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in / and

**Faculty of Mechanical Engineering,
UNIVERSITY OF MARIBOR**

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Portorož 2012

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N. Erhard, S.Babić, Oskar Frech GmbH + Co. KG, Schorndorf, Nemčija

SODOBNO TLAČNO LITJE – DANES IN PRIPRAVA Z INOVACIJAMI NA PRIHODNOSTI

Povzetek

Tlačno litje je tehnično zelo dober proizvodni proces za izdelavo serijskih komponent z visokimi zahtevnostmi. Najpomembnejše neželezne zlitine, ki se proizvajajo v velikih količinah so cink, magnezij in aluminij.

Na voljo sta dva različna procesa tlačnega litja – proces z vročo komoro in/ali proces s hladno komoro. V zadnjih dveh desetletjih so bile tehnologije strojev na visokem tehnološkem nivoju z sodobnimi kontrolnimi metodami in številnimi modularnimi koncepti strojev, kar tudi omogoča prilagoditev modificiranim zahtevam, in to na licu mesta.

Predavanje daje pregled stanja na področju tlačnih livnih strojev - tako za tlačno litje z vročo komoro kot za tlačno litje s hladno komoro.

Dodatno prikazujemo, da so današnje sodobne tlačne »celice« sestavljene iz prilagojene periferije in dodatno povezano opremo za učinkovito, avtomatizirano vodenje procesa.

S tem se bodo odprle nove možnosti, ker te »celice« vsebujejo najnovejšo tehnologijo kot na primer kontrola v realnem času ali pred-polnjenje v vroči komori ali Vacural za proizvodnjo ulitkov, ki jih je možno variti in prenesejo velike napetosti.

Če gledamo naprej, imamo zelo visoko povezanost tehnologije tlačnega litja z drugimi elementi. Učinkovitost povezana z energijo in procesom kot tudi kvaliteto in produktivnostjo, bo izboljšana z ustreznimi inovacijami. V tej zvezi bomo predstavili nov razvoj in raziskave podjetja Oskar Frech, med ostalimi tudi Frech Gating System, na kratko FGS.

Ključne besede: tlačno litje, procesna tehnologija tlačnega litja



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MODERN DIE CASTING – TODAY AND READY FOR THE FUTURE WITH INNOVATIONS !

Summary

Die Casting is a technically mature production process for producing serial components with large complexity. The most important non-ferrous alloys, which are processed in large volumes today, are zinc, magnesium and aluminium.

There are two different processes available for the die caster -the hot chamber process and/or the cold chamber process. During the last two decades the machine technologies have been on a technologically high level with modern control technique and numerous modular machine concepts which also allow an adaption to modified requirements in the field.

This paper will give a survey to the state of the art of die casting machines -for hot chamber die casting as well as for cold chamber die casting.

Additionally it shows that today modern die casting cells consist of appropriate periphery and device-related equipment for efficient, automated process guidance.

With this itself new possibilities will be opened, because these cells include latest techniques, such as e. g. real-time control or pre-filling in hot chamber die casting or Vacural® for production of weldable, highly stressable die castings. This paper will appreciate these topics in suitable context.

Looking ahead, especially the topics relating the process technology of die casting have a special effect. Efficiency related to energy and process, as well as parts quality and productivity will be improved through relevant innovations. In this connection new process developments and research from company Oskar Frech will be presented. Amongst others the Frech Gating System, shortly FGS.

Key words: die casting, process technology for die casting



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STOPNJA CELOTNE SAMOOZDRAVITVE: BRITANSKA LIVARSJA INDUSTRIJA GLEDA V PRIHODNOST

Povzetek

Britanska livarska industrija je „trpela“ zaradi izgube tehničnih, livarsko specifičnih kadrov in sicer v zadnjih letih, to pa zaradi zapiranja mnogih nacionalnih strokovnih šol. Položaj je postal kritičen s povečevanjem zaposlovanja novih vajencev, tehnikov in diplomantov, ki vsi potrebujejo izobraževanje, da nadomestijo delavce, ki so šli v pokoj.

Predavanje prikazuje zelo velike skupne napore britanske livarske industrije, identificiranje poklicnega „društva“ (Inštitut livarskih inženirjev) in regionalnih strokovnih šol za izboljšanje pri reševanju problemov skozi razvoj temeljev oziroma osnov livarske tehnologije. Partnerski odnos, ki ga je vodil ICME, je povezal skupaj livarne, dobavitelje, nacionalna trgovska združenja in druga društva in s tem zagotovil, da so kvalifikacije „prilagojene in ciljno usmerjene“, s tem pa zadovoljimo resnične potrebe industrije. Uspeh, pri katerem je bilo veliko tveganja, pa sedaj ima za posledico nadaljnji razvoj za podporo izobraževanja za jutrišnje livarske inženirje in tehnike.

Ključne besede: izobraževanje, vzgoja kadrov, profesionalno prepoznavanje, razvoj karier, tehnična pomoč



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A DEGREE OF COLLECTIVE SELF-HEALING: THE UK CASTING INDUSTRY LOOKS TO THE FUTURE

Summary

The UK castings industry has suffered from a loss of technical, foundry-specific training provision in recent years with the closure of many national college courses. The situation became critical following the increased employment of new apprentices, technicians and graduates all needing training to replace retiring workforces.

This paper describes the enormous collective efforts of the UK castings industry, its recognised professional body (the Institute of Cast Metals Engineers), and a regional college to remedy this problem through the development of a Foundation Degree in Casting Technology. The partnership, led by ICME, brought together foundries, suppliers, the national trade association and charitable bodies to ensure that the qualification is 'fit for purpose' and meets the industry's exact needs. The venture's success is now leading to further developments in educational support for tomorrow's castings engineers and technicians.

