice DGV do izračun cen ulitka (uporablja se za določanje prodajne cene)
- Iz materialov REFA (vključno z metodo opisovanja ulitka za zagotavljanje podatkov o proizvodnji in dobavi za izračunavanje lastnih stroškov).

Uporabo programske opreme OPTI je mogoče razdeliti na naslednja področja:

Za namene upravljanja materialov obsega programska oprema rešitev za operativne službe, kot so prodaja, nabava in skladiščenje. Tako zagotavlja celovit sistem, primeren za organizacijo poslovanja.

Programska oprema TPP predstavlja celovito rešitev za podjetja na področju izračunavanja stroškov, priprave dela – tehnologije, obvladovanje kakovosti in registracija orodij.

Na področju načrtovanja proizvodnje je programska oprema zasnovana tako, da dogovorjena proizvodnja ustvarja podatke, potrebne za načrtovanje proizvodnje na področju TPP, ti podatki pa so nato na voljo za nadaljnjo obdelavo skladno s proizvodnim nalogom.

the engineer. Systems of this kind are very difficult in terms of programmer's implementation. Compared with the variant CAPP systems they have not found widespread use. Because of its complexity and extensiveness are mostly dedicated to one type of part. Generative CAPP systems based on the analysis of CAD data are able to generate technological process.

2.5 Information Systems

The only information system intended for foundries system is OPTI. It focuses mainly on planning, management and costing activities in companies, its use in the design or support the design of technology is rather limited. The analysis system is based on two basic sources:

- Referrals from DGV to the price calculation of the casting (used to determine the selling price)
- from materials REFA (includes methodology of casting description to provide information for the production and supply data to calculate their own costs).

Use of OPTI can be divided into the following areas:

For the materials management, software includes solution for operational areas such as Sales, Purchasing and Warehouse. Thus, offering a complete system for business organizations.

In the TPP software represents a complete solution for the companies in areas such as costing, work preparation - technology, quality management and tool registration.

In the field of production scheduling is software designed so that in the given production contract is generating data needed for production planning in the field

3 Ustvarjanje sistema CAPP

Sistema CAPP za nerezalne tehnologije ni mogoče ustvariti z uporabo klasične metode izbire predstavnika iz zbirke podatkov, zato smo na našem oddelku zasnovali sistem CAPP na podlagi koncepta tehnoloških skupin z dinamičnim sistemom za razvrščanje. V tem sistemu poteka razvrščanje ulitkov na podlagi naslednjih parametrov:

- tehnologija,
- material,
- geometrija ulitka.

Optimalna izbira proizvodnih metod predstavlja enega najpomembnejših dejavnikov pri razvrščanju ulitkov, kajti vsi parametri so odvisni od izbrane tehnologije litja (natančnost, velikost, funkcija, zahteve glede ekonomičnosti).

Še en parameter je razvrstitev na podlagi oblike ulitka. V programski opremi je uporablja razvrstitev na podlagi zbornika POPV 21-01-01. Ta zbornik se na obliko sklicuje s pomočjo številke, sestavljene iz treh števk. Glavni namen števk je opisan

of TPP, which are then available for further processing according to the production order.

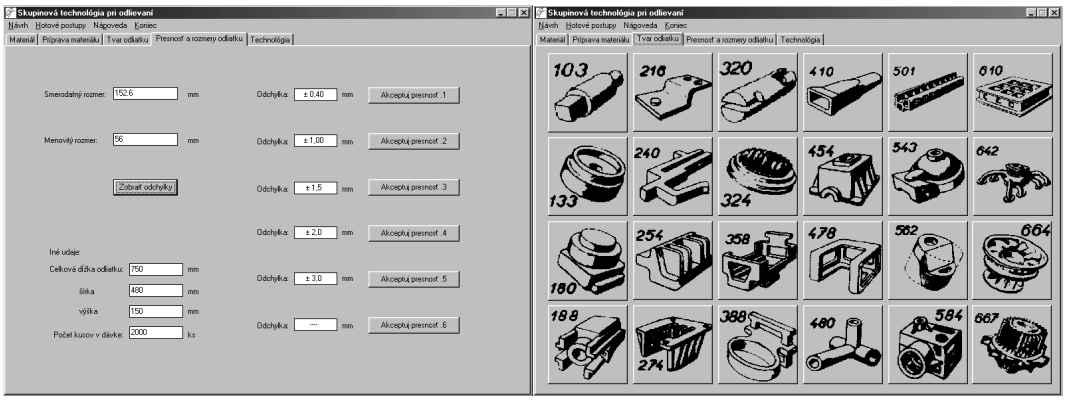
3 Creating the CAPP System

It is not appropriate to use the classical method of selecting representative from the database when creating CAPP system for non-cutting technology, so in our department was designed CAPP system based on the idea of group technology with dynamic sorting system. In this system, the sorting of castings according to the parameters:

- technology
- material
- geometry of the casting.

Optimal selection of production method is among the most important factors for the classification of castings since all parameters are dependent on chosen technology (accuracy, size, function, economic demands) cast.

Another parameter is the categorization based on the shape of the castings. In the



Sl. 5. Ustvarjeno okolje za razvrščanje livnih tehnologij na podlagi natančnosti, dimenzij in oblike ulitka

Fig. 5. The created environment for sorting the casting technology by precision, dimensions and shape of the casting

v spletni aplikaciji za pomoč ali v samem zborniku. Zaradi velikega števila oblik je v spletni aplikaciji za pomoč navedenih zgolj nekaj primerov.

Razvrstitev sistema materialov obsega:
- železne,
- jeklene ulitke,
- neželezne kovinske zlitine.

Sistem vsebuje zbirko podatkov z informacijami o mehanskih lastnostih, uporabi materialov in postopkov za pripravo taline s pravilno sestavo in temperaturo.

Glavni cilj predlagane rešitve je zagotoviti interoperabilnost sistemov ter možnost uporabe koncepta sočasnega inženirstva.

4 Sklepi

Kljub temu, da živimo v digitalni dobi, je obilo (praktičnega) znanja še vedno shranjenega v glavah zaposlenih (odhod delavca torej za podjetje pomeni izgubo znanja).

Znanje je v nekem obsegu mogoče najti v dokumentaciji, vendar takšna v papirnati obliki rahlo prevladuje nad digitalnimi. Še vedno predstavlja najmanjši delež znanja, shranjenega v zbirkah znanja, namen katerih je omogočanje učinkovitega rokovanja z znanjem v prihodnje.

Glavni namen tehnoloških priprav je sestava tehnične dokumentacije za novo proizvedene sestavne dele. Predlagane rešitve je mogoče zasnovati na v interaktivnem načinu, v katerem lahko tehnolog s pomočjo računalnika zagotovi optimalne rezultate. Cilj je sestaviti okvir tehnoloških postopkov v digitalni obliki. Prvi korak je preverjanje predloga s pomočjo programske opreme za simulacije ter iskanje ključnih točk, čemur sledi začetek proizvodnje novih sestavnih delov z litjem.

software is used categorization based on anthology POPV 21-01-01. This anthology refers to the shape with the help of a three-digit number. The main purpose of all digits is described in online help or the anthology itself. Since there is a large number of shapes, in the program online help is used only a few examples.

Classification system for material includes:
- iron
- steel castings
- non-ferrous metal alloys

The system contains a database of information about the mechanical properties, the use of the material and method of preparing a melt of the correct composition and temperature.

The main goal of the proposed solution is the interoperability of the systems and the possibility of using the idea of simultaneous engineering.

4 Conclusion

Despite the digital age, nowadays is still a large amount of information (know-how) stored in the heads and minds of employees (employee departure means the loss of knowledge within the company).

The specific amount of knowledge is contained in the documentation, but most likely the paper form slightly outweighs digital form. It is still the lowest percentage of knowledge stored in the knowledge database systems enabling their efficient processing in future.

The main purpose of technological preparation is the creation of technical documentation for newly produced components. The proposed solutions can be designed in interactive mode between technologists and computer to achieve

Zahvale

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optimal results. The aim is to compile a framework of technological processes in digital form. The first step is to verify this proposal by using simulation software and find critical points before beginning production of new components by casting.

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M. KAMBIČ[1], F. CECCHETTO[2], P. GRUBELNIK[1]

[1]Olma d.o.o. (SI), [2]MotulTech-Baraldi (I)

Nekateri vidiki in izzivi mazanja livarskega bata z oljem

Some Aspects and Challenges of Lubricating the Foundry Piston with Oil

Povzetek

Mazanje bata na visokotlačnih livarskih strojih je vedno predstavljalo svojevrsten izziv. Za zagotavljanje zadostnega mazanja in doseganje dovolj visokega števila ciklov pred zamenjavo livarskega bata in livne komore je treba dodati zadostno količino maziva. Del maziva v fazi polnjenja komore odgori, del maziva pa prehaja v talino in jo tako kontaminira s produkti zgorevanja. Pri gorenju maziva nastajajo plini in nekateri trdi ostanki zgorevanja, kar povečuje plinsko poroznost odlitkov in nekovinske črne vključke.

Del maziva, ki med polnjenjem livne komore s talino zgori, povzroča neželen plamen ter emisijo strupenega in rakotvornega dima v okolici livarskega stroja.

Nekatera sintetična olja nudijo bistveno boljše mazanje, zato se potreba po vnosu maziva bistveno manjša.

Z boljšimi mazalnimi lastnostmi se poveča število ciklov, ki jih lahko izvedemo z enim batom, podaljša se tudi življenjska doba livne komore. Z daljšanjem uporabne dobe bata in livne komore ter s skrajšanjem zastojev zaradi zamenjav bata se znižajo stroški proizvodnje, hkrati pa se poveča razpoložljivost stroja.

Nekatere vrste sintetičnih maziv so formulirane tako, da pri visokih temperaturah razpadejo na nestrupene komponente, ki odparijo brez ostankov. Glavni poudarek prispevka bo zato na uporabi sintetičnih olj brez grafita. Z določenimi sintetičnimi olji opazno znižamo poroznost odlitkov, odpravimo del vključkov, ki so ostanki zgorevanja maziva in bistveno zmanjšamo plamen. Z odpravo dima, ki nastaja pri zgorevanju klasičnih maziv, preprečimo emisijo strupenih in rakotvornih plinov ter tako naredimo okolico stroja varnejšo in čistejšo.

Ključne besede: tlačno litje, livarski stroj, mazanje bata, sintetično olje

Summary

Lubricating the piston on high-pressure casting machines has always been a unique challenge. A sufficient amount of lubricant has to be added to ensure sufficient lubrication and to achieve an acceptably high number of cycles of the foundry piston and shot chamber. Part of the lubricant burns out during the filling phase of the sleeve, and part of the lubricant passes into the melt and thus contaminates it with the combustion products. When lubricant burns, gases and some solid combustion residues occur which increases the gas porosity of the castings and non-metallic black inclusions.

The part of the lubricant that burns during the filling of the shot sleeve with the melt causes an unwanted flame and the emission of toxic and carcinogenic smoke around a casting machine.

Some synthetic oils offer significantly better lubrication, as the amount of oil needed is significantly reduced.

With better lubricating properties, the number of cycles that can be performed with one piston is increased, and the lifetime of the shot chamber is also extended. By extending

the lifetime of the piston and shot chamber and shortening the downtime due to piston replacements, production costs are also reduced.

Some types of synthetic lubricants are formulated to decompose at high temperatures into non-toxic components that evaporate without residue. The main focus of the article will therefore be on the use of synthetic oils without graphite. With certain synthetic oils, we noticeably reduce the porosity of the castings, eliminate some of the inclusions as residues of lubricant combustion, and significantly reduce the flame. By eliminating the smoke generated by the combustion of classical lubricants, we prevent the emission of toxic and carcinogenic gases thus making the surroundings of the machine safer and cleaner.

Key words: high pressure die casting, casting machine, piston lubrication, synthetic oil

1 Sredstva za mazanje batov

Za mazanje batov obstajajo različna sredstva:

1. Trdna maziva
- Praški
- Peleti oziroma granulati
- Masti

Praški so prah naravnih ali sintetičnih voskov z dodanimi aditivi. Njihova barva je od bele do črne (vsebnost grafita). V raztaljenem stanju imajo visoko viskoznost, kar omogoča dobro mazanje bata in livne komore. Vedno se uporabljajo za mazanje v livno komoro.

Prednosti praškov:
- Zelo dobro mazanje in zaščita bata pred obrabo.
- Lahko izboljšajo tečenje taline v kanalih in orodju, kar izboljša kakovost ulitkov.

Omejitve praškov so:
- Povzročajo zelo velik plamen (nevarnost požara)
- Obilno dimljenje pri uporabi.
- Prah slabo teče, rad se zleplja in maši transportne kanale na napravi za doziranje.
- Praški povzročajo nečistost ulitkov in obloge na orodju.

Peleti ali granulati so enake sestave kot praški. Od praškov se razlikujejo samo

1 Piston lubrication agents

There are different agents to lubricate the piston:

1. Solid lubricants
- Powder
- Pellets or granules
- Greases

Powders are powdered natural or synthetic waxes with added additives. Their colour is white to black (graphite content). They have a high viscosity in a molten state, allowing good lubrication of the piston and the shot chamber. They are always used for lubrication in the shot chamber.

Benefits of powders:
- Very good lubrication and protection of the piston from wear.
- Can improve the melt flow in the channels and tools, which improves the quality of castings.

The limitations of powders are:
- Cause very high flame (fire hazard)
- Significant smoking when used.
- The powder flowing poorly, often bonding and blocking transport channels on the dosing device.
- Powders cause impurity to castings and linings on the tool.

Pellets or granules are made up of the same composition as powders. They

v fizični obliki. Njihove prednosti in slabosti so enake kot pri praških. Razlika (prednost) je, da se ne zlepljajo kot praški.

2. Maziva, ki jih mešamo z vodo
- Emulzije mineralnih in delno sintetičnih olj
- Emulzije sintetičnih olj

Emulzije mineralnih ali delno sintetičnih olj so mlečne emulzije olj visoke viskoznosti z dodanimi aditivi. Podobno je pri emulzijah sintetičnih olj, le da so olja popolnoma sintetična.

Prednost te skupine so:
- dobre hladilne lastnosti,
- pogosto (ne vedno) združljivost z ločilnimi sredstvi,
- pogosto nižja cena kot pri drugih vrstah maziv za bate.

Omejitve in pomanjkljivosti te skupine pa so:
- sredstva niso primerna za zahtevne primere uporabe,
- primerna so samo za manjše premere batov, maksimalno do 80 mm, kar pa je odvisno tudi od kvalitete maziva in količine nanosa,
- treba jih je uporabljati previdno. V primeru, da raztaljen aluminij pride v stik z vodo, lahko pride do izmeta taline v okolico stroja. Zato jih moramo nanašati zunaj livne komore. To je tudi razlog, da niso širše prisotna na tržišču.

3. Olja za mazanje batov:
- Olja na mineralni ali delno sintetični osnovi
- Olja na rastlinski osnovi
- Sintetična olja

Mineralna in delno sintetična olja imajo visoko viskoznost in so značilno rjavkaste barve. Dodani so jim aditivi za izboljšanje oprijemljivosti, za povišanje indeksa viskoznosti in izboljšanje nekaterih drugih

differ from powders only in physical form. Their advantages and disadvantages are the same as in powders. The difference (advantage) is that they do not bond like powders.

2. Lubricants mixed with water
- Emulsions of mineral and partly synthetic oils
- Emulsions of synthetic oils

Emulsions of mineral or semi synthetic oils are milk emulsions of high viscosity oils with added additives. This is similar to emulsions of synthetic oils, except that the oils are completely synthetic.

The advantages of this group are:
- Good cooling properties.
- Frequent (not always) compatibility with release agents.
- Often lower price than other types of piston lubricants.

However, the limitations and disadvantages of this group are:
- Not suitable for demanding applications.
- Only suitable for smaller piston diameters up to a maximum of 80 mm, depending also on the quality of the lubricant and the amount of application.
- Should be used with caution. When molten aluminium comes into contact with water, it may eject the melt into the surroundings of the machine. Therefore, they must be applied outside the shot chamber. This is also why they are not widely present on the market.

3. Piston lubrication oils:
- Mineral-based or semi-synthetic-based oils
- Vegetable-based oil
- Synthetic oils

Mineral-based or semi-synthetic-based oils have a high viscosity and are characterised by brownish colours. Additives

lastnosti. Na razpolago so v različnih viskoznostih od 300 mm^2/s do 1.000 mm^2/s z namenom zmanjšanja kapljanja in lažjega nanosa. V različnih obdobjih leta moramo uporabiti različne viskoznosti olja. (višja viskoznost poleti, nižja viskoznost pozimi).

Prednosti mineralnih in delno sintetičnih olj so:
- Dobro mazanjem in sposobnost zaščite bata pred obrabo
- Obilo izkušenj zaradi razširjenosti in dolgoletne prisotnosti na tržišču.
- Možnost izboljšanja osnovnih lastnosti z dodajanje trdnih maziv, na primer grafita.
- Lahko jih uporabimo za mazanje v ali zunaj livne komore.

Omejitve in pomanjkljivosti te skupine so:
- Nezdružljivost z ločilnimi sredstvi
- Povzročajo velik plamen, še zlasti, če jih uporabimo za mazanje v livno komoro.
- Pri zgorevanju nastajajo strupeni in kancerogeni plini.
- Manj »čista« kot sredstva, ki jih mešamo z vodo in kot sintetična olja, zato je v primeru njihove uporabe okolica stroja zelo zamaščena.

Rastlinska olja so rumenkasta in se uporabljajo aditivirana ali pa brez aditivov. Imajo visok indeks viskoznosti in dobre mazalne lastnosti. Pri termični razgradnji tvorijo značilen vonj po cvrtju in škodljive snovi (acrolein), ki so kancerogene.

Sintetična olja so bistre tekočine na osnovi sintetičnih tekočin in aditivov, ki izboljšajo oprijem, preprečujejo obrabo in izboljšujejo druge lastnosti. Imajo višji indeks viskoznosti kot mineralna olja, zato jih običajno ni treba menjati v različnih obdobjih leta.

Njihove prednosti so:
- Zelo dobro mazanje in zaščita bata pred obrabo.

have been added to improve adhesion, to increase the viscosity index and to improve certain other properties. They are available in different viscosities from 300 mm^2/s to 1,000 mm^2/s in order to reduce dripping and simplify the application. During different periods of the year, different viscosity oils must be used (higher viscosity in summer, lower viscosity in winter).

The advantages of mineral-based and semi-synthetic-based oils are:
- Good lubrication and the ability to protect the piston from wear.
- Significant experience due to its prevalence and longstanding presence on the market.
- The possibility of improving the basic properties by adding solid lubricants, such as graphite.
- Can be used for lubrication inside or outside the shot chamber.

The limitations and disadvantages of this group are:
- Incompatibility with release agents.
- Cause a large flame, especially when used for lubrication in the shot chamber.
- Toxic and carcinogenic gases are generated during combustion.
- Less “pure” than those mixed with water and synthetic-based oils, so when used, the surroundings of the machine are very greasy.

Vegetable-based oils are yellowish and are used with or without additives. They have a high viscosity index and good lubricating properties. In thermal decomposition, they form a characteristic smell of frying and harmful substances (acrolein) that are carcinogenic.

Synthetic-based oils are clear liquids based on synthetic liquids and additives that improve traction, prevent wear and improve other properties. They have a higher viscosity index than mineral-based oils, so

- Izredno visok indeks viskoznosti (slika 1)
- Nekatere vrste zagotavljajo visoko zmogljivost in so primerne za doziranje v zelo majhnih količinah.
- Lahko jih dodatno izboljšamo z dodatkom posebnih aditivov, ki jih običajno ne moremo dodajati v mineralna olja.
- Lahko jih uporabimo za mazanje zunaj ali v livno komoro (kapljično ali s pršenjem).
- Ne povzročajo dima.
- Povzročajo manj poroznosti.
- Ne povzročajo črnih nekovinskih vključkov.
- So biološko razgradljiva.