Keywords: Training, Education, Professional Recognition, Career Development, Technical Support



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SLOVENSKO LIVARSTVO IN NJEGOV RAZISKOVALNO-RAZVOJNI POTENCIAL V LETU 2011

Povzetek

Slovenska livarska podjetja so v letu 2011 proizvedla okoli 181.000 ton ulitkov, kar v primerjavi z letom 2010 pomeni skoraj 10% rast. V letu 2011 je livarsko dejavnost opravljalo 65 družb (3 velike, 7 srednjih in 55 majhnih in mikro družb), kar je za dve manj kot v letu 2010. Livarske družbe so v letu 2011 ustvarile prihodek v višini 417 milijona EUR, kar je za 17,5% več kot v letu 2010. V prihodkih so velike družbe bile udeležene s 47,9% deležem, srednje družbe s 29,2% ter majhne in mikro družbe z 22,9% deležem.

V livarskih družbah je bilo skupno 3726 zaposlenih, kar je za 1,9% manj kot v letu 2010. Velike družbe so imele 1532 zaposlenih, srednje 979 ter majhne in mikro družbe 1215 zaposlenih.

V livarskih družbah so ustvarili za 410 milijona EUR čistega prihodka od prodaje, kar je za 17,5% več kot leta 2010. Skupni odhodki so znašali 414,3 milijona EUR in so bili za 18,7% višji kot v letu 2010. V skupnih odhodkih so znašali stroški dela 20,1%, stroški plač 14,4% in amortizacija 5,2%

Ustvarjeno je bilo skupno 124,6 milijona EUR dodane vrednosti, kar je za 10,8 % več kot v letu 2010. Ustvarjena dodana vrednost na zaposlenega je bila 33.450 EUR, kar je za 13,1% več kot v letu 2010.

Predstavljene so raziskovalne naloge, ki sta jih letu 2011 izvajali Univerza v Ljubljani in Univerza v Mariboru.

Univerza v Ljubljani pedagoško in raziskovalno delo izvaja v okviru Katedre za livarstvo, Naravoslovnotehniške fakultete in je tudi v letu 2011 bila osrednja slovenska raziskovalna institucija za področje livarstva. Težišče raziskav je bilo v letu 2011 na področju Al – in Mg-zlitin, sive litine in livarske tehnike. Na katedri je svoja diplomska dela opravilo 8 študentov in doktorate 4 študenti. Izjemno dobro je bilo sodelovanje z industrijo, saj je bilo realiziranih kar 10 projektov. Pomembnejši uporabniki raziskav so bili: LTH Castings, Livar Ivančna Gorica, Kovis Štore, Valji Štore.

Univerza v Mariboru svoje raziskave izvaja na Inštitutu za Tehnologijo materialov Fakultete za strojništvo. Osnovno raziskovalno delo v letu 2011 je vezano na štiriletni raziskovalni program Tehnologija metastabilnih materialov s kovinsko osnovo. Pri tem je povezana s številnimi univerzami in inštituti v tujini ter uporabniki raziskav med katerimi so med livarnami pomembnejše: Mariborska livarna Maribor, CIMOS-TAM Maribor, Magneti Ljubljana, Talum Kidričevo, Zlatarna Celje. Veliko aktivnost izkazuje tudi v pridobivanju Eureka projektov

Prav tako so predstavljeni zahtevnejši ulitki iz različnih livnih materialov šestih slovenskih livarn: LTH Castings Ljubljana, Mariborska livarna Maribor, Livar Ivančna Gorica, Kovis livarna Štore, Croning livarna Ravne, Lama Dekani.

Ključne besede: slovensko livarstvo v letu 2011, raziskovalno delo, primeri zahtevnih ulitkov



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SLOVENIAN FOUNDRY INDUSTRY AND ITS R&D POTENTIAL IN THE YEAR 2011

Summary

In the year 2011 there were 65 foundry enterprises (3 large, 7 middle and 55 small or micro enterprises), that are two less than in the year 2010. In the year 2011 foundries made the total income in the height of 417 millions EURO, what is 17.5 % more than in the year 2010. In this income the share of large companies was 47.9 %, middle companies formed 29.2 % and small or micro companies 22.9 % of total share. In foundries the total number of employees was 3726, that is 1.9 % less than in the year 2010. Large companies had 1532 workers, middle 979 and small or micro companies 1215 employees.

In foundries there were 410 millions EURO net incomes from sale, what is 17.5 % more than in 2010. The expenses were 414.3 millions EURO, what is for 18.7 % more than in 2010. In the expense the share of labours costs was 20.1 %, salaries 14.4 % and the share of amortization was 5.2 %.

The total added value in foundries was in the height of 124.6 millions EURO, what is 10.8% more than in the year 2010. The average formed added value per worker was 33,450 EURO, what is 13.1 % more than in the year 2010.

The research papers carried out at the University of Ljubljana and University of Maribor in the year 2011 are introduced.

The University of Ljubljana performs the pedagogical and research work for the foundry sphere at the Chair for Foundry, Department for Metallurgy and Materials at the Faculty of Natural Sciences and Engineering and it was also in the year 2011 the basic research institution in the foundry domain in Slovenia. The main researches in the last year were in the field of Al- and Mg-alloys, grey iron and foundry technics. At the Chair 8 students acquired the graduate and 4 the doctor's degree. There was a very well cooperation with the industry by the realisation of 10 projects. Some more important users were: LTH Castings, Livar Ivančna Gorica, Kovis Livarna Štore, Valji Štore.

The University of Maribor implements the research work in the foundry field at the Institute for technology of materials at the Faculty for Mechanical Engineering. The basic research work in the year 2011 was bound to the four-year-research programme: Technologies of metastable metallic based materials. For this purpose there are numerous connections to the abroad universities and institutes and to the users of the researches amongst which are more important foundries: Mariborska livarna Maribor, CIMOS-TAM Maribor, Magneti Ljubljana, Talum Kidričevo, Zlatarna Celje. The institute proves a large scale of activities also in the acquiring of the Eureka projects.

Additionally some pretending castings out of the different cast materials from six Slovenian foundries are presented: LTH Castings Ljubljana, Mariborska livarna Maribor, Livar Ivančna Gorica, Kovis livarna Štore, Croning livarna Ravne, Lama Dekani.

Key words: Slovenian Foundry in the year 2011, research works, examples of castings



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NOV RAZVOJ RAČUNALNIŠKE TOMOGRAFIJE Z RENTGENSKIMI ŽARKI ZA AL ZLITINE

Povzetek

Izdelava ulitokv iz aluminijevih zlitin je odvisna od občutljivega ravnotežja med “neizogibnimi” napakami, kot so pore in optimalnimi lastnostmi materiala iz “preostale” osnove. Z vpeljavo izračunane X – žarkovne tomografije so postale detaljne preiskave tehnik na voljo na način, da lahko vidimo od napak kritičnih velikosti ulitkov do manj pomembnih napak v procesu. Seveda pa so 3 dimenzionalne tehnike nestandardizirane kot je to v primeru metalografskih metod za določevanje velikosti por in porazdelitvijo le-teh..Na drugi strani pa je “učinkovanje” osnovne strukture izboljšano s tem, da dobimo enakomerno drobno strukturo, to bomo prikazali za zelo dobro preštudirano modifikacijo evtektskih Al-Si zlitin. Prezentacija bo dala pregled o trenutnem stanju kvantifikacije poroznosti in njenega učinka na mehanske lastnosti.

Ključne besede: metalografske metode, aluminijeve zlitine, osnovne strukture



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NOVEL DEVELOPMENTS IN COMPUTED X-RAY TOMOGRAPHY FOR AL ALLOYS

Summary

The performance of an Al casting depends on the delicate balance between unavoidable defects such as pores and optimised material properties of the remaining matrix. With the introduction of computed X-ray tomography a detailed investigation technique has become available showing defects from a critical size for the casting to function right down to minor processing defects. However, this 3 dimensional technique is still not standardized as it is the case for 2 dimensional metallographic methods to determine pore sizes and distribution. On the other side the performance of the load caring matrix can be improved by obtaining a uniform fine microstructure. This will be demonstrated for the well-studied modification of the eutectic Al-Si alloys. This presentation will give an overview on the current state of the art to quantify pores and their effects on mechanical properties.

Key words: metallographics methods, aluminium alloys, primary structures



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NAPAKE ZARADI POROZNOSTI IN LUKNJIČAVOSTI PRI ŽELEZOVIH ULITKIH – ALI JE ŽE ČAS, DA SE REŠI TA SKRIVNOST

Povzetek

Lunker in poroznost sta dve napaki v ulitkih iz železovih zlitin, ki sta vedno bili skrivnostni in diagnoza vzrokov in uspešno popraviljanje predstavlja izziv za železo livarje. Ekonomski pritiski in povečana konkurenčnost pa zahtevata prej preventivno delovanje kot pa ukvarjanje z dragimi izpadi proizvodnje zaradi napak poroznosti.

Poročilo temelji na izkušnjah avtorja, podprtih z literaturnim pregledom in ima namen, da služi kot vodnik za diagnostificiranje napak zaradi lunke in poroznosti, ima pa osnovo v morfologiji, velikosti in porazdelitvi napak v ulitkih. Moramo si privzeti, da ne obstaja absolutna metoda, obstaja pa splošen pristop, ki ga podajamo v poročilu, je pa v večini primerov možno napako diagnostificirati z veliko natančnostjo in odgovarjajoče korake lahko naredimo, da bi napako odpravili.

Napake luknjavosti ali razpršene poroznosti izhajajo ali iz plinov, ki so absorbirani iz različnih virov med celotno zgodovino taline in njenim kontaktom s formo ali jedrom, ali pa je vzrok krčenje taline pri strjevanju in iz tega izhajajoče volumske spremembe. Te napake so lahko sferične, okrogle ali imajo iregularne morfologije.

Sferična „luknjavost“ se lahko pojavi samo na zgornjih površinah ulitkov zaradi reakcije oksidacijske žilindre, ki lahko „uide“ v votlino forme ali pa nastane med ohlajevanjem taline (reaktivne žilindre) z ogljikom v talini, kar ima za posledico nastanek CO mehurčkov. Sferični mehurčki so lahko razpršeni na površini ulitkov zaradi vodika, dušika ali kompleksnih H/N mehurčkov, ki izhajajo iz vlage v surovem pesku ali zaradi razpada organskih veziv v kemijsko vezanih peskih.

Okrogla luknjavost se lahko pojavi ali na površini ulitkov v obliki „poglobitev“, depresij, ali luknjic, vzrok je v glavnem zaradi napak krčenja. Poročilo obravnava različne napake, povezane z relacijami forma talina zaradi krčenja. Okrogla luknjavost lahko rezultira iz plinov, ki izhajajo iz formarskih materialov, taline ali vložkov v formah.

Napake luknjavosti in poroznosti nepravilnih oblik lahko zopet izhajajo iz izločanja plinov, raztopljenih v talini med strjevanjem v votlini forme ali zaradi krčenja. Krčilna poroznost je lahko razdeljena v makro- ali mikrokrčilno poroznost. Makrokrčenje se pojavi na „debelejših delih“ ali na vročih mestih v ulitkih in ga lahko odpravimo z optimizacijo oblike napajalnikov in/ali mestom postavljanja napajalnikov in se običajno pojavi ali kot izolirana ali povezana nepravilna luknjavost. Na drugi strani, mikrokrčenje je običajno razpršeno po celotnem preseku ulitka in je sestavljeno iz luknjic mikronske velikosti, ki nastanejo med evtektskimi zrnji ali dendritnimi vejami ob koncu evtektskega strjevanja.

Povečano nagnjenje nodularne litine k nastanku mikrokrčilne poroznosti lahko razložimo s posebnostjo, ki jo ima nodularna litina pri strjevanju v primerjavi s strjevanjem železovih litin z lističastim grafitom.

Na koncu pa poročilo podaja pregled naporov, ki smo jih naredili za to, da smo uporabili termično analizo kot orodje za določevanje predvidevanja nastanka poroznosti v ulitkih iz sive litine in zadnji napredek pri tehnikah cepljenja, povezanih z zmanjševanjem napak zaradi poroznosti.