Omejitve sintetičnih olj so:

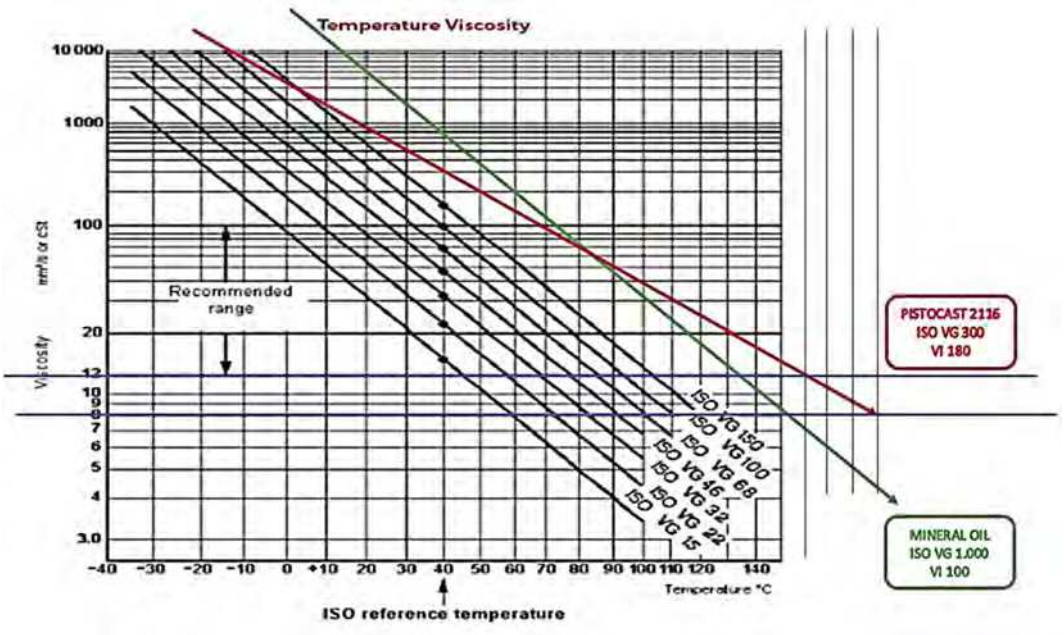
- Nezdružljivost z ločilnimi sredstvi.
- V primeru mazanja v livno komoro povzročajo plamen, ki pa je veliko

they usually do not need to be changed at different times of the year.

Their benefits are:

- Very good lubrication and protection of the piston from wear.
- Ultra-high viscosity index (Figure 1).
- Some types provide high performance and are suitable for dosing in very small amounts.
- Can be further improved by adding special additives that usually cannot be added to mineral-based oils.
- They can be used for lubrication outside or in the shot chamber (drip or spray).
- Do not cause smoke.
- Cause less porosity.
- Do not cause black non-metallic inclusions.
- Are biodegradable.

The limitations of synthetic-based oils are:



Slika 1. Vpliv indeksa viskoznosti olja na viskoznost pri visoki temperaturi

Figure 1. Effect of the oil viscosity index on the viscosity at high temperature

manjši kot pri mineralnih ali delno sintetičnih oljih ter trdnih mazivih.
- Nabavna cena na kg/L je višja od drugih maziv vendar je strošek uporabe nižji.

Sintetična olja zaradi svojih prednosti v zadnjem obdobju pospešeno nadomeščajo mineralna olja in trdna maziva.

2 Doziranje olj za mazanje batov

Sredstva za mazanje batov lahko doziramo v livno komoro ali na bat zunaj livne komore. Zaradi velikega odgora pri mazanju v komoro je v tem primeru potrebno dozirati bistveno večjo količino maziva (dvakrat do trikrat več) kot pri mazanju na bat zunaj komore. Zaradi prednosti olj pred trdnimi mazivi (predvsem možnost mazanja batov zunaj livne komore) se za mazanje batov vedno bolj pogosto uporabljajo olja. V nadaljevanju se bomo zato osredotočili na doziranje olj.

V uporabi sta dva sistema za doziranje olja. Starejši sistem deluje na principu nastavitve časa doziranja, novejši pa na principu nastavitve volumna olja. Prednost naprav, ki delujejo po prvem principu je nižja cena, prednost naprav z volumetričnim doziranjem pa je natančna količina doziranja neodvisno od temperature okolice in viskoznosti olja. Zaradi natančnega in ponovljivega volumna (pri vsakem udarcu) naprave z volumetričnim doziranjem, je poraba olja bistveno manjša, kot pri doziranju z napravo s časovno nastavitvijo. Primer naprave z volumetričnim doziranjem je prikazan na sliki 2.

3 Primeri iz prakse

Primer 1: Uporaba na stroju z večjim premerom bata (130 mm)

Zamenjava načina mazanja bata: granulat → sintetično olje brez grafita

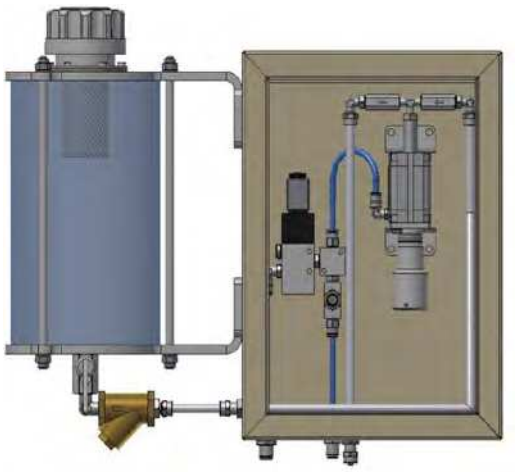
- Incompatibility with release agents.
- They cause a flame in case of lubrication in the shot chamber, but the flame is much smaller than that of mineral-based or semi-synthetic-based oils and solid lubricants.
- The purchase price per kg/l is higher than other lubricants but the cost of use is lower.

Recently, due to their advantages, synthetic-based oils have been rapidly replacing mineral-based oils and solid lubricants.

2 Dosing of piston lubrication oils

Piston lubrication agents can be dosed in the shot chamber or on the piston outside the shot chamber. Due to the large burn-out in lubricating in the chamber, a significantly higher quantity of lubricant (two to three times more) must be dosed than when lubricated on a piston outside the chamber. Due to the advantages of oils compared to solid lubricants (especially the possibility of lubricating pistons outside the shot chamber), the oils are increasingly used to lubricate the pistons. Below, we will therefore focus on oil dosing.

There are two oil dosing systems in use. The older system works on the principle of setting the dosing time, and the newer one on the principle of adjusting the oil volume. The advantage of devices operating based on the first principle is lower price, and the advantage of devices with volumetric dosing is the precise amount of dosing independent of ambient temperature and oil viscosity. Due to the precise and repeatable volume (at every impact) of the device with volumetric dosing, the oil consumption is significantly lower than when dosed with setting the time. An example of a device with volumetric dosing is shown in Figure 2.



Slika 2. Mazalna naprava z volumetričnim doziranjem

Figure 2. Lubricating device with volumetric dosing

Robni pogoji so navedeni v preglednici 1, mazanje pa prikazuje slika 3.

Ugotovljene prednosti pri zamenjavi granulata s sintetičnim oljem so bile:

- minimalen plamen,
- brez dima,

3 Practical Examples

Case 1: Use on a machine with a larger piston diameter (130 mm)

Replacing piston lubrication agent: granulate → synthetic oil without graphite.

Preglednica 1. Robni pogoji na stroju Bühler Carat 160

Table 1. The boundary conditions on Bühler Carat 160 machine

Stroj / Machine:	BUHLER Carat 160
Premer bata / Piston diameter:	130 mm
Delovni gib bata / Piston working stroke:	600 mm
Hitrost bata v 2' fazi / Piston speed in 2' phase	3,96 m/s
Temperature bata / Piston temperature	90 °C
Masa taline / Melt weight	8,4 kg
Zlitina / Alloy	DIN 223
Dnevno število ciklov / Daily number of cycles	1.100
Predhodno v uporabi / Previously in use	
Mazalno sredstvo za bat / Piston lubricant	granulat / granulate
Mesto doziranja / Dosing point	v livno komoro / in the shot chamber
Poraba granulata / Granulate consumption	4,1 g/udarec / g/stroke
V uporabi zdaj / Now in use	BARALDI PISTOCAST 2116
Mesto doziranja / Dosing point	v livno komoro / in the shot chamber
poraba sintetičnega olja / Synthetic-based oil consumption	1.2 g/udarec / g/stroke

Slika 3. Premer bata 130 mm: doziranje v livno komoro

Figure 3. Piston diameter 130 mm: dosing in shot chamber

- znižana poroznost odlitka,
- odlitek brez črnih vključkov,
- kakovostnejša površina odlitka,
- znižanje izmeta,
- podaljšana uporabna doba bata (iz 4.800 na 8.600 udarcev)
- znižanje stroškov proizvodnje (poraba bata, zastoj za zamenjavo bata, nižji izmet, višja produktivnost)
- izboljšanje kakovosti zraka v proizvodni hali (brez dima, brez strupenih plinov)

Neposredni prihranki stroškov maziva za mazanja bata pa so bili:

Strošek prej uporabljanega izdelka- strošek zdaj uporabljanega izdelka na 1000 kosov

16,40 € – 6,00 € = 10,40 €/1.000 kosov
11,28 €/dan/stroj = 3.720 €/leto/stroj (upoštevanih 330 delovnih dni).

The boundary conditions are given in Table 1 and the lubrication is shown in Figure 3.

The advantages identified in replacing the granulate with synthetic-based oil:

- Minimal flame.
- Smoke free.
- Reduced porosity of casting.
- Casting without black inclusions.
- Bigger quality of casting surface.
- Reduction of ejection.
- Extended piston life **(from 4,800 to 8,600 strokes).**
- Decrease in production costs (piston ware, piston replacement congestion, lower ejection, higher productivity).
- Improving air quality in production hall (no smoke, no toxic gases).

The direct cost savings of lubricants for piston lubrication were as follows:

The cost of the previously used product - the cost of the product now used per 1,000 pieces.

Primer 2: Uporaba na stroju z večjim premerom bata (105 mm)

Zamenjava mazanja bata: mineralno olje → sintetično olje brez grafita

Robni pogoji so navedeni v preglednici 2, mazanje pa prikazuje slika 4.

Ugotovljene prednosti pri zamenjavi mineralnega olja s sintetičnim oljem so bile:

- manjši plamen,
- brez dima,
- bistveno znižana poroznost odlitka,
- odlitek brez črnih vključkov,
- kakovostnejša površina odlitka,
- podaljšana uporabna doba bata (iz 10.600 na 14.800 udarcev),
- znižanje izmeta zaradi poroznosti in črnih vključkov,
- znižanje stroškov proizvodnje (poraba bata, zastoj za zamenjavo bata, nižji izmet, višja produktivnost),
- izboljšanje kakovosti zraka v proizvodni hali (brez dima, brez strupenih plinov),
- izboljšanje čistosti okolice stroja (brez politega olja zaradi tečenja olja z bata),
- ni potrebne menjave viskoznosti olja ali

€16.40 – €6.00 = €10.40/1,000 pcs
€11.28/day/machine= €3,720/year/machine
(330 working days taken into account)

Case 2: Use on a machine with a larger piston diameter (105 mm)

Replacing piston lubrication: mineral oil → synthetic oil without graphite.

The boundary conditions are given in Table 2 and the lubrication is shown in Figure 4.

The advantages identified in replacing the mineral-based oil with synthetic-based oil:

- Smaller flame.
- Smoke free.
- Significantly reduced porosity of casting.
- Casting without black inclusions.
- Bigger quality of casting surface.
- Extended piston life (from 10,600 to 14,800 strokes).
- Reduction of ejection due to porosity and black inclusions.

Preglednica 2. Robni pogoji na stroju Bühler Carat 160

Table 2. The boundary conditions on Bühler Carat 160 machine

Stroj / Machine:	BUHLER Carat 160
Premer bata / Piston diameter:	105 mm
Delovni gib bata / Piston working stroke:	600 mm
Hitrost bata v 2' fazi / Piston speed in 2' phase	4,20 m/s
Temperature bata / Piston temperature	100 °C
Masa taline / Melt weight	5,1 kg
Zlitina / Alloy	DIN 223
Dnevno število ciklov / Daily number of cycles	1.200
Predhodno v uporabi / Previously in use	
Mazalno sredstvo za bat / Piston lubricant	Mineralno olje (1.000 cSt)
Mesto doziranja / Dosing point	v livno komoro / in the shot chamber
Poraba mineralnega olja / Mineral-based oil consumption	3,0 g/udarec / g/stroke
V uporabi zdaj / Now in use	BARALDI PISTOCAST 2116
Mesto doziranja / Dosing point	v livno komoro / in the shot chamber
Poraba sintetičnega olja / Synthetic-based oil consumption	1.0 g/udarec / g/stroke

Slika 4. Premer bata 105 mm: doziranje na bat

Figure 4. Piston diameter 105 mm: dosing on piston

količine doziranja v odvisnosti od letnega časa in temperature okolice.

Neposredni prihranki stroškov maziva za mazanja bata so bili:

Strošek prej uporabljanega izdelka- strošek zdaj uporabljanega izdelka na 1000 kosov:

9,38 € – 5,70 € = 3,68 €/1.000 kosov

11,26 €/dan = 3.715 €/leto/stroj

(upoštevanih 330 delovnih dni).

Primer 3: Uporaba na stroju z manjšim premerom bata (60 mm)

Zamenjava mazanja bata: granulat → sintetično olje brez grafita

Robni pogoji so navedeni v preglednici 3, mazanje pa prikazuje slika 5.

Ugotovljene prednosti pri zamenjavi granulata s sintetičnim oljem so bile:

- minimalen plamen,
- Decrease in production costs (piston ware, piston replacement congestion, lower ejection, higher productivity).
- Improving air quality in production hall (no smoke, no toxic gases).
- Improving the cleanliness of the machine's surroundings (without oil spilled off the piston).
- No need to change the viscosity of the oil or the amount of dosing depending on the season and ambient temperature.

The direct cost savings of lubricants for piston lubrication were as follows:

The cost of the previously used product - the cost of the product now used per 1,000 pieces.

€9.38 – €5.70 = €3.68/1,000 pcs

€11.26/day = €3,720/year/machine

(330 working days taken into account)

- brez dima,
- bistveno znižana poroznost odlitka,
- odlitek brez črnih vključkov,
- kakovostnejša površina odlitka
- podaljšana uporabna doba bata (iz 12.000 na 22.000 udarcev)

Case 3: Use on a machine with a smaller piston diameter (60 mm)

Replacing piston lubrication: granulate → synthetic oil without graphite.

The boundary conditions are given in Table 3 and the lubrication is shown in Figure 5.

Preglednica 3. Robni pogoji na stroju Colosio

Table 3. The boundary conditions on Colosio machine

Stroj / Machine	COLOSIO
Premer bata / Piston diameter	60 mm
Delovni gib bata / Piston working stroke	280 mm
Hitrost bata v 2' fazi / Piston speed in 2' phase	2,92 m/s
Temperature bata / Piston temperature	80 °C
Masa taline / Melt weight	2,1 kg
Zlitina / Alloy	DIN 226
Dnevno število ciklov / Daily number of cycles	2.200
Predhodno v uporabi / Previously in use	
Mazalno sredstvo za bat / Piston lubricant	granulat / granulate
Mesto doziranja / Dosing point	v livno komoro / in the shot chamber
Poraba granulata / Granulate consumption	1,6 g/udarec / g/stroke
V uporabi zdaj / Now in use	BARALDI PISTOCAST 2116
Mesto doziranja / Dosing point	V livno komoro / In the shot chamber
poraba sintetičnega olja / Synthetic-based oil consumption	0.48 g/ udarec / g/stroke

Slika 5. Premer bata 60 mm: doziranje v livno komoro

Figure 5. Piston diameter 60 mm: dosing in shot chamber

- izboljšanje kakovosti zraka v proizvodni hali (brez dima, brez strupenih plinov)
- znižanje izmeta zaradi poroznosti na 0,01 %
- znižanje stroškov proizvodnje (poraba bata, zastoj za zamenjavo bata, nižji izmet, višja produktivnost)

Neposredni prihranki stroškov maziva za mazanja bata so bili:

Strošek prej uporabljanega izdelka-strošek zdaj uporabljanega izdelka na 1000 kosov
6,56 € – 2,88 € = 3,68 €/1.000 kosov
8,10 €/dan = 2.670 €/leto/stroj
(upoštevanih 330 delovnih dni)

4 Zaključek

Mazanje batov je pomemben vidik pri proizvodnji ulitkov, saj vpliva na stroške proizvodnje, kakovost ulitkov in okolje.

V prispevku so bila našteta različna maziva za mazanje bata in omenjene njihove prednosti in slabosti. Zaradi svojih prednosti se vse bolj uveljavljajo sintetična olja, še zlasti tista, ki ne vsebujejo grafita. Zato so v zadnjem delu prispevka navedeni trije primeri uporabe sintetičnih olj brez grafita in prihranki, vezani na mazivo, ki so bili doseženi z zamenjavo granulata ali mineralnega olja s sintetičnim oljem brez grafita.

Viri / Sources

1 MotulTech Baraldi, Interno gradivo / internal material
2 Olma d.o.o., Rezultati testiranj v različnih livarnah v Sloveniji in tujini / Results of tests in various foundries in Slovenia and abroad

The advantages identified in replacing the granulate with synthetic-based oil:

- Minimal flame.
- Smoke free.
- Significantly reduced porosity of casting.
- Casting without black inclusions.
- Bigger quality of casting surface.
- Extended piston life **(from 12,000 to 22,000 strokes).**
- Improving air quality in production hall (no smoke, no toxic gases).
- Reduction of ejection due to porosity to 0.01 %.
- Decrease in production costs (piston ware, piston replacement congestion, lower ejection, higher productivity).

The direct cost savings of lubricants for piston lubrication were as follows:

The cost of the previously used product - the cost of the product now used per 1,000 pieces.
€6.56 – €2.88 = €3.68/1,000 pcs
€8.10/day = €2,670/year/machine
(330 working days taken into account)

4 Conclusion

The lubrication of pistons is an important aspect in the production of castings, since it affects the cost of production, the quality of castings and the environment.

The article listed the various lubricant for lubricating the piston as well as their advantages and disadvantages. Synthetic-based oils are increasingly being used due to their advantages, especially the oils not containing graphite. Therefore, the final part of the article lists three examples of how the use of graphite-free synthetic-based oils and lubricant related savings were achieved by replacing granulate or mineral-based oil with synthetic-based oil without graphite.

AKTUALNO / CURRENT

Prispevek slovenskega vedenja, znanja in znanosti k uspešnosti IFC v Portorožu v obdobju 2010 do 2020

The Contribution of Slovenian Know-How, Knowledge and Science to the Success of the IFC in Portorož from 2010 to 2020

V posebni izdaji Livarskega vestnika št. 57/2010 je prof. dr. Milan Trbižan, nekdanji dolgoletni predsednik in tudi častni predsednik Društva livarjev Slovenije, daljše obdobje redni univerzitetni profesor in predstojnik Katedre za livarstvo Oddelka za materiale in metalurgijo na Naravoslovnotehniški fakulteti Univerze v Ljubljani, ob 50-letnici izhajanja Livarskega vestnika predstavil zgodovino in pomen Mednarodne livarske konference – IFC – za razvoj livarske vede in gospodarske panoge livarstva. V prvi letošnji številki Livarskega vestnika (1/2021) je v prispevku pod naslovom »60 let osrednje livarske konference Društva livarjev Slovenije« tudi predsednica Društva livarjev Slovenije, mag. Mirjam Jan-Blažić, podala oris te pomembne dolgoletne mednarodne livarske poti v Sloveniji.

Glavni organizator IFC je bilo tudi v zadnjem 10-letnem obdobju Društvo livarjev Slovenije ob soorganizatorjih: Naravoslovnotehniška fakulteta, Oddelek za metalurgijo Univerze v Ljubljani, in Fakulteta za strojništvo Univerze v Mariboru. Organizatorji so zadržali tradicionalno lokacijo v Portorožu in konferenco redno vsako leto organizirali v sredini septembra. Obe univerzi sta ob tem tudi glavna pokrovitelja konference in sodelujeta v organizacijskem odboru, ki mu je v celotnem obdobju predsedovala predsednica Društva livarjev Slovenije mag.

zasl. prof. dr. Alojz Križman, predsednik programsko-znanstvenega odbora IFC

In a special issue of Livarski vestnik, no. 57/2010, Prof. Dr. Milan Trbižan, former long-term chair and honorary president of the Slovenian Foundrymen Society, former full-time university professor and chair of the Chair of Foundry at the Faculty of Natural Sciences and Engineering, Department of Materials and Metallurgy, University of Ljubljana, presented the history and the importance of the International Foundry Conference – the IFC – for the development of foundry as a science and the development of the foundry as an industry. In this year‘s first issue of Livarski vestnik (1/2021), in an article entitled “60th anniversary of the major foundry conference by the Slovenia Foundrymen Society”, the president of the Slovenian Foundrymen Society, Mag. Mirjam Jan-Blažić, outlined this long-term international course in the foundry sector in Slovenia.

The chief organizer of the IFC during the last 10-year period was the Slovenian Foundrymen Society with a number of co-organizers: the Faculty of Natural Sciences and Engineering, Department of Materials and Metallurgy, University of Ljubljana, and the Faculty of Mechanical Engineering, University of Maribor. The organizers have traditionally held the conference in Portorož regularly every year mid-September. Both universities are also the main sponsors of the conference and participate in the organizing committee, chaired throughout the period by the president of the Slovenian Foundrymen Society, Mag. Mirjam Jan-Blažič. Also, throughout the period, the activities of the chairman of the programme and scientific committee of the conference was performed by honorary Prof. Dr. Alojz Križman

mag. Mirjam Jan Blažić, predsednica organizacijskega odbora IFC

Mirjam Jan-Blažić. Prav tako je v celotnem obdobju delo predsednika programskega in znanstvenega odbora konference opravljal zasl. prof. dr. Alojz Križman z Univerze v Mariboru. Pri pripravi konference pa je imela ves čas zelo pomembno vlogo celotna Katedra za livarstvo Oddelka za materiale in metalurgijo na čelu z njenim predstojnikom rednim prof. dr. Primožem Mrvarjem ter Katedra za metalurško in procesno tehniko s sodelavci in njenim vodjem rednim prof. dr. Jožetom Medvedom. Brez usklajenega sodelovanja tudi ne bi bilo mogoče opraviti tega obsežnega dela v podporo celotni panogi livarstva. Člani obeh kateder so bili tudi organizacijski asistenti pri izvedbah vseh desetih mednarodnih konferenc v tem obdobju. Dokaz o strokovnem spoštovanju tradicionalnega Mednarodnega livarskega posvetovanja v Portorožu (International Foundry Congress – kratica IFC) je vsakoletno zavidanja vredno število udeležencev iz tujih držav, ki so bili vedno znova presenečeni nad strokovno ravnjo referatov. Vsi predavatelji so morali predhodno obvezno poslati kratek vsebinski povzetek predavanj, ki je bil nato objavljen v zborniku posvetovanja v slovenskem in angleškem jeziku. Vsak udeleženec posvetovanja je prejel ta zbornik ob registraciji udeležbe. Prav tako so bili predavatelji dolžni pred začetkom konference poslati celotno vsebino predavanja v digitalni obliki, ki so ga vsi udeleženci prejeli na disku ali pomnilniškem ključku USB. V celotnem obdobju so bila predavanja tematsko razdeljena: prvi dan 8 do 10 plenarnih predavanj, vezanih na osnovna vprašanja o livarski stroki in njenem razvoju, ter drugi dan skupina referatov s področja jeklene litine in litin na osnovi železa in skupina referatov s področja neželeznih zlitin. Celotna konferenca je bila običajno omejena na skupno 36 govornih predstavitev s prezentacijo besedila in slik. Neuvrščeni referati, ki niso bili sprejeti v uraden govorni program, so imeli možnost grafične predstavitve s prikazom plakatov. Vsa plenarna predavanja so bila omejena na čas 30 minut,

from the University of Maribor. In the preparation of the conference, the entire Chair of Foundry of the Department of Materials and Metallurgy, headed by chair, Full Prof. Dr. Primož Mrvar, and the Department of Metallurgical Processing Techniques with associates and its chair, Full Prof. Dr. Jože Medved. Without coordinated collaboration, it would not have been possible to carry out this extensive work supporting the entire foundry industry. Members of both departments also assisted in the organization of all ten international conferences in the period.

The evidence of professional respect for the traditional International Foundry Conference in Portorož (IFC) is the enviable number of participants, who are always surprised by the expertise of the papers presented, that attend from abroad every year. Every lecturer was required to send a short summary of the lecture, which was then published in the proceedings of the conference in both Slovene and English. Each participant in the consultation received the proceedings upon registration. Also, before the start of the conference, the lecturers were required to provide the entire content of the lecture in digital form, which was then received by all participants on a hard drive or USB memory stick. Throughout, lectures were thematically divided; on the first day, 8 to 10 plenary lectures related to basic issues of the foundry sector and its development were held, while on the second day, a string of papers in the field of steel and iron-based alloys as well as in the field of non-ferrous metals was presented. The entire conference was generally limited to a total of 36 lectures with presentation which included both text and images. Unlisted contributions that were not accepted into the official lecture program were given the opportunity of a graphic presentation with posters. All plenary lectures were limited to 30 minutes and all other lectures to 20 minutes. In total, in the entire period from 2011 to 2020, an incredible total of 473 presentations were given (incl. both lectures and posters), of which 147 (or 31%) presentations were by Slovenian authors. The volume of such an extent is in part related to 2019 when we organized simultaneously with the 59th IFC also the World Foundry Organization (WFO) Technical Forum, where a total of 104 presentations divided into five categories were given.

vsa ostala pa na čas 20 minut. Skupno je bilo v celotnem obdobju 2011–2020 predstavljenih z vsemi predavanji in plakati kar neverjetnih 473 prezentacij, od tega 147 predstavitev slovenskih avtorjev, kar je 31 % vseh predstavitev. Tako velik obseg je delno vezan tudi na leto 2019, ko smo sočasno z 59. IFC organizirali tudi Tehniški forum Svetovne livarske organizacije in je bilo v petih skupinah podanih skupno kar 104 predstavitev.

V strokovnem smislu pa je vedno izpostavljeno vprašanje slovenskega znanja in znanosti ter njuna vloga pri razvoju. Livarstvo kot stroka je opredeljeno kot interdisciplinarna tehniška veda. Klasifikacija raziskovalnih ved po ARRS ne izpostavlja livarstva kot raziskovalne vede, področja oz. podpodročja. V osnovi bi ga lahko uvrstili v področje 2. Tehnika, ki v svojih podpodročjih navaja: pod 2.02 Kemijsko inženirstvo, 2.04 Materiali, 2.04.02 Kovinski materiali, 2.10 Proizvodne tehnologije in sistemi, 2.10.02 Izdelovalna tehnologija, 2.10.05 Industrijski inženiring. Evropska klasifikacija raziskovalne dejavnosti (CERIF-CERS) je v primeru livarstva sprejemljivejša in širša, saj pod šifro T 000 izpostavlja program Tehnološke vede in med njimi navaja: T150 Tehnologija materialov in pod T450 Kovinska tehnologija, metalurgija, kovinski izdelki. Torej lahko livarstvo uvrstimo v osnovni program Tehnoloških ved T 000 in livarstvo kot panogo štejemo v T450. Mednarodna livarska konferenca – IFC Portorož – zajema skladno z uradnim priročnikom OECD Frascati Manual iz leta 2015 vsa tri osnovna področja raziskav in razvoja (RR) skladno z uradnim dokumentom OECD: predstavitve temeljnih raziskav, uporabnih raziskav in eksperimentalnega razvoja. Kot majhna država smo tako lahko ponosni, da smo sposobni organizirati mednarodno livarsko konferenco, ki izpolnjuje vsa merila OECD.

Na področju plenarnih predavanj, ki so jih predstavili predstavniki Univerze v Mariboru, Univerze v Ljubljani in Društva livarjev Slovenije je treba izpostaviti naslednje osebe: zasl. prof. dr. Alojz Križmana, Univerza Maribor, ki je bil 9-krat prvi avtor in 9-krat soavtor, redni prof. dr. Primož Mrvar, Univerza Ljubljana, 9-krat prvi avtor in 6-krat soavtor, mag. Martin Debelak, Gospodarska zbornica Slovenije, 1-krat prvi avtor in 9-krat soavtor, mag. Mirjam Jan- Blažić

In a professional sense, however, the issue of Slovenian knowledge and science and their role in the development is always exposed. Foundry as a profession is defined as an interdisciplinary technical science. The classification of research sciences under ARRS does not describe foundry as a research science, class or subdivision. Basically, it could be classified under class 2. Engineering sciences and technologies, the subdivisions of which list: under 2.02 Chemical engineering, 2.04 Materials science and technology, 2.04.02 Metallic materials, 2.10 Manufacturing technologies and systems, 2.10.02 Manufacturing technology, 2.10.05 Industrial engineering. In foundry, the Common European Research Classification Scheme (CERIF-CERS) is more acceptable and broader, as under code T 000 it highlights the Technological Sciences programme, listing among the technological sciences: T150 Materials technology and T450 Metal technology, metallurgy, metal products. This means that foundry can be included in the basic programme of Technological Sciences T 000 while foundry as an industry can be considered part of T450. In line with the official OECD Frascati Manual from 2015, the International Foundry Conference – IFC Portorož covers all three basic R&D (research and development) areas in accordance with the official OECD document: presentations of basic research, applied research and experimental development. As a small country, we can be extremely proud to be able to organize an international foundry conference that meets all of the OECD criteria.

In the field of plenary lectures presented by the representatives of the University of Maribor, the University of Ljubljana and the Slovenian Foundrymen Society, the following persons should be pointed out: Honorary Prof. Dr. Alojz Križman, University of Maribor, who was first author 9-times and co-author 9-times, Full Prof. Dr. Primož Mrvar, University of Ljubljana, 9-times first author and 6-times co-author, Mag. Martin Debelak, Chamber of Commerce and Industry of Slovenia 1-time first author and 9-times co-author, Mag. Mirjam Jan-Blažič, Slovenian Foundrymen Society, 10-times co-author, Assoc. Prof. Dr. Rebeka Rudolf, University of Maribor, 2-times first author, Full Prof. Dr. Jože Medved, University of Ljubljana, 7-times co-author, and

Društvo livarjev, 10-krat soavtor, izr. prof. dr. Rebeka Rudolf, Univerza v Mariboru, 2-krat prvi avtor, redni prof. dr. Jože Medved, Univerza v Ljubljani, 7-krat soavtor, in as. dr. Mitja Petrič, 5-krat soavtor. Že seznam najpomembnejših sodelujočih avtorjev kaže na dobro sodelovanje Društva livarjev Slovenije in univerz v Ljubljani in Mariboru ter Gospodarske zbornice Slovenije. V celotnem obdobju 2011–2020 so bili vedno podani podatki o obsegu proizvodnje. Leta 2010 je proizvodnja slovenskih livarn znašala skupaj 164.715 ton, leta 2019 195.629 ton, kar predstavlja porast za 19 %. V tem obdobju je prišlo do bistvenih strukturnih sprememb v proizvodnji ulitkov iz posameznih zlitin: standardna siva litina -14,9 %, duktilna siva litina +70,2 %, temprana litina +26,7 %, jeklena litina -93,28 %, Al-zlitine +10,6 %, Zn-zlitine + 285,7 %, Cu-zlitine -15,6 % ter Mg-zlitine -10 %. Iz 10-letne primerjave je tako razviden velik porast proizvodnje ulitkov iz: zlitin Al in zlitin Zn ter duktilne sive litine in sočasno popoln zastoj pri izdelavi ulitkov iz zlitin Mg in zaradi stečaja livarne jekla Litostroj izrazito znižanje izdelave ulitkov iz jeklene litine.

V plenarnem predavanju »Znanje in inovacijski potencial kot osnova prihodnosti slovenskega livarstva« je bila kot stalnica izpostavljena usmeritev livarn v proizvodnjo z visoko dodano vrednostjo, ki pa zahteva visoko raven izobraževanja, sodelovanje z uglednimi univerzami v tujini ter povezave z Inštitutom za kovinske materiale in tehnologije, ki ima status centra odličnosti za sodobne kovinske materiale. Prav tako so izpostavljene možnosti izdelave kompleksnih komponent, ki zahtevajo visoko stopnjo obdelovalne in spajalne tehnike. Težišče raziskav samih materialov je usmerjeno v visokokakovostne Al-zlitine in nodularno sivo litino. Kot posebna skupina raziskav sta bila predstavljena program tehnologije metastabilnih materialov s kovinsko osnovo in pa liti kompoziti s keramično utrjevalno fazo ter možnostjo izdelave interpenetracijskih kompozitov. Predstavljene so bile raziskave magnezijeve zlitine in dodatkov keramične utrjevalne faze.

V dobro obiskanih plenarnih predavanjih so predstavniki obeh univerz izpostavili tehnološke dosežke in zahtevne ulitke ter inovacijske dosežke naslednjih slovenskih livarskih podjetij: LTH ulitki d.o.o., Ljubljana in Škofja Loka,

Ass. Dr. Mitja Petrič, 5-times co-author. The list of the most important participating authors already indicates the quality of cooperation between the Slovenian Foundrymen Society and the Universities of Ljubljana and Maribor as well as the Chamber of Commerce of Slovenia. For the entire 2011–2020 period, data on production volumes were presented. In 2010, the production of Slovenian foundries totalled to 164,715 tons vs. 195,629 tons in 2019, constituting a 19% increase. During this period, significant structural changes in the production of castings from individual alloys occurred; standard gray iron -14.9%, ductile gray cast iron +70.2%, malleable cast iron +26.7%, steel alloy -93.28%, Al alloys + 10.6%, Zn alloys +285.7%, Cu alloys -15.6% and Mg alloys -10%. The 10-year comparison shows a large increase in the production of castings produced from: Al and Zn alloys and ductile gray cast irons, and at the same time a complete standstill in the production of castings from Mg alloys and due to the insolvency of the steel foundry Litostroj, resulting in a marked reduction in the production of steel castings.

mag. Martin Debelak (nekdanji strokovni tajnik Društva Livarjev Slovenije in dolgoletni aktivni sodelavec na IFC)

In the plenary lecture “Knowledge and Innovation Potential as the Basis for the Future of the Slovenian Foundry”, the focus of foundries on high value-added production was highlighted, however, which requires a high level of education, cooperation with reputable foreign universities and connections with the Institute of Metals and Technology, boasting the status of a center of excellence for modern metals. The opportunities of producing complex components that require a high level of machining and joining technique are also exposed. The research of materials is focused on high-quality Al alloys and ductile gray iron. As a special group of research, the programme of technology of metastable materials with a metal base and cast composites with a ceramic hardening phase was presented along with the possibility of the production

največja slovenska livarna aluminijskih ulitkov; ETA Cerkno d.o.o., tovarna elektrotermičnih aparatov in livarna sive litine; Kovis livarna d.o.o., livarna sive in nodularne litine, Štore; Mariborska livarna Maribor d.d., Maribor, izdelovalec ulitkov iz aluminijevih zlitin; Valji, proizvodnja valjev in ulitkov d.o.o., Štore; Livar d.d., Ivančna Gorica, največji slovenski izdelovalec ulitkov iz sive in nodularne litine; OMCO Metals Slovenija d.o.o., izdelovalec ulitkov za steklarsko industrijo ter ulitkov iz sive litine in bakrovih zlitin; Akrapovič d.d., Ivančna Gorica, livarna precizijskega litja titanovih in nikljevih zlitin; Talum, Tovarna aluminija d.d., PE Livarna livarski izdelki iz zlitin Al; Magneti Ljubljana d.d., Ljubljana, izdelava ulitih delov za proizvodnjo trajnih magnetov; Zlatarna Celje d.o.o, Celje, litje preciznih izdelkov na bazi plemenitih litin in izdelava nanomaterialov; DIFA d.o.o., livarna in obdelava tlačnih ulitkov Al, Škofja Loka; Titus d.o.o., livarna cinkovih zlitin in izdelava livnih strojev, Dekani; HIDRIA, PE Hidria Alutec, Idrija in Koper, livarna in obdelava ulitkov Al; Croning Livarna d.o.o., Ravne na Koroškem, Livarna Titan d.o.o., Kamnik, livarna temprane litine. S tem je izpostavljeno strokovno sodelovanje obeh univerz z številnimi industrijskimi podjetji, ki izdelujejo in obdelujejo zahtevne lite komponente.

Janko Čevka, Exoterm d.d., dolgoletni aktivni sodelavec IFC

V smislu reindustrializacije je ekspertna evropska komisija za metalurgijo v Evropi pripravila program Metalurgija v Evropi v obdobju 2012–2022 in ob strateškem pomenu kovinskih materialov uvrstila metalurgijo med prioritetna razvojna področja. V Sloveniji je bil imenovan Strateški svet za metalurgijo, v katerem sodelujeta tudi obe univerzi, med drugim so vanj vključeni tudi trije člani, tesno povezani z livarstvom in IFC Portorož (iz Univerze v Ljubljani: prof. dr. Jože Medved in prof. dr. Primož Mrvar z Univerze v Mariboru: zasl. prof. dr. Alojz Križman). Strateški svet vodi predsednik uprave Talum, Tovarna aluminija d.d., Kidričevo, Marko Drobnič. Livarstvo je bilo na

of interpenetration composites. Research on magnesium alloys and ceramic hardening phase additives was presented.

In well-attended plenary lectures, the representatives of both universities highlighted the technological achievements and complex castings as well as the innovations by the following Slovenian companies engaged in the foundry industry: LTH ulitki d.o.o. Ljubljana and Škofja Loka, the largest Slovenian foundry of aluminum castings; ETA Cerkno d.o.o., electrothermal appliances production factory and gray iron foundry; Kovis livarna d.o.o., gray and ductile iron foundry, Štore; Mariborska livarna Maribor d.d. Maribor, manufacturer of aluminium alloy castings; Valji d.o.o. proizvodnja valjev in ulitkov d.o.o. Štore; Livar d.d. Ivančna Gorica, as the largest Slovenian manufacturer of gray and ductile iron castings; OMCO Metals Slovenija d.o.o., manufacturer of castings for the glass industry and gray iron and copper alloy castings; Akrapovič d.d. Ivančna Gorica, foundry for precision casting of titanium and nickel alloys; Talum, Tovarna aluminija d.d. PE Livarna, Al alloy foundry products; Magneti Ljubljana d.d., Ljubljana, production of cast parts for the production of permanent magnets; Zlatarna Celje d.o.o., Celje, casting of precision precious metal-based products and production of nanomaterials; DIFA d.o.o., foundry and processing of Al pressure castings, Škofja Loka; Titus d.o.o., zinc alloy foundry and casting machinery production, Dekani; HIDRIA, PE Hidria Alutec, Idrija and Koper, foundry and processing of Al castings; Croning Livarna d.o.o., Ravne na Koroškem, Livarna Titan d.o.o., Kamnik, foundry of malleable cast iron. This highlights the professional cooperation of both universities with many industrial companies that produce and process complex cast components.

In terms of reindustrialization, the prominent European metallurgy committee prepared the programme Metallurgy Europe for the period between 2012 and 2022, classifying metallurgy based on the strategic importance of metallic materials among priority development areas. In Slovenia, a Strategic Council for Metallurgy was appointed in the context of which both universities also participate. More specifically, it also includes three members closely associated with foundry and IFC Portorož (from the University

osnovi dela Strateškega sveta zajeto v Strategiji pametne specializacije RS in v povezovalni verigi: proizvodnja kovinskih materialov, izdelava orodij-izdelava ulitkov-mehanska, toplotna in površinska obdelava-izdelava obdelanih ulitkov in sklopov. Za livarstvo je bilo opredeljeno področje RR: oblikovanje kovinskih materialov in zahtevnih izdelkov z litjem (celoten prispevek je bil predstavljen na IFC leta 2015). Integracija livarske stroke v razvojni program 2015–2025 je tako tudi rezultat skupnega dela obeh univerz ter Inštituta za kovinske materiale in tehnologije. Prav tako je bila v tem letu na IFC predstavljena izdelava referenčnih vzorcev za potrebe proizvodnje na področju kovinskih materialov z litjem vzorcev na bakreno ploščo, ohlajeno s tekočim dušikom.

V celotnem razvoju slovenskega livarstva ima ključno mesto visokotlačno litje (HPDC) aluminija. Pri ulitkih s kompleksno geometrijo in dimenzijsko natančnostjo je izjemnega pomena ustrezno načrtovanje elementov ulivnega in napajalnega sistema in obvladovanje vseh robnih pogojev v procesni verigi. Predstavnika obeh univerz (P. Mrvar in A. Križman) sta s sodelavci Mariborske livarne v skupni predstavitvi izpostavila primer virtualne obravnave ulitka ohišja menjalnika z izbiro tehnologije in izračunom procesa ter primerjavo z eksperimentalno pridobljenimi vrednostmi. Uporabljeni so bili računalniška tomografija in 3D-meritve.