Ključne besede: napake v ulitkih, preprečevanje napak



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POROSITY AND CAVITY DEFECTS IN IRON CASTINGS – IS IT THE TIME TO SOLVE THE MISTERY?

Summary

The cavity and porosity defects in iron castings have always been a mystery, and diagnosis of its causes and successful corrective action represent a challenge to iron founders. However, modern economic pressures and increasing competitiveness demand prevention rather than dealing with costly outbreaks of porosity defects.

This report, based on author's experience supported by comprehensive literature review is intended to serve as a guide for diagnosing cavity and porosity defects based on morphology, size and distribution of defects in the casting. It should be borne in mind, that there is no absolute method, but if the general approach outlined in this report is carefully used, then in most cases a defect can be diagnosed to a high degree of certainty and the appropriate action may be then taken to eliminate it.

Cavity or dispersed porosity defects result either from gases absorbed from different sources throughout the life history of the molten metal and its contact with mould or cores, or may be related to shrinkage of molten metal on solidification and the resulting volume reduction. These defects may be of spherical, rounded or irregular morphologies.

Spherical cavities may appear only on the upper surfaces of the casting due to the reaction of oxidized slags either escaping into the mold cavity or forming during cooling of molten metal (reactive slags) with the carbon of the molten metal, leading to the formation of CO blowholes. Spherical pinholes may be scattered all over the casting surface due to hydrogen, nitrogen or complex H/N pinholes arising from moisture in greensand or decomposition of organic binders in the chemically bonded sands.

The rounded cavity may appear either on the casting surfaces in the form of sinks, depressions or punctures and these are mainly related to shrinkage defects. The report discusses different mold – and metal related factors affecting shrinkage defects. Rounded cavities may as well result from gases evolved from mold material, molten metal or mold inserts.

Cavity and porosity defects of irregular forms may again result from rejection of gases dissolved in molten metal during solidification into the mold cavity or due to shrinkage. Shrinkage porosity may be divided into macro- or micro-shrinkage porosities. Macroshrinkage overwhelmingly appears in heavy sections or at hotspots in the casting and could be eliminated through the optimization of the riser design and/or location and usually appears either as isolated or interconnected irregular cavities. On the other side; microshrinkage is usually dispersed in the whole cross section of the casting and consists of micron-size cavities formed between the eutectic grains or dendrite arms at the end of eutectic solidification.

The increased tendency of ductile iron to microshrinkage porosity formation is explained in the light of the peculiarities of ductile iron solidification compared to that of flake graphite irons.

Finally, the report surveys the efforts carried out to use thermal analysis as a tool to predict porosity formation in iron castings and the recent advances in inoculation techniques directed to reduce porosity defects.

Key words: defects in castings, prevention of defects



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PASIVNE IN AKTIVNE KOMORE ZA TLAČNO LITJE NA HLADNOKOMORNIM STROJIM

Povzetek

V delu, ki obravnava problematiko litja Al in Mg zlitin s hladno komornim tlačnim strojem smo proučili možnosti za izboljšanje učinkovitosti delovanja komore z vidika zmanjšanja predstrjevanja taline v komori, litja pri nižji temperaturi, povečanja vzdržljivosti garniture komora-bat, ter povečanja izplena tekoče litine. V ta namen je bila izvedena študija, ki vključuje preveritev idejnih rešitev, ki se nanašajo tako na material komor kot tudi na tehnologijo izdelave le teh z računalniško simulacijo livarskih procesov. Predstavljen bo koncept pasivne in aktivne komore za tlačno litje. Glede na problem, ki se nanaša na deformacijo komor med delovanjem, ter nizkotemperaturno delovanje zaradi topnosti Fe v tekoči Al litini je ugotovljeno, da je obstoječi sistem mogoče bistveno prenoviti z novim konceptom, ki ima aktivno delovanje v povezavi z novimi gradijentnimi materiali na »in situ« kompozitni osnovi.

Ključne besede: tlačno litje, hladnokomorni stroji



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PASSIVE AND ACTIVE CHAMBERS FOR DIE CASTING COLD-CHAMBER MACHINES

Summary

In examination which discuss the problems of casting of Al in Mg alloys on high pressure die casting with cold chamber machine the possibility of increasing the efficiency of working chamber. This is related on decreasing the solidification of molten alloy in chamber, pouring at lower temperature, increasing the life time of sleeve and piston and increasing of yield of molten metal.

For this purposes the examination study was done. It involves the check of ideas and innovative solutions what are connected with materials of sleeve and technology of production of it with computer simulation of casting process. The concept of passive and active chamber for high pressure die casting will be presented. According to problems which are connect with solubility of iron in Al alloys it is find out that currently used systems can be essence renew with new concept which have active working and contain also new gradient materials on a "in situ" composite base.

Key words: die casting, cold-chamber machines



K.Weiß, RWP GmbH, Nemčija

SIMULACIJA LIVARSKIH PROCESOV - ZGODOVINA, SEDANJE STANJE, PRIHODNJI RAZVOJ

Povzetek

Današnji razvojni projekti zahtevajo uporabo virtualne resničnosti kot eno od orodij za pospeševanje časa razvoja. Programi virtualne resničnosti so kombinacija geometrije in zahtev v dobro razviti vizualni „sobi“. Pot za povezovanje med zahtevami in geometrijo je lahko ali visokokompleksna s povezavami do različnih računalniških programov ali na mnogo bolj enostaven način z samo organizacijsko povezavo.

Livarska industrija kot eden od osnovnih proizvajalcev avtomobilskih delov je poskušala že pred petdesetimi leti z uporabo nadomestnih sistemov, da bi tako dobili več znanja in večje zaupanje v livarske procese. Ko je „prišla“ doba računalništva in je postajala čedalje bolj popularna, je seveda tudi livarstvo zahtevalo uporabo takšnih orodij. Danes uporabljamo veliko število različnih simulacijskih orodij, ne da bi poznali osnove in poti oziroma načine teh orodij. Za uporabo orodij na pravilen način moramo poznati in razumeti osnovne procese.