Obe univerzi, povezani z gospodarstvom, sta soustanoviteljici Strateško-razvojnega partnerstva Materiali kot končni produkti – SRIP MATPRO, ki sta ga pri Gospodarski zbornici Slovenije ustanovila Združenje kovinske industrije in Združenje kemijske industrije. Za livarstvo so bila opredeljena naslednja bistvena prednostna področja: tlačno litje zlitin Al, napredne tehnologije litja, izdelava ulitkov ob integrirani simulaciji optimizacije proizvodnje ulitkov. Ob tem je potrebno izkoristiti naslednje primerjalne prednosti: visoka stopnja prilagodljivosti, vključenost v globalne verige vrednosti in mreže, učinkovita izraba surovinskih in energetskih virov, visoka stopnja recikliranja, tesno sodelovanje gospodarskih družb in institucij znanja. Na osnovi partnerstva med univerzami, raziskovalnimi inštituti in gospodarstvom je po mnenju avtorjev A. Križmana in P. Mrvarja

of Ljubljana, Prof. Dr. Jože Medved and Prof. Dr. Primož Mrvar, and from the University of Maribor, Honorary Prof. Dr. Alojz Križman). The Strategic Council is chaired by the President of the Management Board of Talum, Tovarna aluminija d.d., Kidričevo, Mr. Marko Drobnič. Based on the work of the Strategic Council, the foundry was included in the Smart Specialization Strategy of the Republic of Slovenia and included in the connection – the production of metals, tool making-casting-mechanical, heat and surface treatment-production of machined castings and assemblies. The following R&D area was determined for the foundry sector: Design of metals and sophisticated products via casting (the full paper was presented at IFC in 2015). The integration of foundry into the 2015-2025 development programme is therefore also the result of the joint efforts of both universities and the Institute of Metals and Technology. Similarly, during the same year, the production of reference samples for production needs in the field of metals by the casting of samples onto a copper plate cooled with liquid nitrogen was presented at the IFC.

High-pressure die casting (HPDC) of aluminum occupies a prominent place throughout the entire development of Slovenian foundry. In the case of castings with complex geometries and strict dimensional accuracy requirements, it is highly important to properly design the elements of the casting and supply system as well as to manage every boundary condition in the process chain. Representatives of both universities (P. Mrvar and A. Križman) as well as their colleagues from Mariborska livarna highlighted in a joint presentation the case of virtual processing of a gearbox housing casting by incl. selected technology and process calculation as well as comparison with experimentally obtained values. Computed tomography and 3D dimensional measurements were utilized.

Both universities associated with the economy are the co-founders of the Strategic Research and Innovation Partnership Materials as end Products (SRIP MATPRO), which was established at the Chamber of Commerce and Industry of Slovenia by Metal Processing Industry Association and the Chemical Industries Association. The following focal priority areas

treba strmeti k višji ravni inovacij in proizvodnji zahtevnejših ulitkov z višjo dodano vrednostjo. To sta oba navedena avtorja izpostavila tudi v plenarnem prispevku »Celovito načrtovanje in obvladovanje kompleksnih ulitkov v tehnologiji tlačnega litja«.

Posebnega pomena med plenarnimi prispevki je predstavitev avtorskega prispevka v letu 2018 avtorjev A. Križman, P. Mrvar, M. Jan-Blažić in M. Debelak z naslovom »Smernice razvoja slovenskega livarstva«. Slovenska livarska industrija je v več kot 90 % vezana na izvoz v razvite države. S tem je primorana slediti vsem razvojnim trendom in se povezovati v mreže s svojimi odjemalci in uporabniki ulitkov. Ob tem so izrednega pomena izobraževani sistemi ter inventivnost kadra, ki lahko sledijo današnjim razvojnim trendom. Prav tako so pomembni inventivnost posameznikov in inventivni sistem podjetij, ki lahko zagotavljajo sodelovanje z najzahtevnejšimi odjemalci kot partnerji. Izpostavljena je tendenca prenosa znanja na področja različnih uporabnih materialov z namenom doseganja trajnostnega razvoja v krožnem gospodarstvu. Na istem posvetovanju je bil s strani avtorjev Univerze v Mariboru (R. Rudolf, A. Križman in I. Anžel) ter soavtorjev Zlatarne Celje predstavljen plenarni prispevek »Nanotehnologija kot tehnologija prihodnosti«. Predstavljena je možnost vključevanja nanotehnologije v izdelavo novih pametnih materialov (jeklo, stekla, nanosi, medicina, stomatologija, elektronika, elektrotehnika itd.).

prof. dr. Rebeka Rudolf (Univerza Maribor in Zlatarna Celje)

V letu 2019, ko sta sočasno potekala 59. IFC in Tehnični forum Svetovne livarske organizacije, sta avtorja dveh slovenskih univerz (A. Križman, Maribor, in P. Mrvar, Ljubljana) s soavtorji predstavila za tako številno obiskan in zahteven kongres predavanje z naslovom » Usmeritev slovenskih livarn v tehnično zahtevne, termično, mehansko in površinsko obdelane ulitke kot sestavne in kompleksne dele za neposredno vgradnjo v končne izdelke«. Izpostavljena je bila

have been identified for the foundry sector: die casting of Al alloys, advanced casting technologies, casting production with integrated casting production optimization simulation. The following comparative advantages need to be exploited: a high degree of flexibility, participation in global value chains and networks, efficient use of raw materials and energy resources, high recycling rate, close collaboration between companies and knowledge institutions. In the opinions of authors A. Križman and P. Mrvar, based on the partnership between universities, research institutes and the economy, it is necessary to strive for a higher degree of innovation and the production of more complex castings with higher added value. This was again highlighted by the authors with co-authors in the scope of the plenary contribution dubbed “Comprehensive Planning and Management of Complex Castings in High-pressure Die-casting”.

Among the plenary contributions, in 2018, the presentation by authors A. Križman, P. Mrvar, M. Jan-Blažić and M. Debelak titled “Guidelines for the Development of Slovenian Foundry”. In more than 90%, the foundry industry in Slovenia is tied to export to developed countries. As a result, it is bound to follow all the trends in development and to network with its customers and users of castings. That is why the educational systems and cadre ingenuity are of particular importance in order to keep up with today’s trends in development. Also essential are the ingenuity of individuals and of enterprise systems, which are capable of providing for the collaboration with the most demanding customers in a partnership sphere. The tendency to transfer knowledge to various useful material fields in order to provide for sustainable development in the circular economy is exposed. At the same conference, the authors from the University of Maribor (R. Rudolf, A. Križman and I. Anžel) as well as co-authors from Zlatarna Celje presented the plenary paper, “Nanotechnology as the technology of the future”. The opportunity of integrating nanotechnology in the production of new smart materials (steel, glass, coatings, medicine, dentistry, electronics, electrical engineering etc.) was presented.

In 2019, when the 59th IFC and the World Foundry Organization Technical Forum were held simultaneously, authors from two Slovenian

izjemno visoka zahteva po kakovosti ulitkov ter visoki stopnji obdelave in merski natančnosti, ki je ključna zahteva za omogočanje neposredne vgradnje v končni tržni proizvod. To je mogoče doseči samo z visokim vložkom različnih znanj, končno zahtevno kontrolo dimenzij in lastnosti z vrhunsko opremo ter seveda tržno konkurenčnostjo cene. Prikazani so bili ulitki petih slovenskih livarna (LTH Castings, Mariborska livarna Maribor, TALUM PE Ulitki, Kovis-Livarna, ETA Cerkno).

Tudi v letu 2020 sta obe univerzi prispevali dve plenarni predavanji. Kot prvo A. Križman (MB) in P. Mrvar (LJ) z naslovom »Slovensko livarstvo: iz tradicije v prihodnost, zasnovano na znanju, ustvarjalnosti in inovativnosti«. Tradicija slovenskega livarstva izhaja iz 4. stoletja pr. n. št. z litjem sekiric iz bakra v kalupe iz gline na Igu pri Ljubljani. Zgodovina livarstva je povezana z litjem zvonov v livarnah v Ljubljani, Celju in Gorici. Najstarejši še ohranjen zvon je bil ulit v Celju leta 1550. Posebno zgodovinsko vrednost pa ima razvoj litja tankostenskih ulitkov, ki ga je razvil J. V. Valvasor s svojim najbolj znanim ulitkom kipa sv. Marije iz posebne bakrove zlitine z deležem Zn 16 % ter legirnimi dodatki Sn in Pb. Ulitek stoji še danes kot izjemna kulturna znamenitost na Marijinem spominskem stebru pred cerkvijo sv. Jakoba v Ljubljani. Prispevek o tem postopku litja je J. V. Valvasor objavil angleškem jeziku leta 1687 v Philosophical Transactionys of Royal Society in pet let kasneje leta 1692 v latinskem jeziku v najstarejšem znanstvenem glasilu Acta Eroditorum v Leipzigu. Te objave veljajo za najstarejše znanstvene objave slovenske znanosti tehniških ved.

Trendi razvoja slovenskih livarn so danes zasnovani na digitalizaciji in avtomatizaciji proizvodnje, visoki stopnji mehanske, površinske in termične obdelave ter visoki merski natančnosti. Prikazani so bili tudi primeri zelo zahtevnih ulitkov podjetij Akrapovič d.d., Ivančna Gorica, s primerom vakuumskega litja izpušnih cevi iz Ti zlitin; TALUM Kidričevo s primerom zahtevnega ulitka iz Al-zlitine z nizkotlačnim litjem za motorno industrijo; Livar d.d., Ivančna Gorica, računalniška modifikacija geometrije proizvoda pokrovov iz sive litine; Mariborska livarna Maribor d. d., primer zahtevnega ulitka antivibracijskega elementa nosilca motorja z notranjim zgorevanjem. Drugo plenarno

universities (A. Križman, Maribor, and P. Mrvar, Ljubljana) and their co-authors presented the lecture for a packed hall of knowledge-thirsty attendees dubbed, “Orientation of Slovenian foundries into technically complex, thermal, mechanically and surface-treated castings as integral and complex parts for direct installation into finished products”. Exposed was the extremely high demand regarding the quality of castings as well as the high level of processing and measurement accuracy, which are necessary for the direct installation into the final market product. This can only be achieved through a thorough investment of various skills, final rigorous control of dimensions and properties using state-of-the-art equipment and, of course, a competitive price. The castings by five Slovenian foundries (LTH Castings, Mariborska livarna Maribor, TALUM PE Ulitki, Kovis-Livarna, ETA Cerkno) were presented.

Also, in 2020, both universities contributed two further plenary lectures. The first by A. Križman (MB) and P. Mrvar (LJ) with co-authors dubbed, “Slovenian Foundry: from tradition to the future based on knowledge, creativity and innovation”. The tradition of Slovenian foundry dates back to 4th century BC when at Ig near Ljubljana, copper axes were cast into clay molds. A related part of the history of foundry is related to the casting of bells in foundries in Ljubljana, Celje and Gorizia. The oldest surviving bell was cast in Celje in 1550. Of particular historical value is the development of thin-walled castings J.V. Valvasor, whose most famous casting of the statue of St. Mary is made from a special copper alloy with a Zn content of 16% and alloying additives Sn and Pb. The casting is still displayed as an exceptional cultural landmark at St. Mary‘s memorial pillar in front of the church of St. Jakob in Ljubljana, Slovenia. A paper on the casting process was published by J.V. Valvasor in English in 1687 in the Philosophical Transactionys of the Royal Society and five years later in 1692 also in Latin in the oldest scientific journal, Acta Eroditorum, in Leipzig. These publications are considered to be the oldest scientific publications of Slovenian technical sciences.

Nowadays, the development trends of Slovenian foundries are based on digitalization and automation of production, a high level of

predavanje na IFC 2020 je pripravila univerza v Mariboru (R. Rudolf prvi avtor, soavtorji P. Majerić, Ž. Jelen in A. Križman) in je nosilo naslov »Prenos nanotehnologije na industrijski nivo na primeru nanodelcev zlata kot primer dobre prakse v Zlatarni Celje d.o.o.«. Nanodelci iz zlata imajo izjemne lastnosti, npr. optične, inertnost in biokompatibilnost. Njihova uporaba je predvidena predvsem v medicini, zato je izdelava in uporaba povezana z zelo strogimi zahtevami uporabnikov. Ena izmed tehnologij izdelave nanodelcev zlata temelji na ultrazvočni razpršilni pirolizi – USP, ki je osnovana na ultrazvočnem razprševanju raztopine želenega materiala v kapljice aerosola. Inertni nosilni plin prenaša nastale kapljice v reakcijsko peč, kjer potekajo faze sinteze v končne nanodelce. V odvisnosti od hitrosti izhlapevanja lahko izdelamo različne oblike in velikosti nanodelcev. V Zlatarni Celje se želi z raziskavami preiti na industrijsko raven izdelave nanodelcev.

Predavanja predstavnikov univerz in raziskovalnih inštitutov z navedbo prvih avtorjev iz sekcije jeklolitina in železove litine ter livarske tehnologije na IFC v obdobju 2011–2020.

prof. dr. PRIMOŽ MRVAR (Univerza v Ljubljani)

P. Mrvar (ULj) je s soavtorji z obeh univerz in podjetja Livar iz Ivančne Gorice na IFC 2014 podal zelo zahtevno temo z naslovom »**Tehnologija izdelave in karakterizacija gradientnega ulitka«.** Predstavljena je bila kombinacija horizontalnega centrifugalnega litja legirane bele litine, legirane s kromom (površina valjev), in gravitacijskega litja jedra iz sive litine s kroglastim grafitom. Vmesna plast ima strukturo sive litine z lističastim grafitom. Mikrostrukturne komponente so bile določene kvantitativno in kvalitativno. S pomočjo računalniških programov so bili narejeni izračuni gostote za vsako posamezno mikrostrukturno komponento. Različna gostota mikrostrukturnih komponent je posledica centrifugalnih sil. Izračunane in izmerjene so mechanical, surface and thermal processing and high measurement accuracy. Examples of highly complex castings for the following companies were also presented: Akrapovič d.d. Ivančna Gorica with an example of vacuum casting of exhaust pipes from Ti alloys; TALUM Kidričevo as an example of a demanding casting made of Al alloy, with low-pressure casting for the motor industry; Livar d.d. Ivančna Gorica, computer modification of the geometry of gray iron covers; Mariborska livarna Maribor d.d., an example of the complex casting of an anti-vibration element for an internal combustion engine bracket. The second plenary lecture at IFC 2020 was prepared by the University of Maribor (R. Rudolf, first author, co-authors P. Majerić, Ž. Jelena and A. Križman) and dubbed “Transfer of nanotechnology to the industrial level – as an example of good practice in Zlatarna Celje d.o.o. on the case of gold nanoparticles«. Gold nanoparticles have outstanding properties, e.g. optical, inertness and biocompatibility. Their use is expected primarily in medicine, meaning that their production and application is associated with stringent requirements. One of the technologies for making gold nanoparticles is based on ultrasonic spray pyrolysis – USP, which encompasses the ultrasonic spraying of a solution of the desired material into aerosol droplets. The inert carrier gas transfers the resulting droplets to the reaction furnace where the synthesis phases until the final nanoparticles take place. Depending on the evaporation rate, different shapes and sizes of nanoparticles can be obtained. Zlatarna Celje aims to move the research to the industrial level of nanoparticle production.

Lectures by representatives of universities and research institutes with indications of the first authors from the section: steel, cast iron and foundry technology at IFC in the period between 2011 and 2020.

At IFC 2014, P**. Mrvar (ULj) with co-authors from both universities and Livar from Ivančna Gorica** presented a very demanding topic dubbed **“Manufacturing technology and characterization of gradient casting”.** A combination of horizontal centrifugal casting of white cast iron alloyed with chromium (cylinder surface) and gravity casting of a gray cast iron

bile notranje napetosti v ulitku in pojasnjen vpliv nehomogenosti porazdelitve karbidov v prvi in drugi plasti kot tudi vpliv jedra na mehanske lastnosti ulitka.

P. Mrvar je s soavtorji z obeh univerz na IFC 2018 predstavil predavanje »**Nova siva litina za transport staljenih zlitin Al«.** Prikazana sta bila razvoj in preizkušanje nove sive litine z dobro obrabno obstojnostjo in odlično toplotno prevodnostjo, ki jo je mogoče uporabiti za komore za tlačno litje. Preiskovana siva litina je bila preizkušena v tehnološki industrijski praksi, pri čemer je bilo izvedeno vrednotenje tribološkega procesa na površini cevi. Stroški proizvodnje elementa za komore iz nove prilagojene litine so bili zmanjšani za eno tretjino.

Predavanja predstavnikov univerz in raziskovalnih inštitutov kot prvih avtorjev iz sekcije neželeznih zlitin na IFC v obdobju 2011–2020.

Če sta univerzi in raziskovalni inštituti relativno slabo vključeni v sekciji jeklenih litin in litin Fe, pa je število odličnih prispevkov na področju livarstva neželeznih kovin zelo visoko; zato se bomo omejili le na 10 znanstveno in razvojno najbolj aktualnih prispevkov.

P. Mrvar (ULj) je s soavtorji na IFC v letu 2011 predstavil prispevek »**Nove možnosti izdelave kompleksnih komponent s tlačnim litjem in spajanjem**«. Pri spajanju ulitkov iz zlitin Al se vse pogosteje uporablja torno mešalno varjenje (FSW). Namen postopka je spajanje delov z različnimi lastnostmi na mestih, povezanih s strožjimi zahtevami. Dovajanje toplote pri tem spajanju je manjše kot pri standardnem talilnem varjenju, kar pomeni manjše deformacije in zaostale napetosti. Glavna težava je temperaturna porazdelitev okoli spoja med zlitino Al in čistim Al. Porazdelitev temperature je bila izračunana z metodo končnih elementov.

J. Medved je s fakultetnimi sodelavci (ULj) na 52. IFC podal predavanje **»Termodinamično modeliranje kot pomoč pri optimiranju materialov Al in tehnologij«.** Termodinamska karakterizacija livnih zlitin Al z izračunanimi in eksperimentalno pridobljenimi podatki povečuje razumevanje zlitin na osnovi Al. Pomembna je uporaba različnih kombinacij

core with spherical graphite was presented. The intermediate layer has a gray cast iron structure with flake graphite. The microstructural components were determined both quantitatively and qualitatively. With the help of computer software, density calculations were completed for each individual microstructural component. The different densities of microstructural components are the result of centrifugal forces. The internal stresses in the casting were calculated and measured and the influence of the non-homogeneity of the carbide distribution in the first and second layers as well as the influence of the core on the mechanical properties of the casting were interpreted.

At IFC 2018, **P. Mrvar with co-authors from both universities** gave the lecture titled, "**New cast iron alloy for transport of molten Al-alloys**". The development and testing of a new gray cast iron with good wear resistance and excellent thermal conductivity characteristics that can be used for die casting chambers were presented. The investigated gray iron was tested in a practical technological-industrial setting whereby the evaluation of the tribological process on the pipe surface was also undertaken. The cost of production of a chamber element from new custom cast iron was reduced by a third.

Lectures by representatives of universities and research institutes as first authors from the section for non-ferrous alloys at IFC in the period between 2011 and 2020.

Even though the universities and research institutes are relatively poorly represented in the steel and Fe castings section, the number of excellent contributions in the field of non-ferrous metal castings is extremely high, which is why we have limited ourselves to only the 10 most scientifically and developmentally relevant contributions.

In 2011 at the IFC, **P. Mrvar (ULj) and co-authors** presented the article dubbed, **"New possibilities in the production of complex components via die casting and joining".** Friction stir welding (FSW) is becoming more commonly used in the joining of Al-alloy castings. The objective of the procedure is to join parts with different characteristics in locations associated with more stringent requirements. In this type

elementov v določenih temperaturnih področjih za pridobivanje podatkov o tvorbi različnih faz. Določali so sestavo, vrsto in delež posameznih faz ter poteke ravnotežnih in neravnotežnih procesov kot tudi karakterističnih temperatur. S termično analizo so bile pridobljene informacije o termodinamičnih lastnostih, faznih premenah in izločanju faz, ki jih lahko uporabimo za zbirke podatkov in simulacije. Bistvene so natančne termodinamične lastnosti zlitin kot osnova za nadaljnje preiskave in aplikacije.

dr. Mitja Petrič (Univerza v Ljubljani)

M. Petrič je s fakultetnimi sodelavci (ULj) na 53. IFC predstavil temo **»Meritve električne upornosti zlitin Al-Si**«. Problem je vezan na izbiro ustreznega materiala za elektrode glede na tehniko štirih vzorcev zlitin Al in Al-Si. Elektrode med meritvami oksidirajo, kar poviša upornost in daje nepravilne rezultate. Preiskovani so bili različni materiali in izbrane aluminijeve elektrode. Prednost je v tem, da med ulivanjem ne nastopajo vmesne faze. Razvita je bila merilna naprava skupaj z merilno celico za meritve električne upornosti med strjevanjem »in situ«. Analizirane so bile različne Al-Si-zlitine. Ugotovljeno je bilo višanje upornosti z rastjo vsebnosti silicija**.**

J. Medved je s fakultetnimi sodelavci (ULj) in (UM) na 54. IFC izpostavil temo, ki je širše koristna za livarstvo aluminija, z naslovom »**Fazna ravnotežja v aluminijevih livarskih zlitinah v odvisnosti od vsebnosti Si in Fe«.** Železo v zlitinah Al predstavlja težavo ne toliko zaradi zvišanja trdote, ampak povečanja krhkosti. Raziskana so bila fazna ravnotežja v zlitinah Al-Si in vpliv razmerja železo/silicij. Pri preiskavi so uvajali železno žico v iz čistih komponent izdelano zlitino AlSi12Cu (Fe) pri temperaturi 750 °C in različnih časih raztapljanja. Za ugotavljanje značilnih temperatur procesa taljenja in strjevanja in s tem sproščanja toplote je bila uporabljena metoda simultane termične analize (STA). Z uporabo programa Thermo-Calc so bili izvedeni termodinamična simulacija napovedovanja faznega

of joining, the heat charge is lower compared to standard fusion welding, resulting in reduced deformation and less residual stresses. The main problem is the temperature distribution near the junction between the Al alloy and pure Al. The temperature distribution was calculated via the finite element method.

At the 52nd IFC, **J. Medved with faculty associates from (ULj)** gave the lecture dubbed, **"Thermodynamic modeling as a support for optimization of aluminium materials and technologies"**. The thermodynamic characterization of Al-cast alloys with calculated and experimentally obtained data improves the understanding of Al-based alloys. It is imperative to use different combinations of elements in specific temperature ranges in order to obtain data on the formation of various phases. The composition, type and proportion of individual phases was determined along with the course of equilibrium and non-equilibrium processes as well as characteristic temperatures. The thermal analysis has granted insight into thermodynamic properties, phase transformations and phase precipitation that can be used for databases and simulations. The precise thermodynamic properties of alloys are the basis for further research and applications.

At the 53rd IFC, **M. Petrič with faculty associates from (ULj)** gave the lecture titled, **"Measurement of electrical resistance of Al-Si alloys".** The issue is related to the selection of a suitable electrode material in line with the technology of four samples of Al- and Al-Si alloys. During measurement, the electrodes oxidize, increasing the resistance and yielding incorrect results. Various materials and selected aluminum electrodes were investigated. The advantage is that no intermediate phases occur during casting. A measuring device was developed together with an "in situ" measuring cell for the measurement of electrical resistance during solidification. Various Al-Si alloys were analyzed. It was determined that the resistance increases with the increased Si content.

At the 54th IFC, **J. Medved with faculty associates from (ULj) and (UM)** presented a topic useful throughout the aluminium casting industry titled, **"Phase equilibrium in aluminium cast alloys depending on Si and Fe content".** Iron in Al-alloys pose a problem

ravnotežja nastalih faz železa in vrednotenje eksperimentalnih podatkov kot tudi izračun za fazne diagrame pri različnih razmerjih Fe/Si. **M. Petrič je s fakultetnimi sodelavci (ULj) in (UM)** na 55. IFC podal raziskovalno temo »**Meritve dimenzijskih sprememb med strjevanjem zlitin Al-Si**«. Predstavljeno je bilo strjevanje AlSI12-zlizine z uporabo različnih tehnik, kot so termična analiza, dilatometrijska analiza in termodinamični izračuni s programsko opremo Thermo-Calc. Metalografske raziskave so bile izvedene z optično mikroskopijo in mikroskopijo SEM. Fazne analize so izdelane z EDS. Analizirani so bili štirje vzorci: osnovna zlitina AlSi12 brez dodatkov, zlitina ALTi5B1 z udrobnjevanjem zrn, modificirana osnovna zlitina AlSi10 in osnovna zlitina. Analizirane so bile mikrostrukture in izvedena dilatometrična analiza, ki je pokazala razlike v krčenju osnovne litine in modificiranih litin, kjer je ugotovljeno manjše krčenje.

dr. Maja Vončina (Univerza v Ljubljani)

M. Vončina je s soavtorji s fakultete (ULj) in zainteresiranim podjetjem Hidria Rotomatika, na 56. IFC predstavila skupno raziskavo z naslovom »**Vpliv livarskih napak na električne lastnosti ulitka iz aluminija**«. Dosedanja tehnologija visokotlačnega litja aluminijskih kratkostičnih kletk rotorja indukcijskega elektromotorja je sicer zadovoljila zahtevam po visoki produktivnosti, ne pa tudi končni učinkovitosti elektromotorjev. Zato je bila izvedena raziskava vpliva nečistoč in poroznosti na električne lastnosti ulitkov iz Al s sestavo: Al99,99; Al99,7; in Al99,5; pri različnih pogojih litja, in sicer v vakuumu in na zraku. Med strjevanjem sta bili merjeni temperatura ter električna prevodnost ulitka. Vzorci so bili analizirani z optičnim mikroskopom z namenom analize poroznosti in z vrstičnim elektronskim mikroskopom z namenom analize faz in nečistoč. Na osnovi navedenih analiz je bil pojasnjen vpliv deleža nečistoč in poroznosti na električne lastnosti ulitega aluminija.

not due to the increase in hardness, but instead increased brittleness. Phase equilibria in Al-Si alloys and the influence of iron v. silicon ratio were researched. In the research, iron wire was introduced into an AlSi12Cu (Fe) alloy made from pure components at the temperature of 750 °C and at different melting times. The Simultaneous Thermal Analysis (STA) method was used to determine the typical temperatures of the melting and solidification processes and consequently heat release. Using the Thermo-Calc software, a thermodynamic simulation of the phase equilibrium prediction of the generated iron phases was carried out along with the evaluation of experimental data and the calculations for phase diagrams for different Fe/Si ratios.

At the 55th IFC, **M. Petrič with faculty associates from (ULj) and (UM)** gave the lecture named, **"Measurement of dimensional changes of AlSi alloys during solidification".** Examined was the curing of AlSI12 using various techniques such as thermal analysis, dilatometry and thermodynamic calculations using Thermo-Calc. Metallographic investigations were carried out via optical and SEM microscopy. Phase analyzes were performed using EDS. Four samples were analyzed: AlSi12 base alloy without additives, ALTi5B1 alloy with grain refinement, modified AlSi10 base alloy and base alloy. Microstructures were analyzed and dilatometry was performed, showcasing the differences in the shrinkage of base cast iron and modified cast iron, where a lesser degree of shrinkage was determined.

At the 56th IFC, **M. Vončina with co-authors from the Faculty (ULj) and the participating undertaking Hidria Rotomatika**, presented the joint research dubbed, **"Influence of foundry defects on the electrical properties of Al-castings".** The current technology of high-pressure die casting of aluminum induction electric motor short-circuit cages has met the requirements for high productivity, however, the target efficiency of electric motors has not. As a result, the study was conducted on the influence of impurities and porosity on the electrical properties of Al castings with the following composition: Al99.99; Al99.7; and Al99.5; under different casting conditions, i.e. vacuum and atmospheric. During solidification,

prof. dr. FRANC ZUPANIČ (Univerza v Mariboru)

F. Zupanič (UM) je s sodelavci s fakultete na 57. IFC predstavil raziskavo **»Uporaba fokusiranega ionskega snopa pri karakterizaciji livnih zlitin Al**«. Mikrostrukture livnih zlitin Al vsebujejo številne mikrostrukturne sestavine mikro- ali nanovelikosti. Za metalografsko analizo se najpogosteje uporabljajo standardne metode, kot so svetlobna mikroskopija, vrstična in presevna elektronska mikroskopija ter rentgenska difrakcija. Dodatne informacije o mikrostrukturi pa nam omogočajo metode dvojnega snopa: fokusiranega ionskega snopa (FIB) in elektronskega snopa (SEM). Pri FIB pospešeni ioni (običajno galijevi) ob trku z vzorcem izbijajo atome in tako odstranjujejo material. Pri tem nastajajo različni signali, ki se lahko uporabljajo za slikanje s SEM. Predstavljena je raziskava FTB-SEM pri metalografskih raziskavah livnih zlitin Al. Možni so prečni prerezi na točno določenih mestih ter odkrivanje razporeditve in oblike mikrostrukturnih sestavin pod površino vzorca. Možna je tudi 3D-rekonstrukcija mikrostrukture.

prof. dr. Jožef Medved (Univerza v Ljubljani)

J. Medved je s sodelavci s fakultete (ULj) in strokovnjakom iz podjetja Talum d.d. na 58. IFC podal skupno raziskavo »**Vpliv manjšega dodatka legirnih elementov na livarske Al-zlitine**«. Predstavitev je obravnavala modeliranje inovativnih zlitin Al z boljšimi lastnostmi za visokotemperaturne aplikacije. Podana je bila analiza vpliva dodatka Zr in Mo na strjevanje AlSiMgMn-zlitine z uporabo termodinamičnih izračunov, termične analize in diferencialne kalorimetrije. Za določanje mikrostrukture preiskovanih zlitin pa sta bila uporabljena optična mikroskopija in elektronska vrstična mikroskopija z energijsko disperzijsko

the temperature and electrical conductivity of the casting were measured. The samples were analyzed using an optical microscope for the purpose of porosity analysis and with a scanning electron microscope for the purpose of phase and impurity analysis. Based on these analyses, the influence of impurities and porosity on the electrical properties of cast aluminum was interpreted.

At the 57th IFC, **F. Zupanič (UM) with the associates from the faculty** presented the research dubbed, **"Application of a focussed ion beam by characterization of casting Al-alloys".** The microstructures of cast Al-alloys contain numerous microstructural components in the micro and nano ranges. Standard methods, e.g. light microscopy, scanning and transmission electron microscopy as well as X-ray diffraction, are used mostly in metallographic analysis. Additional information on the microstructure is obtained via the dual beam methods: focused ion beam (FIB) and electron beam (SEM). In FIB, accelerated ions (as a rule gallium) eject atoms upon impact with the sample, eliminating material. This generates various signals that can be used in SEM imaging. The FTB-SEM research in metallographic studies of Al-cast alloys is presented. Cross-sections at precisely defined locations and the detection of the distribution and shape of microstructural components below the sample surface are possible. 3D-reconstruction of the microstructure is also possible.

At the 58th IFC, **J. Medved with associates from the faculty (ULj) and the expert from Talum** d.d., presented the joint study, **"Impact of small addition of alloying elements on Al alloys".** The presentation addressed the modeling of innovative Al alloys with improved properties for high-temperature applications. An analysis of the influence of the addition of Zr and Mo on the solidification of AlSiMgMn using thermodynamic calculations, thermal analysis and differential calorimetry was presented. Optical microscopy and electron scanning microscopy with energy-dispersive X-ray spectroscopy were used to determine the microstructure of the investigated alloys. The chemical composition, type and amount of phases as well as solidification temperatures of laboratory and industrial samples of alloys were analyzed. With the addition of Zr, a new

spektroskopijo. Analizirana je bila kemična sestava, vrsta in količina faz ter temperatura strjevanja laboratorijskih in industrijskih vzorcev zlitin. Z dodatkom Zr se v zlitini oblikuje nova igličasta faza. Dodani Mo je vključen v fazo AlFeMnSi, pri čemer delno oblikuje novo fazo AlFeMnMoSi z drugačno morfologijo.

B. Zeka je s sodelavci s fakultete (ULj) je na skupnem 59. IFC in Tehničnem forumu Svetovne livarske organizacije predstavil raziskavo **»Razvoj novih livarskih zlitin na osnovi Al z dodatkom Li«.** Dodatek litija k Al predstavlja zmanjšanje teže ulitka, saj vsak ut.% Li, dodan k Al, zmanjša gostoto za 3 % in zviša modul elastičnosti. Raziskan je bil učinek dodatka Li v količini 1,46 ut.% k zlitini AlSi7Mg (7,05 %Si in o,35 %Mg). Zlitina ima po naravnem staranju zmanjšano gostoto in višjo trdoto. Z raziskavo je bilo dokazano, da se z dodatkom Li spremenijo mikrostrukturne in mehanske lastnosti. V strukturi nastane nova faza AlSiLi, ki izboljša trdnost zlitine. Z vrstično elektronsko mikroskopijo in rentgensko difrakcijo je bilo potrjeno, da dodatek Li vodi mikrogradnike AlLiSi , α-Al in βSi.

J. Medved (ULj) je s soavtorji iz Inštituta za kovinske materiale in tehnologijo z ULj ter podjetja Talum d.d. Kidričevo na skupnem 59. IFC in Tehničnem forumu Svetovne livarske organizacije predstavili raziskavo »**Kemijska, mehanska in toplotna obraba orodij ob stiku z livnimi zlitinami Al«.** Tlačno litje je eden najpomembnejših livarskih postopkov. Med postopkom prihaja do neposrednega stika in s tem do kemične interakcije med orodjem iz jekla in talino. To vodi do mehanske in toplotne obrabe orodij. Visoka produktivnosti postopka zahteva visoko odpornost orodja. V raziskavi sta bila uporabljena vzorca iz jekel UTOPMO1 in RAVNEX XD, in sicer za analizo odpornosti proti obrabi ob stiku z litino Al99,7 in AlSi12. Izdelana je bila laboratorijska naprava za testiranje orodnih jekel pri dveh različnih temperaturah v času 4 ure pri 75 vrtljajih na minuto. Posledica interakcije je rast reakcijske plasti. Odpornost orodnega jekla UTOPMO1je v zlitini AlSi12 v primerjavi z zlitino Al99,7 veliko boljša kot odpornost jekla RAVNEX HD. Prav tako velja ugotovitev, da se debelina interakcijskega sloja poveča s naraščajočo temperaturo.

needle phase is formed in the alloy. The alloying Mo is included in the AlFeMnSi phase, partially forming a new AlFeMnMoSi phase with a different morphology.

At the joint 59th IFC and World Foundry Organization Technical Forum, **B. Zeka with associates from the faculty (ULj)** presented the research labelled **"Development of new Al-based alloys with the addition of Li".** The addition of lithium to Al constitutes a reduction in the weight of the casting since each wt.% Li added to Al reduces density by 3% while increasing the elastic modulus. The effect of the addition of Li in the total of 1.46 wt.% to AlSi7Mg (7.05% Si and 0.35% Mg) was investigated. The alloy has a reduced density and a higher hardness following natural aging. Research has shown that the addition of Li changes the microstructural and mechanical properties. A new AlSiLi phase is formed in the structure, improving the strength of the alloy. Via scanning electron microscopy and X-ray diffraction, it was confirmed that the addition of Li leads the micro constituents AlLiSi, α-Al and βSi.

At the joint 59th IFC and World Foundry Organization Technical Forum, **J. Medved (ULj) with co-authors from the Institute of Metals and Technology, ULj and Talum d.d. Kidričevo** presented the research **"Chemical, mechanical and thermal wear of tools in contact with Al alloys".** Die casting is one of the most important casting processes. During die casting occurs the direct contact and thus the chemical interaction between the steel die and the melt. This causes mechanical and thermal wear of the dies. High process productivity requires high tool resistance. Samples made of UTOPMO1 and RAVNEX XD steels were used in the research to analyze the wear resistance upon contact with Al99,7 and AlSi12 alloys. A laboratory device was fabricated for the testing of tool steels at two different temperatures for 4 hours at 75 rpm. The interaction results in the growth of the reaction layer. The resistance of UTOPMO1 tool steel in AlSi12 is much better versus Al99.7 compared to the resistance of RAVNEX HD steel. It is also true that the thickness of the interaction layer increases with temperature.

V nadaljevanju vam predstavljamo najpomembnejša predavanja predstavnikov slovenskih livarskih podjetij v obdobju 2011–2020 kot prispevek k razvoju znanja in tehnološkega napredka ter uspešnosti mednarodne livarske konference v Portorožu.

Na področju jeklo-litine in železove litine ter livarske tehnologije predstavljamo naslednje prve avtorje, podjetja, iz katerih prihajajo, in leto predstavitve:

Bojan Črtalič
(FerroČrtalič d.o.o.)

B. Črtalič (FerroČrtalič d.o.o., Dolenjske Toplice) in soavtorji, 2012: Izjemne tehnološke rešitve razigljevanja in čiščenja livarskih izdelkov z avtomatizacijo, robotizacijo in novimi tehnologijami, razvitimi v podjetju.

Prva rešitev razigljevanja drobnih in preciznih ulitkov iz zlitin Zn je sicer konvencionalna. Razvoj je bil narejen na zelo preciznih kosih, namenjenih masovni proizvodnji telefonov, elektronskih komponent in navigacijskih naprav, ki zahtevajo zelo natančno rokovanje in rešitve. Uvedena je bila popolna avtomatizacija procesa brez prisotnosti upravljavca. Druga rešitev razigljevanja je bila predstavljena na primeru zaporednega zalaganja z robotom in zaporedne avtomatske operacije peskanja posameznih mest na izdelku vse do robotske vizualizacije. Študije so pokazale veliko prednost čiščenja z mikro peleti iz suhega ledu in v določenih primerih tudi s suhim snegom.

J. Pristavec (EXOTERM-IT, Kranj) in soavtorji, 2013: Razvoj ter optimizacija livarske tehnologije ulitka iz nodularne litine z uporabo numerične simulacije.

Prikazan je bil proces razvoja ter optimizacije tehnologije litja zahtevnega ulitka z ročno izdelavo forme iz mešanice kremenčevega peska in vodnega stekla z neto težo 3.400 kg in bruto težo 4.560 kg iz nodularne litine EN-GJS-400 -15 . Livni sistem je bil najprej določen na osnovi standardnega preračuna geometrijskih modulov kritičnih delov ulitka. S standardno rešitvijo zahtevnega ulitka ni bilo mogoče izdelati brez

Hereinafter, we present the most important lectures of representatives of Slovenian foundry companies in the period between 2011 and 2020, as contributions to the development of knowledge and technological progress as well as the success of the international foundry conference in Portorož.

In the field of steel foundry as well as cast iron and foundry technology, we present the following first authors, the companies they are employed with and the year of the presentation:

B. Črtalič (FerroČrtalič d.o.o. Dolenjske Toplice) and co-authors, 2012: Exceptional technological solutions for deburring and cleaning of foundry products via automation, robotics and new technologies developed in the company.

The first solution for degreasing small and precise castings from Zn-alloys is conventional. The development was made on very precise pieces intended for the mass production of telephones, electronic components and navigation devices that require very precise handling and solutions. Full process automation without the operator's presence has been introduced. Another deburring solution was presented based on the example of sequential loading using a robot and sequential automatic sandblasting operations of individual product areas, all the way to robotic visualization. Studies have indicated a great advantage of cleaning with dry ice micro pellets and in certain cases also dry snow micro pellets.

J. Pristavec (EXOTERM-IT, Kranj) and co-authors, 2013: Development and optimization of ductile iron casting foundry technology using numerical simulation.

The development and optimization process of casting technology for demanding castings with manually produced moulds from a mixture of quartz sand and sodium silicate with a net weight of 3,400 kg and a gross weight of 4,560 kg from ductile iron EN-GJS-400 -15 is presented. The casting system was first determined on the basis of a standard calculation of the geometric modules of the casting's critical parts. However, with the standard solution, it was not possible to produce a complex casting without defects. As a result, a more efficient computer simulation process for the calculation of critical parts of the casting was investigated. The Magma 5v5.20

napak. Zato se je pristopilo k učinkovitejšemu postopku računalniške simulacije preračunov kritičnih delov ulitka. Uporaben je bil paket Magma 5v5.20, ki se vključuje že v razvojno fazo načrtovanja in nato v samo optimizacijo tehnologije litja ter predvidene končne lastnosti ulitka. Bistveni elementi izboljšave so bili na zunanjem obodu zahtevnega ulitka z uporabo hladilnih kokil in usmerjenim strjevanjem ter znižanjem temperature litja. Izrazito je bil zmanjšan izmet, skrajšan čas izdelave ter znižani stroški.

D. Mitrović (Livar d.d., Ivančna Gorica) in soavtorji, 2014: Učinek vibracij in lokalne ohlajevalne hitrosti na evtektoidno premeno v sivi litini s kroglastim grafitom.