S tem bomo začeli. Podali bomo kratek pregled o zgodovini in osnove, ki smo jih uporabili pri livarsko povezanih simulacijskih programih. Naslednji korak bo pokazal stanje v tem trenutku in podal nekaj opomb o uporabi in uspešnosti livarskega simulacijskega „sveta“. V tretjem delu tega pregleda pa bomo poskušali najti nujnosti in možnosti v virtualni resničnosti, da bi našli pravo mesto s podporo IT v naslednjem desetletju.

Ključne besede: simulacijski procesi, zgodovina in prihodnost simulacij



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SIMULATION FOR FOUNDRY PROCESSES- HISTORY, STATE OF THE ART, FUTURE DEVELOPMENT

Summary

Today development projects require the use of virtual reality as one of the tools to speed up the development time. The virtual reality programs are combining geometry and requirements inside of a well developed visual room. The way of the connectivity between the requirements and the geometry can be either high complex with links to different calculation programs or in a more simple way just in an organizational connection.

The foundry industry as one of the basic producer of the e.g. automotive parts tried already more than 50 years ago use standby systems to get more knowledge and more confidence in the foundry process. When computers came up and get more and more popular also the foundry industry required the use of these tools. Today we use a couple of different simulation tools, without knowing the basics and roots of these tools. To use the tools in the right way we have still to know and understand the basics.

Here we start with this article. We will give a short overview about the history and the basics used by the foundry related simulation programs. The next step will show the state of the art and will give some remarks of the usage and the success of the foundry simulation world. In the third part of this overview we tried to find out the necessities and the possibilities in the virtual reality to find the right place in the concert of the IT support in the next decade.

Key words: simulation of processes, history and future of simulation



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TEHNOLOŠKE RAZISKAVE IN RAZVOJ VELIKIH, TANKOSTENSKIH, VISOKOKAKOVOSTNIH ALUMINIJEVIH ULITKOV

Povzetek

Tehnologija precizijskega litja je ena od livarskih tehnologij, ki omogoča, da dobimo tako zelo ozke dimenzijske tolerance (takoimenovana „tehnologija končnih dimenzij“) kot tudi zelo kompleksne oblike ulitkov. Celotni koncept triletnega raziskovalnega projekta, ki sta ga delala Fimes – livarna za precizijsko litje aluminija in Tehnološka univerza v Brnu., je bil usmerjen v razvoj te tehnologije. Glavni namen te raziskave je implementacija doseženih rezultatov v vsakodnevno livarsko prakso v podjetju Fimes in bi tako povečali možnost, da se obrnemo na kupce iz področja letalstva, vesoljske tehnike, obrambne industrije in podobne hi-tech industrije. Celotni projekt in seveda to predavanje je razdeljeno v 7 delov, ki sledijo glavnim fazam precizijskega litja:

1/ „Matična“ forma (kovinska forma za izdelavo voščenih modelov)

Razvit in testiran je bil nov software za simulacijo polnjenja voska v „matično“ kovinsko formo. Ta nov poseben software naj bi pomagal oblikovalcem te „matične“ forme, da bi predlagali napajalni sistem za vbrizgavanje voska, da bi dobili visokokvalitetne voščene modele „tako v prvem poskusu“.

2/ Voščeni model

Detaljna laboratorijska analiza različnih vrst voskov, ki so primerni za tankostenske modele je bila narejena v Blaystonu (Velika Britanija). Osnovne fizikalne, reološke in tehnološke lastnosti različnih voskov so bile narejene in priporočene so bile najboljše verzije za uporabo v livarni Fimes. Na osnovi dobljenih rezultatov optimalnih kombinacij modelov in voskov so bile narejeni testi na polproizvodni način.

3/ Keramična lupina

Detaljna laboratorijska analiza različnih vrst in sestav keramičnih „lupin“, ki jih uporabljajo v livarni Fimes, je bila narejena v CARRD laboratoriju v Imeryju (A). Na osnovi teh rezultatov je bila predlagana optimalna sestava keramične lupine (sestave suspenzije in tudi prevleke tako za primarni kot drugi nanos). To smo potem testirali na polproizvodni način in najboljša varianta bo vpeljana v polno proizvodnjo proti koncem leta 2012.

4/ Priprava taline aluminija

Detaljna analiza tehnoloških operacij povezanih s pripravo taline za ulivanje je bila narejena, in sicer čiščenje, modificiranje, udrobnjavanje zrn, in razplinjevanje. Narejena je bila tudi on-line analiza preverjanja kvalitete taline, s tem da bi tako prakso uvedli v livarsko proizvodnjo.

5/ Tehnika ulivanja

V tem delu raziskave so bila narejena osnovna merjenja temperaturnih polj sistema „keramična forma – zlitina aluminija“. Med temi poizkusi je bil narejen posebno prilagojen



test za merjenje tekočnosti taline (in sicer zmožnost tekoče kovine za zapolnitev livne votline). Preizkusili smo tudi vpliv možne filtracije taline med temi eksperimenti.

6/ Polnjenje votline keramične forme s talino

Te preiskave so zelo ozko povezane s prejšnjimi meritvami. Po teh prvih rezultatih so bili narejeni tudi posebni „napajalni sistemi v kletki“ za velike ulitke (do 700 mm dolžine). Vse te nove oblike posebnih napajalnih sistemov so bile predlagane na osnovi rezultatov, dobljenih pri simulaciji tako polnjenja livne votline s talino aluminija kot tudi pri strjevanju.

7/ Končne operacije

Ta del raziskave pokriva monitoring celotnega procesa v livarni, kar naj bi imelo za posledico, da bi dobili certifikat NADCAP (nivo letalske industrije in vesoljske tehnike).