Študija je izpostavila vpliv vibriranja in hitrosti ohlajevanja na evtektoidno transformacijo v litini EN-GJS-500-7. Ulitki so bili uliti v podjetju Livar z uporabo avtomatske horizontalne linije za sveži pesek, in sicer na standarden način ulivanja. Raziskana je bila evtektoidna transformacija. Uporabljene so bile metode metalografskih raziskav z optičnim mikroskopom in različne rastrske kalorimetrične metode, izvedene meritve trdote različnih debelin ulitkov in meritve nateznih trdnosti ter morfologije grafitnih delcev in mikrostrukturnih komponent. S simulacijo strjevanja in termično analizo so bile določene strjevalne značilnosti ter ohlajevalne krivulje.

U. Klančnik (Valji d.o.o., Štore) in soavtorji, 2015: Karakterizacija modificirane indefinitne litine za izdelavo delovne plasti valjev.

dr. Matej Drobne
(Valji d.o.o.)

Za doseganje zahtevanih končnih lastnosti plasti ulitih valjev je ključno doseganje ustrezne lite strukture. Za zagotovitev potreb po primerni granulaciji sestave drobnozrnatih modifikacij se dodajajo heterogene nukleacijske kali, ki omogočajo razvoj zahtevanih struktur posameznih plasti. Predstavljen je bil učinek modificiranja taline s ferovanadijem in ferovolframom. Modifikator je bil v curek taline med samim izpustom litine iz peči dodajan v obliki

software suite, which is already used in the planning development phase and during the optimization of casting technology as well as the anticipated final properties of the casting. The essential elements of improvement were located on the outer perimeter of the demanding casting using cooling moulds and directional solidification as well as by lowering of the casting temperature. Ejection was significantly reduced while production time and costs were reduced.

D. Mitrović (Livar d.d., Ivančna Gorica) and co-authors, 2014: Effect of Vibration and Cooling Rate Effect on Eutectoid Transformation in Spheroidal Graphite Cast Iron.

The research highlighted the impact of vibration and cooling rate on the eutectoid transformation of cast iron EN-GJS-500-7. The castings were cast at Livar using an automatic horizontal green sand line in a standard casting process. The eutectoid transformation was investigated. The methods of metallographic research with optical microscopy and various raster calorimetric methods were used, along with hardness measurements of different casting thicknesses and tensile strength measurements, as well as the morphology of graphite particles and microstructural components. Coagulation characteristics and cooling curves were determined in a solidification simulation and via thermal analysis.

U. Klančnik (Valji d.o.o., Štore) and co-authors, 2015: Characterization of a modified indefinite chill cast iron working layer in rolls.

In order to achieve the required final cast roll layer structure, it is crucial to provide for the suitable casting structure. To meet the need for appropriate granulation of the composition for fine-grained modifications, heterogeneous nucleation seeds are added, enabling the development of the required structures of individual layers. The effect of melt modification with ferrovanadium and ferrotungsten was presented. The modifier was added to the melt stream in the form of a fine-grained powder during the discharge of the cast iron from the furnace. Analyses of individual casting layers were carried out via optical microscopy and scanning electron microscopy equipped with an EDS analyzer. With proper alloying and inoculation, the achieved level of hardness was comparable to

drobnozrnatega prahu. Preiskave posameznih plasti ulitka so bile izvedene z optičnim mikroskopom ter z vrstičnim elektronskim mikroskopom, opremljenim z analizatorjem EDS. Ob pravilnem legiranju in modifikaciji je bila dosežena raven trdot, primerljiva z indefinitnimi litinami, ob hkratni ohranitvi deleža cementita v strukturi. Z analizo EDS je bila tudi dokazana prisotnost precipitatov na osnovi vanadija in volframa, ki v primerljivih kakovostih modifikacije niso bili dokazani.

B. ČUK (Siapro d.o.o., Most na Soči), 2016: Znižanje proizvodnih stroškov z regeneracijo bentonitnega peska.

V livarnah, ki uporabljajo bentonitne peske, se srečujejo s težavami prekomerne količine peska v obtoku in neprimerne granulacijske sestave peska, ki ima prevelik delež finih frakcij in inertnih snovi, iz česar izhajajo napake na ulitkih. Z raziskavami so prikazali, da lahko s primerno regeneracijo povratnega peska inertne snovi in fine frakcije vzdržujejo na ustrezni ravni in s tem zmanjšajo porabo peska tudi do 40 %. Ob tem se zmanjša tudi poraba bentonita in črnine. S takim pristopom se investicija v regeneracijo lahko povrne tudi že v dveh letih, kar pomeni močno zmanjšanje proizvodnih stroškov.

A. DROLC (ETA Cerkno d.o.o.) in soavtorji, 2017: Posodobitev livnega sistema za litje tankostenskih ulitkov iz sive litine v peščene forme.

Ob izdelavi novega izdelka iz programa kaminskih delov se je livarna soočila z visokim deležem površinskih napak, ki jih ni bilo mogoče odpraviti. Prve korekcije tehnologije litja so še vedno izkazovale napake na vidnih površinah. Napak z značilno globoko črto ni bilo mogoče odpraviti. Domneva je bila, da so za napake krive previsoke hitrosti litja, neenakomerni pretoki litine v dovodnih kanalih in posledično visoke temperature na določenih izpostavljenih mestih. Zaradi tega je bilo narejenih več simulacij litja in na ta način s kombinacijo pridobljenih rezultatov izvedene simulacije nastanka teh napak. Na osnovi analiz teh simulacij je bil posodobljen ulivni sistem, ki je nato preprečil nastanek površinskih napak na vidnih mestih izdelanega ulitka.

A. TEKAVČIČ (Kovis-Livarna d.o.o., Štore) in soavtorji, 2018: Pojav lamelnega grafita pod eksotermnimi napajalniki v ulitkih

indefinite alloys while the proportion of cementite in the structure was maintained. The presence of vanadium and tungsten-based precipitates which have not been identified in comparable modification qualities, was also demonstrated via EDS analysis.

B. ČUK (Siapro d.o.o., Most na Soči), 2016: Reduction of production costs via bentonite clay powder reclamation.

In foundries that use bentonite sands, they face problems with excess circulated sand and inadequate granular sand composition with an excessive proportion of fine fractions and inert substances, resulting in defects in castings. Research has shown that, with proper regeneration of recirculated sand, inert substances and fine fractions can be maintained at the appropriate levels while at the same time reducing sand consumption by up to 40%. At the same time, the consumption of bentonite and blacking is also reduced. Thanks to the approach, the investment into reclamation can be returned in as little as two years, resulting in a sharp reduction in production costs.

A. DROLC (ETA Cerkno d.o.o.) and co-authors, 2017: Modernization of the casting system for the casting of thin-walled castings from gray cast iron into sand molds.

When producing a new product from the fireplace parts program, the foundry was faced with a high proportion of surface defects that could not be eliminated. The first adjustments of the casting technology still resulted in defects on visible surfaces. Defects with a characteristic deep line could not be remedied. It was assumed that the errors were the result of excessive casting speeds, uneven flow of cast iron in the gate and consequently high temperatures in certain exposed locations. As a result, several casting simulations were carried out. This way, based on a combination of the obtained results, simulations of the generation of such defects were performed. Based on the analysis of these simulations, the casting system was modernized, preventing the occurrence of surface defects in visible places of the manufactured casting.

A. TEKAVČIČ (Kovis-Livarna d.o.o. Štore) and co-authors, 2018: Flake graphite formation under exothermic riser sleeves in ductile iron casting – causes and remedies

iz sive litine s kroglastim grafitom-vzroki in sredstva.

Mini napajalniki na osnovi eksotermnega procesa so na področju livarstva stroškovno izjemno pomembni, saj pri železovih zlitinah omogočajo povečanje izplenov in zmanjšanje poroznosti. Ob pozitivnih učinkih pa lahko ob tem nastajajo določene livarske napake. Predvsem je mogoče pri tem opaziti degeneracijo kroglastega grafita v lamelni grafit. Te napake se pojavljajo predvsem na predelih ulitkov, kjer so pod mini napajalniki večje debelostenske ravne površine. Namen raziskav je bil raziskati vzroke pojava degenerirane mikrostrukture ter zagotoviti ukrepe za preprečevanje teh napak. Izvršene so bile analize z optično mikroskopijo. Ugotovljeno je bilo, da prihaja pod mini napajalniki do zmanjšanja preostalega magnezija na površini ulitka. Raziskan je bil vpliv tehnoloških parametrov na nastajanje teh napak. Na osnovi teh analiz so bili določeni najustreznejši ukrepi za zmanjšanje navedenih napak oziroma za njihovo popolno preprečevanje.

M. Žbontar (EXOTERM-IT d.o.o.) in soavtorji, 2018: Uporaba tehnologije sol-gel v livarskih premazih.

Premazi na peščeni formi ali peščenem jedru omogočajo visoko temperaturno bariero med talino in formo in s tem preprečujejo medsebojne fizikalno-kemijske reakcije, kar posredno vpliva na izboljšanje površine ulitkov. Optimizacijo sestave premaza je mogoče doseči z dodajanjem komponente sol-gel, kar bistveno izboljša površino ulitka in reološke lastnosti premaza. Raziskan je bil učinek uporabe komponente sol-gel kot dodatka k premazu na vodni osnovi in cirkonskim polnilom. Preiskan je bil vpliv treh kemijsko različnih komponent sol-gel in različnih masnih razmerij med osnovnim premazom in komponento sol-gel na kakovost površine ulitkov. Uporabljena je bila metoda diferenčne vrstične kalorimetrije. Rezultati raziskav so pokazali, da uporaba komponente sol-gel v premazu izboljša površinsko kakovost ulitkov.

J. KOVAČIČ (Livar d. d., Ivančna Gorica) in soavtorji, 2019: Izdelava in karakterizacija legirane sive litine s kroglastim grafitom, ki je odporna na toplotno utrujanje.

Namen raziskave je bil izdelava legirane sive litine, ki je odporna na termično utrujanje, in

Mini exothermic process-based risers are extremely important in the foundry sector since they enable an increased yield and the reduction of porosity in iron alloys. However, thee positive effects can be accompanied also by certain foundry defects. Above all, the degeneration of spherical graphite into lamellar graphite can be observed. These defects occur mainly in the areas of castings with large thick-walled flat surfaces under the mini risers. The objective of the research was to investigate the causes of the degenerated microstructure and to provide solutions for the prevention of such errors. Completed were optical microscopy analyses. It was determined that there is a reduction of residual magnesium on the surface of the casting under the mini risers. The impact of technological parameters on the occurrence of these errors was investigated. Based on these analyses, the most appropriate measures were determined to reduce the indicated errors or to prevent them entirely.

M. Žbontar (EXOTERM-IT d.o.o.) and co-authors, 2018: Application of Sol-Gel Technology in Foundry Coatings.

A mould or core coating creates a high thermal integrity barrier between the melt and the mould, preventing physico-chemical reactions, indirectly impacting the improvement of the surface of the castings. The optimization of the coating composition can be achieved by adding a sol-gel component that significantly improves the casting surface and rheological properties of the coating. Investigated was the effect of using a sol-gel component as an additive to a water-based coating and zirconium filler. The influence of three sol-gel components with different chemical compositions and weight ratios between the base coat and sol-gel component on the surface quality of the castings was investigated. The differential scanning calorimetry method was used. The results of the research indicate that the use of the sol-gel component in the coating improves the surface quality of the castings.

J. KOVAČIČ (Livar d.d. Ivančna Gorica) and co-authors, 2019: Production and characterization of gray cast iron with spherical graphite which is resistant to thermal fatigue

s tem uporabna tako pri sobnih kot pri povišanih temperaturah. V ta namen so uporabili feritno sivo litino, ki jo predpisuje standard ISO EN-GJS 600-10, ki so ji dodajali molibden v obliki predzlitine FeMo65. Med procesom strjevanja je bila izvedena enostavna termična analiza. Iz ulitih vzorcev pa so izdelali tudi vzorce, primerne za natezni preizkus. Na fizikalnem simulatorju metalurških stanj Gleeble 1500 D so pri temperaturi 600 °C z obremenitvijo 200, 500, 1.000, 2.000 in 4.000 ciklov testirali sedem vzorcev. Z emisijskim spektrometrom je bila analizirana kemijska sestava vzorcev in na stroju Instron 5985 izvedeni natezni preizkusi. Pregledana in analizirana je bila mikrostruktura prelomnih površin, s pomočjo svetlobnega in elektronskega mikroskopa so bili analizirani nastanek in napredovanje razpok kot tudi njihova usmerjenost ter gostota. Rezultati analiz in raziskav so omogočili optimalno karakterizacijo odpornosti na toplotno utrujanje.

Janez Pristavec
(Exoterm-IT d.o.o.)

J. Pristavec (EXOTERM IT d. o. o., Kranj) in soavtorji, 2020: Analiza in optimizacija procesa izdelave peščenih jeder s pomočjo numerične simulacije in statističnih orodij.

Izdelava radijev na robovih dveh izvrtin peščenega jedra zahteva postopek v dveh korakih. V prvem se izdela segment jedra z odprtinami z radiji, v drugem pa se ta segment vstavi v jedrovnik s končno obliko jedra, tako se izdela celotno jedro po postopku coldbox. Ob tem je nastopila težava, da je v področju vnaprej izdelanega segmenta kritično mesto ostalo nezapolnjeno. Za odpravo težav je bila najprej izvedena analiza obstoječe tehnologije s programom MAGMASOFT in modulom MAGMA c+m. Ustrezni parametri so bili pridobljeni z metodo DOE in analizo rezultatov. Gonilna sila pri polnjenju jedrovnikov s peščeno mešanico je tlak zraka. Ugotovljen je bil nizek tlak v kritičnem področju, ki se ne zapolni s peskom. Z virtualno metodo so ugotavljali zapolnjenost kritičnega področja. S pomočjo programskega paketa vgrajenih statističnih orodij je bila izbrana

The purpose of the research was to produce an alloyed grey cast iron, which is resistant to thermal fatigue and is suitable for use both at room and at elevated temperatures. In the investigation, we used ferrite cast iron as defined by ISO EN-GJS 600-10, to which molybdenum was added in the form of FeMo65 master alloy. A simple thermal analysis was completed during the solidification process. From the cast samples, suitable samples for tensile testing were also produced. Seven samples were tested at a temperature of 600 °C at 200, 500, 1,000, 2,000 and 4,000 cycles on Gleeble 1500 D physical simulator of metallurgical conditions. The chemical composition of the samples was analyzed using an emission spectrometer and tensile testing was carried out using via Instron 5985. The microstructure of fractured surfaces was examined and analyzed and the formation and progression of cracks, their orientation and density were analyzed via optical and electron microscopy. The results of analyses and research has made possible the optimal characterization of resistance to thermal fatigue.

J. Pristavec (EXOTERM IT d.o.o., Kranj) and co-authors, 2020: Analysis and optimization of the sand core manufacturing process using numerical simulation and statistical tools

The generation of radii at the edges of two holes in a sand core requires a two-step process. In the first step, a segment of the core is created with openings with the radii and in the second, the same segment is inserted into the corebox with the final shape of the core and so entire core is produced via the coldbox process. Simultaneously, a problem arose where in the area of the prefabricated segment, the critical location remained unfilled. To solve the issue, an analysis of the existing technology was first carried out via MAGMASOFT software and the MAGMA c + m module. The relevant parameters were obtained via the DOE method and result analysis. The driving force when it comes to the filling of coldboxes with a sand mixture is air pressure. Low pressure was found in the critical area that was not filled with sand. The filling of the critical area was determined via a virtual method. The optimal combination of vents was determined with the use of a suite of built-

najboljša kombinacija zračnikov. To je omogočilo proizvodnja kakovostno ustreznih jeder.

Na področju livarstva barvnih kovin in z njimi povezanih tehnologij predstavljamo naslednje prve avtorje, podjetja, iz katerih prihajajo, in leto predstavitve:

mag. Andrej Megušar
(LTH Castings d.o.o.)

A. Megušar (LTH Ulitki d.o.o., Škofja Loka/Ljubljana), 2011: Optimizacija tlačnega litja z visoko zahtevo po estetskem videzu.

Uplinjači iz zlitin Al se običajno vgrajujejo na vidno mesto v prostoru motorja in s tem so povezane tudi estetske zahteve. Ulitki morajo imeti visoko kakovost površine ulitka, biti morajo brez hladnih zvarov, nezalitosti ali toplotnih razpok. Optimizacija procesa tlačnega litja je v tem primeru potekala na naslednjih področjih:

- izdelana je simulacija toka taline od talilne peči do tlačnega orodja s ciljem zagotavljanja optimalne temperature taline ob vstopu v tlačno orodje in s tem odprave hladnih zvarov;
- optimizacija polnjenja livne votline in izboljšano prezračevanje tlačnega orodja s ciljem zmanjšanja nezalitosti;
- simulacija napetosti v tlačnem orodju med procesom litja za zmanjšanje toplotnih razpok in optimiranje temperirnega sistema v tlačnem orodju.

A. Megušar (LTH Ulitki d.o.o., Ljubljana) in soavtorji, 2012: Uporaba sistema »jet cooling« za lokalno usmerjeno strjevanje ulitkov iz Al-zlitine.

Tlačni ulitki iz zlitin Al imajo pogosto funkcijo nosilnega ali tesnilnega elementa, kar zahteva visoko kakovost strukture materiala. Prav tako ni vedno mogoče zagotoviti oblike, ki bi bila najboljša za proces tlačnega litja. Posledica je nastajanje poroznosti, ki je s klasičnim litjem ni mogoče vedno odpraviti. Zato lahko lokalno uporabimo usmerjeno strjevanje, ki v določenih

in statistical tools. This way, the production of quality cores was made possible.

In the field of non-ferrous metal foundry and related technologies, we present the following first authors, the companies they are employed with and the year of the presentation:

A. Megušar (LTH Ulitki d.o.o., Škofja Loka / Ljubljana), 2011: Optimization of the pressure die casting process of a carburettor with a great demand to look perfect

Al alloy carburetors are usually installed in a visible place in the engine compartment so they are subject to aesthetic requirements. Castings must have a high quality of the surface, with no traces of cold welds, non-filling or thermal cracks. In this case, the optimization of the die casting process was focused on the following areas:

- Simulation of the melt flow from the melting furnace to the die cast tool is made with the objective of providing for the optimal melt temperatures at the entrance to the die cast tool and thus the elimination of cold welds;
- Optimization of casting cavity filling and improved ventilation of the die cast tool with the objective of reducing non-filling;
- Simulation of stress in a die cast tool during the casting process to reduce thermal cracks and optimization of the tempering system in the die cast tool.

A. Megušar (LTH Ulitki d.o.o., Ljubljana) and co-authors, 2012: Application of Jet-Cooling System for Local Directional Solidification of Aluminium-Alloy Castings

Al alloy die castings often function as load-bearing or sealing elements, thus requiring a high quality material structure. Furthermore, it is also not always possible to ensure that the shape is best suited for the die casting process. The result is the formation of porosity, which cannot always be eliminated via conventional casting. Because of this, directional solidification can be used locally, improving the quality in certain parts of the casting. Local directional solidification was performed in the following steps:

1. The parameters of the die casting process with implemented forced cooling of cores were analyzed. A solidification simulation using these cores was generated.
2. Testing of the die casting tool with the

delih ulitka izboljša kakovost. Lokalno usmerjeno strjevanje je bilo izpeljano v naslednjih korakih:

1. Analizirali so se parametri procesa tlačnega litja z implementiranimi prisilno hlajenimi jedri. Izdelana je bila simulacija strjevanja pri uporabi teh jeder. Izvedeni so bili testi tlačnega orodja z implementiranim sistemom prisilnega hlajenja jeder.
2. Izvedeni so bili primerjalni testi in ovrednotene razlike s klasičnim tlačnim litjem. Implementacija prisilno hlajenih jeder je ob zmanjšanju poroznosti omogočila drobnejšo strukturo ter izboljšanje kakovosti na področju okoli jeder.

U. Eržen (LTH Castings d. o. o., Škofja Loka) in soavtor, 2014: Simulacija tlačnega litja s pomočjo programskega paketa Magma in vpliv na življenjsko dobo orodja.