Ključne besede: proces precizijskega litja, faze procesov, tehnologija



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RESEARCH AND DEVELOPMENT OF TECHNOLOGY FOR LARGE – THIN WALL – HIGH QUALITY ALUMINIUM CASTINGS FOR AIRCRAFT INDUSTRY

Summary

Investment casting technology is one of the foundry technologies enabling to achieve both very narrow dimensional casting tolerances (so called “net shape technology”) and also very complex casting shapes. The whole concept of the three years research joint project of Fimes,a.s.- aluminium investment casting foundry and the Brno University of Technology, is focused to development of this technology. The main goal of this research is the implementation of the achieved results into daily Fimes foundry practice and thus to increase the foundry chances to address customers from aircraft, aerospace, defence and similar hi-tech industries. The whole project and therefore also this paper is divided into 7 parts following the main phases of investment casting technology:

1/ “Mother” die (metal mould for making wax patterns)

Developed and tested the new software for simulation of wax filling into “mother” dies. This unique software should help the designers of “mother” dies to propose the correct gating systems for wax injection to achieve high quality wax patterns “right in the first time”.

2/ Wax pattern

Detail laboratory analysis of several types of waxes suitable for thin wall wax patterns have been done at Blayson (UK) laboratory. The basic physical, rheological and technological properties of different waxes have been tested and the best versions recommended for its use at Fimes foundry. Based on the achieved results the optimal combination of pattern and runner waxes are now being tested in semi-production scale.

3/ Ceramic shell mould

Detail laboratory analysis of several types of so far at Fimes used ceramic shell compositions have been done at the CARRD laboratory of Imerys (A).Based on these results the optimal ceramic shell composition has been suggested (i.e. compositions of slurries and also stuccos for both primary and back up coats). These are now being tested in semi-production scale and the best version will be introduced into full production in late 2012.

4/ Preparation of aluminium melt

Detail analysis of all technological operations connected with preparation of the melt for pouring has been done, i.e. purification, modification, grain refining and degassing. Also analysis of on-line checking of the melt quality has been analyzed with the aim of introducing it into the foundry production.

5/ Pouring technique

In this part of the research the basic measurements of temperature fields of the system “ceramic mould – aluminium alloy” have been done. During these tests an especially design test for measuring of metal fluidity (i.e. ability of the molten metal to fulfill the mould cavity) has been used. Also influence of possible metal filtration has been tested during these experiments.

6/ Filling the ceramic mould cavity by molten metal



These investigations are very closely connected with previous measurements. Following to these first results also testing of special “cage gating systems” for larger castings (up to 700 mm length) have been done. All designs of these special gating systems have been proposed based on the results achieved by simulation of both filling mould cavities by molten Al alloy and also its solidification.

7/ Finishing operations

This part of the research is covering the monitoring of the whole process at the foundry which in the end should achieve the NADCAP certification (aircraft and aerospace level).

Key words: investment casting, phases of investment casting, technology



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OPTIMIZACIJA IZDELAVE NODULARNE LITINE KAKOVOSTI 400-18

Povzetek

Nodularno litino 400 – 18 smo naredili v ulitem stanju in toplotno obdelanem stanju v različnih livarskih pogojih z uporabo oziroma izdelavo šarž z obdelavo z in brez magnezija in brez dodatkov redkih zemelj in z različnimi parametri cepljenja. Ugotovili smo, da dodatki silicija bistveno zmanjšajo raztezek in precej povečajo izkoristek in natezne trdnosti pri trdotah 150 – 170 HB. Perlitni vplivni faktor (P_x) in akcijski antinodulacijski faktor (K_1) sta se pokazala kot zelo pomemben vpliv na prelomno in natezno trdnost in duktilnost, prav tako imata vpliv vsebnosti Mn in P, metalurška kvaliteta taline dodatek redkih zemelj in moč cepljenja.

Vpliv mangana je obratnosorazmeren s fosforjem in količino oligoelementov. Če hočemo dobiti v litem stanju feritno strukturo, je potrebna naslednja količina elementov in $P_x < 0.03\%P$, $< 0.2\%Mn$ in $P_x < 2.0$. Pri enaki nizki vsebnosti Mn in P pa pri povečanju faktorja $P_x > 2.0$ to vodi k pojavu perlita v liti strukturi, vendar pa dobimo feritno strukturo po kratki toplotni obdelavi. Nižja vsebnost fosforja ($< 0.025\%$) in količini oligoelementov ($P_x < 2.0$) ima za posledico, da dobimo feritno strukturo v litem stanju pri relativno visoki vsebnosti Mn (0.32 – 0.38%). Višja vsebnost fosforja (0.04% - 0.045%) in mangana (0.25% - 0.35%) pa stabilizirata perlit pri nizkem faktorju ($P_x > 2.0$).

Učinek elementov, ki zavirajo cepljenje, lahko preprečimo do vrednosti $K_1 = 2.0$ vključno z dodatkom redkih zemelj in obdelavo z zlitinami magnezija; dodatki redkih zemelj so učinkoviti za $K_1 < 1.2$ in obvezni za $K_1 > 1.2$.

Končna kemijska sestava, vključno s kontrolnimi faktorji P_x in K_1 za nodularno litino 400 – 18 v litem stanju, pogoji za uporabo visoko čistega surovega železa oziroma vložka, uporaba FeSiMg (redke zemlje) in učinkovita cepiva, to so priporočila livarske prakse.

Ključne besede: tehnologija izdelave nodularne litine, optimizacija



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400 – 18 DUCTILE IRON GRADE PRODUCTION OPTIMIZATION

Summary

As cast and heat treated 400 – 18 grade ductile cast iron was obtained in different foundry conditions, using various metallic charges, Mg treatment with and without rare earth (RE) additions and various inoculation parameters. Silicon additions were found to significantly decrease elongation and moderately increase yield and tensile strength at 150 – 170 HB hardness. Pearlitic influence factor (P_x) and antinodularising action factor (K_1) were found to have an important influence on ultimate and tensile yield strength and ductility, as did Mn and P content, the metallurgical quality of the melt, RE addition and inoculation power.