V procesu tlačnega litja zlitin Al in Mg se za premazovanja tlačnih orodij v 90 % primerov uporabljajo premazi na vodni osnovi in le v 10 odstotkih t. i. mikro-mazanje. Slabost premazov na vodni osnovi je, da prihaja na gravuri orodij do temperaturnih šokov, kar ob nastanku napetosti pospeši nastanek razpok. Pri uporabi tehnologije mikro mazanja na površini gravurnih delov ne prihaja do temperaturnih šokov, vendar je odvajanje toplote, ki se akumulira v gravurnih delih orodja, bistveno slabše. Akumulirano toploto je treba iz orodja odvesti s pomočjo ustrezne izvedbe temperirnih kanalov. V ta namen uporabljajo v podjetju LTH Castings pri konstruiranju programski paket MaGma 5.2. Po kalibraciji programskega paketa lahko izdelajo simulacijo celotnega procesa litja. Pri tovrstni simulaciji je treba upoštevati kompletno geometrijo orodja in temperirnih kanalov kot tudi večje število ciklov litja. Na osnovi rezultatov simulacije lahko optimirajo geometrijo temperirnih kanalov in parametre procesa, s katerim lahko dosežejo toplotno uravnoteženost orodja. S tem lahko dosežejo daljšo življenjsko dobo orodja.

D. Sojer (Magneti Ljubljana d. d.) in soavtorji, 2015: Centrifugalna atomizacija kosmičev Nd-Fe-B za uporabo pri izdelavi trajnih magnetov.

Trajni magneti Nd-Fe-B so v široki uporabi pri aplikacijah, kjer se zahteva visoko magnetni proizvod z namenom zmanjšanja teže izdelka. Ti magneti se uporabljajo predvsem v

implemented core forced cooling system was carried out. Comparative testing was completed and the differences vs. classic die casting evaluated. The implementation of forced-cooled cores, while reducing porosity, made possible a finer structure and improved quality in the area surrounding the cores.

U. Eržen (LTH Castings d.o.o., Škofja Loka) and co-author, 2014: Simulation of die casting using the Magma software suite and the impact on tool life.

For the process of die casting of Al and Mg alloys, 90% of water-based coatings and only 10% of so-called micro-lubrications are used for the coating of die casting tools. The disadvantage of water-based coatings is that the engraving of the tools is impacted by thermal shock, accelerating the formation of cracks on the engraving parts of the tool following the stress build-up. When using micro-lubrication technology, there are no temperature shocks impacting the surface of the engraving parts, however, the heat dissipation that accumulates in the engraving parts of the tool is substantially reduced. The accumulated heat must be removed from the tool by means of a suitable design of the tempering channels. For this purpose, LTH Castings uses the MaGma 5.2 software suite in the construction process. After the calibration of the software suite, the company can generate a simulation of the complete casting process. In the context of the simulation, it is necessary to take into account the complete geometry of the tool and the tempering channels as well as the larger number of casting cycles. Based on the simulation results, the geometry of the tempering channels and the process parameters used to achieve the thermal balance of the tool can be optimized. This makes it possible to extend the life-span of the die casting tool.

D. Sojer (Magneti Ljubljana d.d.) and co-authors, 2015: Centrifugal atomization of Nd-Fe-B flakes used for the production of permanent magnets

Permanent Nd-Fe-B magnets are widely used in applications where a highly magnetic product is required in order to reduce the weight of the product. These magnets are used primarily in the automotive and wind turbine industries. In this case, conventional casting techniques

avtomobilski industriji in v industriji vetrnih turbin. Konvencionalne livne tehnike v tem primeru povzročajo nastanek Fe in velika področja obogatenih redkih zemelj. Litje trakov, melt spinning in centrifugalna atomizacija pa dajejo homogeno in drobno strukturo. Predstavljena je bila uporaba hitrega strjevanja s centrifugalno atomizacijo za pripravo kosmičev Nd-Fe-B. Raziskani so bili vpliv sestave zlitine in različnih procesnih parametrov centrifugalne atomizacije na mikrostrukturo hitro strjenih zlitin Nd-Fe-B. Uporabljene so bile klasične metalografske metode ter optična in rasterska elektronska mikroskopija. Podani so bili vplivi procesnih metod na mikrostrukturo kosmičev v litem stanju in magnetnih lastnosti tako pripravljenih magnetov.

M. Potočnik (LTH Castings d.o.o., Ljubljana) in soavtorji, 2018: Analiza vpliva parametrov tlačnega litja na ravnost ohišja elektronike.

V avtomobilski industriji se za ohišje električnega napajalnega sistema zahteva uporaba zlitin Al. Zelo tanke stene in sorazmerno velika površina ulitka predstavljajo zahteven tehniški izziv. Funkcionalnost tozadevnega ulitka zahteva ob samih karakteristikah še zelo visoko stopnjo ravnosti ulitka. Le ulitki, ki v celoti izpolnjujejo zahtevane pogoje, zagotavljajo ustrezno delovanje ter življenjsko dobo komponente. Predstavljena je bila analiza vpliva parametrov procesa tlačnega litja na zahteve izdelane komponente: časa strjevanja, temperature tlačnega orodja, časa hlajenja ulitka v vodi ter oblike dolivnega sistema. V podjetju LTH je bil s testiranjem v serijskih pogojih preverjen vpliv parametrov litja v serijskih pogojih. Rezultate meritev na 3D-koordinatnem merilnem stroju se je analiziralo po tehnologiji 6 sigma in izvedeno je bilo tudi 3D-skeniranje ulitka. Vpliv dolivnega sistema pa je bil analiziran s pomočjo računalniške simulacije.

J. Trček (Hidria d.o.o., Ljubljana, PE Alutec) in soavtor, 2019: Optimizacija 1. faze visokotlačnega litja

Za ulitke za avtomobilsko industrijo veljajo zelo stroge zahteve glede poroznosti in tesnosti ulitkov. Pri visokotlačnem litju zahtevnih ulitkov Al na kakovost ulitka vpliva že vsaka najmanjša sprememba. Postopek poteka v treh fazah: 1. faza – polnjenje komore in dovoda ob počasnem

result in the formation of Fe and large areas of enriched rare earths. Strip casting, melt spinning, and centrifugal atomization, however, result in a homogeneous and fine structure. Outlined is the use of fast solidification via centrifugal atomization for the preparation of Nd-Fe-B flakes. The influence of the alloy composition and different process parameters of centrifugal atomization on the microstructure of rapidly solidified Nd-Fe-B alloys was examined. Classical metallographic methods and optical and scanning electron microscopy methods were used. The impacts of process methods on the flake microstructure in the as-cast state and the magnetic properties of magnets prepared in such a way were presented.

M. Potočnik (LTH Castings d.o.o., Ljubljana) and co-authors, 2018: Analysis of the influence of die casting parameters on electronics housing flatness.

In the automotive industry, power supply system housings are made from Al alloys. The very thin walls and a relatively large surface area of the casting represent a demanding technical challenge. The functionality of the casting in question requires, in addition to other characteristics, an extremely high degree of flatness of the casting. Only castings that fully meet the required conditions guarantee the proper functioning and component life. Presented was an analysis of the impact of die casting process parameters: solidification time, die casting tool temperature, cooling time of casting in water and the design of the filling system on the requirements of the manufactured component. At LTH, the impact of serial casting parameters was examined via serial testing. The results of measurements on a 3D coordinate measuring machine were analyzed using Six Sigma methodology while 3D-scanning of the casting was also performed. The influence of the filling system, however, was analyzed with the help of a computer simulations.

J. Trček (Hidria d.o.o., Ljubljana, PE Alutec) and co-author, 2019: Optimization of the 1st HPDC phase

In castings for the automotive industry, the requirements for porosity and tightness of castings are stringent. In the high-pressure die casting of demanding Al castings, even the slightest of changes will impact the quality of the


Jaka Trček (Hidria d.o.o.)

premiku bata; 2. faza – polnjenje gravure in pretokov ob hitrem pomiku bata; 3. faza – visok končni tlak bata kot nadomestilo krčenja v gravuri. Pomembna kakovostna zahteva je preprečevanje poroznosti. Zračno poroznost lahko povzročimo z napačno nastavitvijo že v prvi fazi. S pomočjo simulacijskega programa Magmasoft so simulirali produkcijsko krivuljo. Izvedena je bila virtualna optimizacija prve faze in preizkušena na dejanskem procesu s testiranjem polnjenja ter izbrana rešitev, ki je bistveno zmanjšala poroznost ulitkov. Najboljši rezultati so bili doseženi s hitrostjo bata v 1. fazi 0,29 m/s.

M. Purg (Talum d. d., Kidričevo), 2019: Učinkovit poslovni model za inovativni razvoj in trajnostno rast na področju proizvodnje aluminijevih ulitkov v podjetju Talum d.d.


M. Purg
(Talum d. d., Kidričevo)

Podjetje Talum d.d. je razvilo svoj model povečanja proizvodnje izdelkov z višjo dodano vrednostjo, kamor prištevajo tudi proizvodnjo ulitkov. Razvoj proizvodnje ulitkov Al, ki je v zadnjih letih zelo intenziven, je zasnovan na treh različnih postopkih: visokotlačnem, nizkotlačnem in nagibno-gravitacijskem kokilnem litju. Pospešen razvoj proizvodnje ulitkov je vezan na osnoven program raziskav in razvoja celotnega podjetja, ki sloni na lastnem modelu povečanja proizvodnje izdelkov z višjo dodano vrednostjo ob vključevanju dosedanje tradicije proizvodnje zlitin Al, avtomatizacije, izdelave orodij in proizvodne opreme ter celovitega vključevanja informacijske podpore. Prednost je tudi v prenosu obstoječega znanja v dodatne dejavnosti, ki zagotavljajo višjo vrednost. Talum ima specifična znanja in tehniške rešitve, ki omogočajo hitrejši razvoj

casting. The process takes place in three stages: Phase 1 filling of the chamber and inlet with slow piston movement. Phase 2 filling of engraving and flows with rapid piston movement. Stage 3 final high piston pressure to compensate for the shrinkage in the engraving. The prevention of porosity is an important aspect of quality requirement. Air porosity can be caused by the incorrect adjustment already during the first phase. The production curve was simulated using the MagmaSoft simulation software. The virtual optimization of the first phase was performed and tested on the concrete process by test filling while a solution was selected that significantly reduces the porosity of the castings. The best results were achieved with a piston speed of 0.29 m/s in phase 1.

M. Purg (Talum d.d., Kidričevo), 2019: An efficient business model for the innovative development and sustainable growth of the production of aluminum castings in Talum d.d.

Talum d.d. has developed its own model for increasing the production of products with higher added value, which also encompasses the production of castings. The development of Al casting production, which has become highly intensive in recent years, is based on three processes: high pressure die casting, low pressure die casting and tilting gravity die casting. The accelerated development of casting production is connected to the fundamental R&D programme of the total company, which is based on its own model of increasing the production of higher value-added products, incorporating the current tradition of production of Al alloys, automation, tooling and production equipment as well as the comprehensive integration of information support. The advantage is also in the transfer of existing knowledge into additional activities that provide higher value. Talum possesses specific knowledge and technical solutions that facilitate the development of new activities. Talum has also established an innovative and efficient development environment that, thanks to collaboration of other companies as well as educational and research institutions, provides for efficient development.

A. Gusel (Mariborska livarna Maribor d.d.) and co-author, 2019: Prediction and preventive correction of distortions of

novih dejavnosti. Talum je vzpostavil tudi inovativno in učinkovito razvojno okolje, ki ob sodelovanju drugih podjetij in izobraževalno-raziskovalnih institucij omogoča učinkovit razvoj.

A. Gusel (Mariborska livarna Maribor d. d.) in soavtor, 2019: Določanje in preventivna korekcija deformacij tlačno ulitih aluminijskih izdelkov za avtomobilsko industrijo.

Ena glavnih težav pri litju geometrijsko kompleksnih izdelkov iz aluminijskih zlitin so deformacije ulitkov. To še posebej velja pri zelo ozkih tolerancah izmer ulitkov, ki naknadno niso mehansko obdelani. Prav tako lahko težave povzročajo zaostale napetosti v ulitkih. Zato težavo rešujejo s predvidevanjem deformacij. V ta namen se upoštevajo praktične in računske deformacije ulitkov. Praktično je to mogoče z dejanskim litjem v prototipno orodje, teoretično pa z numeričnimi simulacijami s paketom Magmasoft. Primerjava med simulirano deformacijo in dejansko deformiranim delom se izvaja s postopkom 3D-skeniranja ulitka. V naslednjem koraku se izvede preddeformirani 3D-model, s katerim se želi izničiti deformacije. Končni cilj je uporaba korigiranega 3D-modela za izdelavo serijskega orodja, ki bi v serijski proizvodnji zagotavljalo oblikovno skoraj popolne dele.

K. Turk, (LTH Castings d. o. o., Ljubljana), 2020: Lasersko procesiranje visokotlačnih aluminijskih ulitkov z namenom povišanja adhezivnosti površine.

Ohišja in pokrovi elektronskih komponent, proizvedeni s postopkom visokotlačnega litja, imajo pogosto visoke zahteve za čistost in adhezivnost površine tlačnega ulitka. Pri procesu tlačnega litja se na površino izdelka vnaša nečistoče, ki so posledica narave samega postopka in okolja livarne. Kljub kasnejšemu vibracijskemu loščenju izdelkov in pranju ulitkov se nečistoče s površine ne odstranijo v zadostni meri, ki bi zagotavljala ustrezno adhezivnost površine. Obstaja več postopkov za izboljšanje adhezivnosti površine. V tej raziskavi pa je bila uporabljena rešitev z laserskim procesiranjem površine tlačnega ulitka. S hitro pulzirajočim laserjem visoke moči in ustreznim oblikovanjem žarka ter fokusne pege laserja lahko dosežemo odstranitev nečistoč s površine in zelo plitko pretalitev zgornjega sloja površine, kar izboljša tudi korozijsko odpornost površine. Kljub vnosu

high-pressure die-cast aluminium parts for automotive industry.

One of the main issues in the casting of geometrically-complex aluminum alloy castings are the deformation of castings. This is especially true in case of very dimension tolerances of castings that are not subsequently machined. Similarly, they can also result in issues due to residual stress in castings. As a result, the issue is being solved via deformation prediction. For this purpose, practical and computational casting deformations are considered. In a practical sense, this is possible with actual casting into a prototype tool, and in theory, with numerical simulations with the Magmasoft software suite. The comparison between the simulated deformation and the actual deformed part is performed via 3D scanning of the casting. In the next step, a pre-deformed 3D-model is implemented in order to eliminate the deformations. The ultimate objective is to use a corrected 3D-model that would enable the production of a serial tool that ensures the production of parts in serial production of near-perfect dimensions.

K. Turk, (LTH Castings d.o.o., Ljubljana), 2020: Laser processing of HPDC aluminium parts with the aim of increasing surface adhesion.

Enclosures and covers for electronic components manufactured via high-pressure die casting often have strict requirements regarding the purity and adhesiveness of the die cast surface. In the die casting process, impurities are introduced onto the surface of the product, which are the result of the nature of the process itself as well as the foundry environment. Despite subsequent vibration polishing of the products and the washing of the castings, impurities are not removed from the surface to a sufficient extent in order to achieve adequate surface adhesion. There are several procedures that aim to improve surface adhesion. However, in this study, a solution with laser processing of the die cast surface was used. With a quick pulsing high-power laser and the appropriate beam and focal spot design, the removal of impurities from the surface and very shallow melting of the upper layer of the surface can be achieved, improving also the corrosion resistance of the surface. Despite the high energy input into the surface as

velike energije v površino se zaradi hitrosti pulziranja in kratkega časa pulza površina ne segreje, zato ni vpliva na geometrijo izdelka. Ustreznost postopka se potrjuje s postopkom testiranja sklopa v slani komori, testi odpornosti na korozijo, pregledom mikrostrukture in testom lepljenja, kjer se opazuje, ali prihaja do kohezivnega ali adhezivnega loma silikona.

N. Marčič (Mariborska livarna Maribor d. d.) in soavtorji, 2020: Optimizacija hlajenja tlačno ulitega dela z uporabo numeričnega izračuna.

Numerični izračuni livarskih procesov nam omogočajo vpogled v posamezno sekvenco litja in pomagajo odkriti in razumeti vzroke za nastale napake. Z razumevanjem vzrokov napak se lahko procesi učinkovito optimizirajo in novo tehnologijo preizkusimo najprej virtualno z izračunom z optimiziranimi robnimi pogoji. Prikazan je primer uspešne uporabe numeričnih izračunov za optimizacijo tlačno ulitega elementa. V tem primeru je prihajalo do težav s pregrevanjem posameznih delov orodja in jeder. Na podlagi natančne analize z numeričnim izračunom so bile predlagane spremembe hladilnega sistema. K reševanju izvedbe hlajenja se je nato pristopilo z numeričnim izračunom. Za učinkovito odvajanje toplote je bilo treba povečati površino hladilnega sistema na kritičnih mestih. Najbolj inovativen način je bil uporabljen na jedrih. Hladilni kanali so bili ustrezno približani površini jedra in s tem so izboljšali odvajanje toplote. Na kompleksnejših delih orodja je bila uporabljena kombinacija klasičnega vrtanja in varjenja za optimalno razporeditev hladilnih kanalov. Vse rešitve so bile najprej z numeričnimi izračuni preizkušene virtualno in po doseženem želenem temperaturnem polju v orodju so bile izvedene dejanske spremembe orodja.

Slovenska znanost je kreator znanja in znanje je bistveno za razvoj. Slovensko livarstvo je bilo kot panoga dokaj stabilno, z rastjo in tudi spremembami skladno z zahtevami trga in možnostmi. IFC Portorož je zaradi sodelovanja industrijske panoge s tujim trgom izjemnega pomena, saj spremlja aktualne spremembe ne le v tehnologiji, temveč tudi v ustvarjanju poslovnih mrež, ki jih panoga za obstoj nujno potrebuje. Univerza je mesto, kjer nastaja znanje, ki se prenaša na mlajše generacije. Vključevanje

a result of the pulsation speed and short pulse time, the surface does not heat up and does not affect the product geometry. The suitability of the process is confirmed via testing of the assembly in the salt chamber, corrosion resistance testing, microstructure examination and adhesion testing, where cohesive or adhesive silicone fracture is observed or occurs.

Mag. Andrej Mikložič, zvesti udeleženec IFC iz Mariborske livarne Maribor

N. Marčič (Mariborska livarna Maribor d.d.) and co-authors, 2020: Cooling optimization HPDC casted part using numerical calculation.

Numerical calculations of foundry processes provide insight into an individual casting sequence and help discover as well as understand the causes of the resulting defects. By understanding the causes of errors, processes can be efficiently optimized while the new technology is initially tested in a virtual setting via the calculation with optimized boundary conditions. An example of the successful use of numerical calculations for the optimization of a die cast element is presented. In this example, problems with the overheating of individual parts of the tool and cores arose. Based on a detailed analysis by means of numerical calculations, changes to the cooling system were proposed. The cooling issue was then subjected to a numerical calculation. For efficient heat dissipation, it was necessary to increase the area of the cooling system in critical locations. The most innovative method was used on the cores. The cooling channels were suitable close to the surface of the core, which increased heat dissipation. On more complex tool parts, a combination of classic drilling and welding was used for the optimal arrangement of cooling channels. Every solution was first tested virtually via numerical calculations while after the desired temperature field in the tool was reached, actual tool changes were implemented.

Slovenian science is the originator of knowledge and knowledge is essential for

Dr. Sebastjan Kastelic, dolgoletni aktivni sodelavec IFC

študentov v projekte, ki jih vodi univerza, je osnova za hitrejše vključevanje v gospodarstvo. Vsakoletni livarski kongres v Portorožu ima tradicijo in sloves ter je ena prioritet v sodelovanju z lastnim gospodarstvom in mednarodnim prostorom. To danost dosedanjih generacij je treba spoštovati in s tem izkoristiti vse povezave, ki so možne tudi prek IFC. 60 let IFC je vrednota, ki jo ima le malokatera industrijska panoga. Vsi, ki sodelujemo, bi morali to ceniti in se vključevati v čim uspešnejše in konkurenčne projekte. Če s tem povežemo še naš Livarski vestnik kot strokovno glasilo z 67-letno tradicijo, potem imamo ob dobrih izobraževalnih in raziskovalnih inštitucijah nekaj, kar daje panogi ugled in možnosti konkurenčnosti na vse zahtevnejšem globalnem trgu.

Vodja znanstvenega in programskega odbora IFC Portorož
Zasl. prof. dr. Alojz Križman

development. The Slovenian foundry industry has been quite stable, with growth and changes parallel to market requirements and opportunities. As a result of the collaboration of the industry with the foreign market, IFC Portorož is extremely important as it keeps abreast of current changes not only in technology, but also in the creation of business networks that the industry urgently needs to survive. The university is a place where knowledge originates and is passed on to younger generations. Involving students in university-led projects is the foundation that facilitates integration into the economy. The traditional annual foundry conference in Portorož is highly reputable and is considered one of the priorities in the context of collaboration both in the domestic market as well as internationally. This characteristic of previous generations must be respected and the connections that can also be made through the IFC taken advantage of. 60 years of the IFC is an achievement few industries are privy to. Every participant should appreciate this and strive to collaborate in the most successful and competitive projects accessible. If we wrap up by tying everything to our Livarski vestnik journal with 67 years of tradition, we get something, alongside good educational and research institutions, that gives the industry the reputation and opportunity for competitiveness in an increasingly demanding global market.

Hon. Prof. Dr. Alojz Križman,
Head of the Scientific and
Programme Committee at IFC

AKTUALNO / CURRENT

Razgovor z direktorjem podjetja CIMOS d. d. | Tovarna Vuzenica

Silvo Kekec
univ. dipl. ing. strojništva,
sedanji direktor
Tovarne Vuzenica

Sedanji direktor Livarne v Vuzenici, ki je v sklopu podjetja CIMOS d. d., Silvo Kekec dipl. ing. strojništva , ima skupaj 37 let delovnih izkušenj in je direktor Tovarne Vuzenica šele osem mesecev. V zadnjih dvajsetih letih je opravljal zelo odgovorne naloge v okviru večje italijanske korporacije. V tej delniški družbi je bil pet let tehniški direktor, nato pa 10 let, vse do leta 2019 generalni direktor le te v Sloveniji. V okviru te mednarodne skupine je vodil tudi mednarodno koordinacijo za specialne tehnologije znotraj skupine, ki je v svojem okviru imela tovarne v Evropi, Aziji in Ameriki. Zadnji dve leti pred prihodom v livarno v Vuzenici pa je delal kot svetovalec za Lean–production in tehniški napredek v industriji.

Sedanja livarna v Vuzenici je ena od naslednic velike tovarne v Muti z več kot kot 400 letno tradicijo kovaštva in livarstva. Ali mi lahko podate glavne obrise te neverjetno bogate tradicije.

Železarstvo pod Pohorjem v dolini reke Drave obstoja že od leta 1573. Razvoj železarstva so omogočale predvsem rudna nahajališča in vodna energija, ki je prva poganjala tako zvane repače, kladiva na vodni pogon, na Muti ob potoku Bistrica. Zaradi izgradnje hidroelektrarne Vuhred, je akumulacijsko jezero reke Drave, začelo poplavljati staro livarno. Drugi razlog je bila bližina železniške proge v Vuzenici na desnem bregu Drave in njen industrijski tir. Tako je bila v obdobju 1958/59 v bližini železniške proge, na desni strani Drave v Vuzenici zgrajena nova livarna za izdelavo individualnih ulitkov z eno samo kupolno pečjo, z letno zmogljivostjo le ca. 1.500 ton ulitkov iz sive litine. Povpraševanje po serijski izdelavi ulitkov je vodilo k temu, da je bila postavljena še ena kupolka in s tem ob izvedbi linije za izdelavo form možna serijska proizvodnja ulitkov.

Bogata zgodovina in tradicija ter ustrezna lokacija in s tem ločitev od tovarne v Muti, ki se je na levi strani Drave izključno usmerila v kovaško dejavnost, so tako dejansko omogočili samostojen razvoj livarstva na desni strani Drave v Vuzenici in samostojno podjetje Livarna Vuzenica.

Da, danes je to posodobljena livarna sive litine, ki zaposluje cca. 300 delavcev in s kapaciteto izdelave ca. 25.000 ton ulitkov letno. Današnji proizvodnji program je usmerjen v serijsko izdelavo ulitkov izključno iz sive litine, ki svoje izdelke skoraj v celoti usmerja v avtomobilsko industrijo. Zaradi določenih težav, ki so bile predvsem povezane z preusmeritvijo proizvodnje in spremembo programa, je livarna od leta 2002 vključena kot samostojen obrat Livarna Vuzenica v poslovni sistem delniške družbe CIMOS d. d. in z uradnim nazivom Tovarna Vuzenica.

Pogled na današnjo livarno sive litine v Vuzenici, na desni strani reke Drave, med železniško progo Maribor-Dravograd in reko Dravo

Kakšen je danes proizvodni program Tovarne Vuzenica?

Proizvodni program livarne so danes predvsem izdelki za avtomobilsko industrijo med katerimi je primarnih pet skupin proizvodov. Največji delež imajo ohišja za turbo kompresorje, sledijo zavorni diski in bobni, nato pa še vztrajniki ter potisne plošče za sklopke. Glede vrste litine so to proizvodi iz sive litine EN-GJL 200, EN-GJL250 in EN-GJL-300.

Prikaz količinske proizvodnje, finančnih prihodkov in števila zaposlenih v zadnjih 5-letih:

Leto	Bruto masa ulitkov v tonah	Finančni prihodki v EUR	Število zaposlenih	Opombe
2017	32.775	18.717.206	254	
2018	27.277	16.579.544	243	
2019	28.126	18.442.395	266	
2020	22.743	12.788.731	240	Vpliv pandemije
2021	27.600	15.600.000	260	Ocena za leto 2021

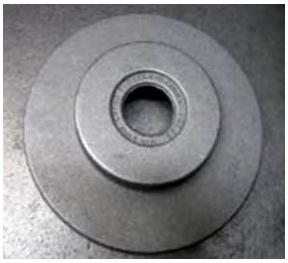
Kateri so najpomembnejši proizvodi, ki jih danes proizvaja Tovarna Vuzenica?

Med najpomembnejše proizvode lahko prištevamo: ohišja turbokompresorjev, zavorne bobne, zavorne diske, potisne plošče za sklopke in vztrajnike za sklopke. Vsi ti pomembni izdelki se proizvajajo za avtomobilsko industrijo in njihovi deleži absolutno prevladujejo v proizvodnem programu tovarne.

Prikaz najpomembnejših ulitkov in njihovi deleži v celotni proizvodnji:

a) 

b) 

c) 

d) 

e) 

a) Ohišja za turbokompresorje (ca. 50 % delež)
b) Zavorni bobni (ca. 20 % delež)
c) Zavorni diski (ca. 10% delež)
d) Vztrajniki za sklopke (ca.10 % delež)
e) Potisne plošče za sklopke (ca. 5 % delež)

Tovarna Vuzenica v pripravi proizvodnega procesa in izdelka (APQP) uporablja računalniško podprto načrtovanje (CAD) vzorcev in jeder ter za simulacijo litja in strjevanja ulitkov računalniški program Magma.

Dnevno morate za litje pripraviti ca. 115 do 120 ton taline. Katere agregate uporabljate v te namene?

Za izdelavo taline uporabljamo srednje frekvenčno indukcijsko peč Junker s talilno zmogljivostjo 5 ton izdelane taline na uro in duplex sistem Inductotherm z dvema srednje frekvenčnima indukcijskima talilnima agregatoma s talilno kapaciteto 3,4 tone na uro. S tem zagotovimo ca. 120 ton potrebne taline na dan.

Na kakšen način se pripravljajo forme za litje?

Podjetje ima dve formarski liniji:

Prva je formarska linija HWS je avtomatska linija za izdelavo peščenih form s sistemom za tlačenje peska v okvir forme. Dimenzija form je 700 × 1000 ×(300x2) mm. Nominalna kapaciteta izdelave na liniji je 95 form na uro in je računalniško vodena in ima avtomatsko pripravo peska - linija WEBAC. Livni stroj je kapacitete 4.000 kg z možnostjo samodejnega cepljenja taline direktno v curek taline. Druga avtomatska formarska linija je AFA-GISAG z dvema strojema za stiskanje peska v okvir forme. Dimenzija form je 630×500× (230×2)mm, Teoretična nominalna kapaciteta je 101 form na uro. Livni stroj ima kapaciteto 2.500 kg in možnost avtomatskega cepljenja direktno v curek taline.

Avtomatska formarska linija AFA

Za pripravo form seveda potrebujete modelarno in jedrarno. Kako je s tema dvema za livarsko proizvodnjo pomembnima elementoma za proizvodnjo ulitkov?

Seveda imamo v sklopu tovarne obe pomembni fazi proizvodnje Naša lastna modelarna je izjemnega pomena za pripravo modelov za formanje in izdelavo jeder ter njihovo vzdrževanje. Kompleksne modele za izdelavo form ter jedrovnike izdelujemo v lastnih delavnicah s pomočjo izkušenih modelarjev in orodjarjev. Pri tem si interno pomagamo s 3D modeliranjem. V jedrarni s Croning postopkom ob podpori zelo izkušenih izdelovalcev jeder in uporabi osmih strojev za izdelavo croning jeder izdelujemo zelo zahtevna jedra potrebna za izdelavo ulitkov. Kot premaz za jedra uporabljamo grafitne ali alumosilikatne premaze.

Izdelava Croning jeder, premazovanje in sušenje premazanih jeder

Ulitki so po odstranjevanju iz forme prav gotovo podvrženi peskanju?

Za odstranjevanje sprijetega peska s površine ulitkov uporabljamo: komorni stroj, peskalna bobna G-750, Orbital16 avtomatske peskalne stroje za notranje peskanje, in tudi ročne peskalne komore za notranje peskanje. Prav tako uporabljamo brusilnico za in-line finalizacijo: brušenje-notranje peskanje-boroskopska kontrola.

Brusilni roboti za centralna ohišja turbokompresorjev (ABB, Motoman, Yaskawa)

Katere osnovne kontrolne postopke uporabljate?

V okviru livarne uporabljamo naslednje osnovne kontrolne postopke:

- kontrola vhodnih surovin (spektralna analiza)
- kontrola procesa priprave taline (spektralna analiza)
- kontrola procesa litja (termovizijska kamera)
- kontrola po finalni obdelavi (trdota, natezna trdnost, mikrostruktura, boroskopija)

Kateri so vaši najpomembnejši odjemalci ulitkov?

Glavni kupci so podjetja iz skupine CIMOS d. d. in sicer CIMOS Senožeče SI in CIMOS Gradačac iz BIH ter podjetje Nolicom (izdelava in obdelava kovinskih izdelkov d.o.o., Novo mesto SI), Knott Gmbh, Nemčija.

Obratovanje livarn je vedno povezano tudi z vprašanji varovanja okolja. Kako rešujete ta vprašanja?

Zavedamo se, da je varovanje okolja in tudi zdravja na delovnem mestu zelo pomemben dejavnik znotraj našega proizvodnega procesa. Že sama nova instalirana oprema pripomore k temu.Trudimo se zadostiti v največji možni meri standarde do katerih nas zavezujejo tudi ISO in IATF po katerih smo certificirani. CIMOS d.d. Tovarna Vuzenica ima certifikat ISO 9001:2015 za sistem vodenja kakovosti in varnosti DELA izdan s strani QUALITY AUSTRIA leta 2017 in certifikat IATF 16949:2016 izdan s strani QUALITY AUSTRIA glede kakovosti

proizvodov za avtomobilsko industrijo in sistema za upravljanje z energijo, verifikacije ogljičnega odtisa in poročanja o trajnostnem razvoju iz leta 2017. Ustrezne SIQ in NET ISO 14001:2015 certifikate ima tudi matična družba CIMOS d.d..

V livarnah so pogosto izpostavljeni problemi ustreznih strokovnih kadrov. Ali se tudi vi s tem problemom soočate?

Ob povečanih naročil moramo konstantno skrbeti za zaposlovanje v sami livarni in to na vseh področjih.Za ta dela je v našem okolju zelo težko dobiti ustrezen kader, predvsem velja to za delavce v proizvodnji. Težave so tudi s potrebnimi strokovnimi kadri iz področij : metalurgija, strojništvo in elektrotehnika.

Kako je s sodelovanjem z inštituti in univerzo ter kakšen je vaš pogled v prihodnost?

Neposrednega razvojnega sodelovanja ni. Sodelujemo pa z metalografskim laboratorijem Slovenske industrije jekla Metal Ravne d.o.o., za potrebne analize za katere nimamo lastnega laboratorija in znanja. Trenutno je povpraševanje po naših proizvodih v porastu. Zato si prizadevamo biti kakovostna livarna, konkurenčna na zahtevnih trgih v širšem mednarodnem prostoru. Konkurenca iz širšega azijskega prostora, predvsem Indije in Kitajske, zahteva stalnost v posodobitvah z novo opremo in nadgradnjo obstoječega znanja ter visoko stopnjo avtomatizacije in digitalizacije.

Razgovor vodil in za objavo uredil
zasl. prof. dr. Alojz Križman
glavni in odgovorni urednik Livarskega vestnika

AKTUALNO / CURRENT

Pregled livarskih prireditev v letih 2021 in 2022

Datum dogodka	Ime dogodka	Mesto in država
08. - 10.09.2021	Zink Die Casting Conference	Koblenz, Nemčija
15. - 17.09.2021	61. IFC Portorož 2021	Portorož, Slovenija
28. - 29.09.2021	Iron Melting Conference & Exihibition 2021	Saarbrücken, Nemčija
28. - 29.09.2021	Aluminium Sand- und Kokillenguss Grundlagen Block 2	Leimen, Nemčija
30.09.2021	Aluminium Bauteile gussgerecht konstruieren	Nußloch, Nemčija
08. - 10.09.2021	Zink Die Casting Conference	Koblenz, Nemčija
27. - 28.10.2021	VDI-Fachtagung »Gießtechnik im Motorenbau« 2021	Magdeburg, Nemčija
11.11.2021	Gussfehler in Leichtmetallguss-Bauteilen analysieren und richtig bewerten	Nußloch, Nemčija
02. - 03.12.2021	Formstoffbedingte Gussfehler	Düsseldorf, Nemčija
07.12.2021	Eigenschaften und Schmelztechnik der Aluminium-Gusswerkstoffe	Düsseldorf, Nemčija
07. - 08.12.2021	Prozessoptimierung in Gießereien	Bad Dürkheim, Nemčija
18. - 20.01.2022	EUROGUSS	Nuernberg, Nemčija

IN MEMORIAM

Spomin na Valterja Breznika


Valter Breznik

Železarstvo na Muti z več stoletno tradicijo (1573) kovaštva in livarstva je ohranjeno do danes. Del te zgodovine je sooblikoval domačin, 90 letni Valter Breznik, ki je preminil v tem korona času. Njegova poklicna pot se je začela v Tovarni Muta (Kovačija), kjer se je leta 1947 izučil za ključavničarja. Kasneje se je dodatno izobraževal v Ljubljani, Mariboru in na Švedskem pri firmi SKF. Pretežno je delal kot tehnolog v razvoju Tovarne poljedelskega orodja in livarne Muta. Zaradi širitve proizvodnje, se je povsem preusmeril v livarstvo.

V Livarni Muta se je srečal z zastarelo livarsko tehnologijo. Kupolka iz leta 1908, dva lesena konzolna žerjava, nekaj kaluparskih strojev, talno formanje, naravni pesek. V zatonu je bila proizvodnja komerčne litine. Za tovarno TOBI Bistrica ob Dravi je sodeloval pri razvoju grelnih plošč za električne štedilnike, ki so jih kasneje izdelali na milijone.

Nova je bila proizvodnja jeklenega peska iz bele trde litine, za potrebe čiščenja ulitkov in v strojni industriji. Njegovo delo je bila tudi uvedba proizvodnje sekanca iz patentirane žice.

Z dograditvijo Hidroelektrarne Vuhred na reki Dravi (poplave), so iskali novo nadomestno lokacijo in se odločili za Vuzenico, ki je imela železniško povezavo. Leta 1958 je tako stekla proizvodnja v novi livarni s površino 2400 m2, letna proizvodnja 1.500 ton sive litine.

Valter Breznik je z velikim zanimanjem spremljal in uvajal nove livarske tehnologije, tudi s pomočjo domače in tuje livarske literature. Znanje je pridobival na Mednarodnih livarskih posvetovanjih in razstavah. S seboj je vedno peljal mlade livarske strokovnjake, saj mu je znanje nemščine odpiralo številna vrata. Za spremljanje stroškov je znal izdelati izvirno mesečno livarsko poročilo, ki je bilo osnova za obdelavo podatkov v računovodstvu.

Leta 1973 so na novi lokaciji Sp. Gortina pri Muti dali v pogon livarno za proizvodnjo jeklenega granulata po italijanski tehnologiji. Tako je Valter Breznik postal šef treh livarn in ponosen član Društva livarjev Slovenije.

Leta 1990 se je Valter Breznik upokojil. Vsi ki smo poznali ali delali z Valterjem Breznikom, se ga bomo radi spominjali kot zvestega stanovskega kolega in predanega livarskega strokovnjaka.

Ludvik Jerčič

DRUŠTVO LIVARJEV SLOVENIJE

Vabilo za

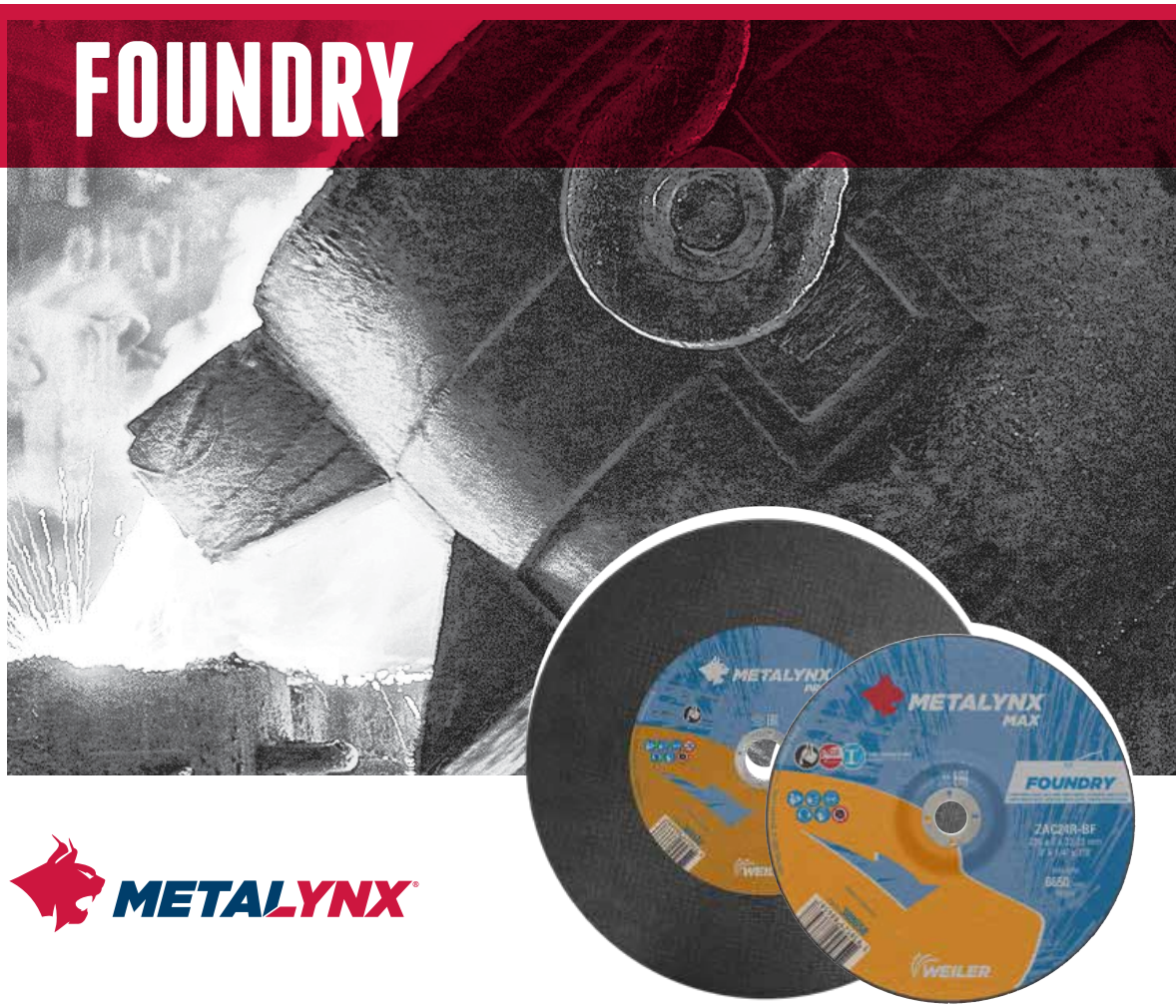
61. IFC PORTOROŽ 2021

z livarsko razstavo

15.-17. SEPTEMBER 2021

Kontakt: DRUŠTVO LIVARJEV SLOVENIJE,
Lepi pot 6, p.p. 424, 1001 Ljubljana
T: +386 1 2522 488, F: +386 1 4269 934
drustvo.livarjev@siol.net, www.drustvo-livarjev.si

FOUNDRY



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