The influence of Mn was in turn influenced by the phosphorus and residual element contents. To obtain an as cast ferritic structure $< 0.03\%P$, $< 0.2\%Mn$ and $P_x < 2.0$ is required. At the same low levels of Mn and P, increasing residual content ($P_x > 2.0$) leads to the appearance of pearlite in the as cast structure, but a ferritic structure is obtained after a short annealing treatment. Lower level of phosphorus ($< 0.025\%$) and residual elements ($P_x < 2.0$) allow as cast ferritic structures to be obtained at relatively high Mn content (0.32 – 0.38%). Higher P (0.04 – 0.045%) and Mn (0.25 – 0.35%) contents stabilized pearlite at lower residual levels ($P_x < 2.0$).

The action of antinodularising elements could be counteracted up to $K_1 = 2.0$, by including REs in the Mg treatment alloy: RE additions are beneficial for $K_1 < 1.2$ and compulsory for $K_1 > 1.2$.

A final chemical composition, including residual elements control factors P_x and K_1 for as cast 400 – 18 ductile iron grade and conditions to use high purity pig iron, RE bearing FeSiMg and a powerful inoculant are recommended for foundry application.

Key words: technology of ductile iron production, optimizations



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ŠTUDIJE O ANALIZI LIVNEGA GENOMA PRI LITJU BLOKOV IZ SIVE LITINE

Povzetek

Livarska industrija se je kontinuirano globalno razvijala preko dvanajst tisoč let. Razvijala se je v veliko število livarn (50.000), ki so locirane geografsko na različnih mestih, proizvaja pa veliko količino ulitkov (100 milijonov ton) letno. Indija je drugi največji proizvajalec na svetu. Kovine, nekovine ali kompozitni materiali so v široki uporabi od rojstva do smrti. Ali drugače od podvodnega sveta do uporabe v vesolju..

Uspešno sodelovanje oziroma sodelovanje velikega števila raziskovalcev in inženirjev iz preko petdesetih držav na svetu se je razširilo iz genomskega projekta za obdobje petnajstih let v genetsko aplikacijsko paradigmo, ki pokriva druga inženirska področja livarske industrije. Z razvojem ene milijarde codonov različnih genov triindvajsetih kromosomov je rezultiralo v zmožnost proizvodnje generacij s fizikalnimi in intelektualnimi spretnostmi. V podani raziskavi je bil narejen poskus študija genomske mape glede na livne kromosome, livne gene, livne kodone, livne „zbirke“, livne klone. Livarna avtomobilskih delov je upoštevala razvoj livne genetske mape za ulivanje blokov motorjev.

Livna genomska mapa je sestavljena iz osnovnih kromosomov, livnih genov, livnih kodonov in livnih „množic“. Osnovni livni kromosomi so razporejeni v štiri takoimenovane materialne kromosome, procesne kromosome, dimenzijske kromosome in uporabniške kromosome. Livni kromosomi so razporejeni v različne livne gene. Vsak od štirih kromosomov je nadalje razdeljen v vsakega od treh genov, vsega skupaj dvanajst osnovnih genov. Materialni kromosomi so razdeljeni v „materialno“ družino s sestavo „čistih“ genov in genov s splošnimi lastnostmi. Podobno so procesni kromosomi razdeljeni v tri osnovne gene kot je formanje, izdelava jeder in polnjenje form. Geometrijski kromosom je klasificiran v tri gene kot na primer teža in izkoristek, gen debeline in gen notranjih „poroznosti/luknjičavosti“. Končno je aplikacijski kromosom razdeljen v dimenzijske gene, gene notranje trdnosti in gen „pogojev“ površine. Livni kodoni so osnovni gradbeni delci livnega genoma. Vsak livni gen je razdeljen v različne kodone. Livno področje je sekvenca kodonov za proizvodnjo ulitkov brez napak. Za vsako livno področje so bil razviti kodoni za proizvodnjo dobrih ulitkov na osnovi najboljše prakse v okolju livarne. V predstavljenem delu smo podali razvoj ulivanja ulitkov za bloke motorjev. Prišli smo do večjega števila uporabnih zaključkov.

Kovinske ulitke uporabljamo virtualno od rojstva do smrti. Več kot 90% vseh izdelanih izdelkov in osnovne opreme uporablja ulitke kot inženirsko komponento. Svetovno livarstvo zadovoljuje univerzalne potrebe ljudi na zemlji, na morjih in oceanih, v zraku in v vesolju na „potovanjih“ do drugih planetov v razdaljah, ki jo merimo v svetlobnih letih. Nič ni čudnega, če livarska industrija zadovoljuje univerzalne ljudske potrebe. Livarstvo tudi „ustvarja“ idole oziroma božanstva, cerkvene zvonove, kraljevske krone, kraljice, kot tudi Miss in mistra sveta. Zadovoljuje globalne družinske potrebe kot prehranjevanje in oblačenje (tekstilni stroji in kmetijski stroji), čiščenje in prenos vode (črpalke in dodatki), gradi avtoceste, železniške proge, lokomotive in avtomobile za prevoz ljudi, gradi letala, ladje in podmornice, ki plujejo na sedmih morjih in ne nazadnje merijo globine oceanov. Izdeluje tudi kolesa iz ADI litine za najhitrejši vlak na svetu in tudi izdeluje najlažje stroje iz magnezijevih zlitin, izdeluje tudi



orodja in orožje za obrambo pred sovražniki. Livarski proizvodi so v bolnišničnih sobah, v družinski uporabi in ne nazadnje za peči za krematorije ali pralnice in podobno. Letala, rakete, sateliti, vesoljske postaje, lunarna vcozila, vse to uporablja ulitke. Prvi človek v vesolju Jurij Gagarin je bil pravtako livar. Širina uporabljenih materialov odpira vrata do univerzalne livarne in nano tehnologije v nano-livarne. Zato smo lahko ponosni, da smo globalni livarji in služimo človeštvu.

Ključne besede: livni genom, blok motorja, livni kromosom, livni geni, livni kodoni



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STUDIES ON CASTING GENOME ANALYSIS OF GREY IRON ENGINE BLOCK CASTING

Summary

Metal casting industry has been evolving continuously globally beyond twelve millenniums. Global foundry industry has been evolving into large number of foundries (50,000) located geographically at different places producing large quantities (100 million tons) of castings annually. India is the second largest casting producer in the world. Metallic, non-metallic or composites are widely in use from womb to tomb or under water to outer space applications.

The successful participation of a large number of scientists and engineers from over fifty countries in the world in the human genome project for period of fifteen years has expanded the genetic application paradigm to the other engineering areas of foundry industry. With the development of one billion codons with one lakh of different genes from twenty-three pairs of chromosomes has resulted into the capability to the production of generations with high physical and intellectual abilities. Hence, in the present research investigation an attempt has been made to study casting genome map considering casting chromosomes, casting genes, casting codons, casting arrays, casting clones or arrays. An automobile real foundry has been considered for development of casting genetic road map for engine block casting.

Casting genome map consists of basic casting chromosomes, casting genes, casting codons and casting arrays. Basically casting chromosomes are classified into four i.e., material chromosome, process chromosome, dimensional chromosome and application chromosome. Casting chromosome is sub-divided into various casting genes. Each of the four chromosomes is sub-divided into three genes each, totaling twelve basic casting genes. Material chromosome is sub-divided into material family gene, composition and purity gene and general properties enhancement gene. Similarly process chromosome is sub-divided into three basic genes like moulding, core making and fill condition. Geometry chromosome is classified into three genes like weight and yield gene, thickness gene and internal holes/recesses gene. Finally application chromosome is divided into dimensional genes, internal soundness gene and surface condition gene. Casting codons are basic building blocks of casting genome. Each casting gene is sub-divided into several codons. Casting array is a sequence of codons for production of a sound casting. For each casting array of codons have been developed for the production of good quality castings based on the best practices established in foundry shopfloor environments. In the present work casting arrays for grey iron engine block castings have been developed. Several useful conclusions have been arrived at.

Metal castings are used virtually from womb to tomb. More than 90% of all manufactured goods and capital equipment use castings as engineered components. World foundrymen have been catering to the universal needs of people on land, seas and oceans, air and space and to travel trillions and zillions of light years to other Planets, Milky Way and the Universe, Omniverse and All-That-Is. It is no wonder world foundry industry is doing a great task to the universal needs of people. It also makes idols of God and Goddess, bells of Church, crowns of Emperor, Queen, Miss World and Miss Universe as well. It caters the needs of global family like feeding and clothing of people (textile machines and agricultural machines), purify and transportation of water (pumps and accessories), building highways,



rail roads, locomotive and automobiles that travel over them for mobility of people, manufacturing aircrafts that fly in air, ships and submarines that ply in the seven seas and measure the depth of the Pacific ocean. It also makes the wheels (ADI) for the fastest train in the world and also makes lightest engine with magnesium alloy for cars. It also makes tools and implements of war to defend people from enemies. Products of foundry are in hospital delivery rooms, household appliances and mortuary furnaces and accessories or metal laundries for jobbing fettling. Aircrafts, spacecrafts, satellites, multi-storied buildings in space, moon and celestial bodies and space stations use castings. The first person in space Mr. Yuri Gagarin was also a foundryman. Space processing of materials opened the doors to universal foundry and nano-technology to nano-foundries. Let us all proud to be global foundrymen and serving the global population.

Keywords: Casting genome, engine block, casting chromosomes, casting genes, casting codons .

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OPTIMIZACIJA SPECIFIČNIH PROCESOV GLEDE NA MATERIALE PRI SIMULACIJI IZDELAVE BAINITNO POBOLJŠANE NODULARNE LITINE

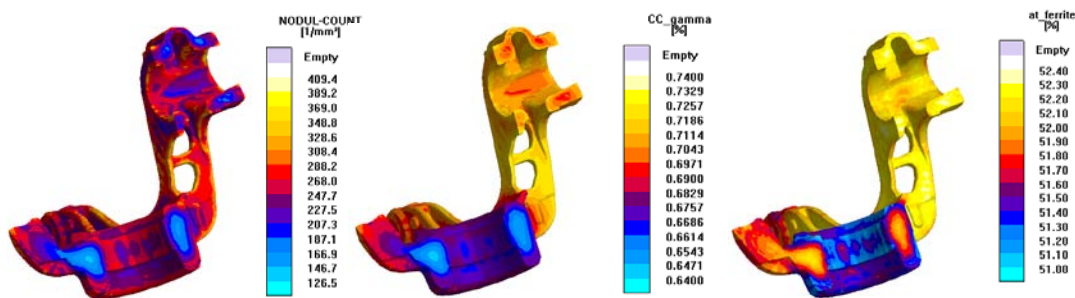
Povzetek

ADI materiali (poboljšana nodularna litina, DIN EN 1564), nudijo široko paleto uporabe zaradi prednostne kombinacije njihovih mehanskih lastnosti. Njihov razpon nateznih trdnosti se začne od 800 N/mm² in gre do 1600 N/mm² v kombinaciji z visokimi raztezki do 10%, dobro duktilnostjo in visokimi nihajnimi trdnostmi. ADI materiali imajo gostoto približno 10% nižjo kot jeklo in trikrat višjo trdnost v primerjavi z aluminijevimi zlitinami pri samo 2.6 krat večji teži. To ima za posledico visok potencial za lahke konstrukcije. Nezanosljivost v smislu obnašanja materiala in reproduktivnosti obvladanja procesa pa je preprečila širšo uporabo kot material za konstrukcije.

Če hočemo doseči te lastnosti oziroma prednosti na način, ki je reproduktiven in dobro kontroliran, je to lahko doseči med litjem in toplotno obdelavo. Namen simulacije pri izdelavnem procesu je predvideti vpliv kemijske sestave in vodenja procesa na mehanske lastnosti. Tako lahko povečamo stabilnost procesa in stroški se znižajo. Še več, možno je dobiti informacijo o riziku proizvodnje in varnostne meje lahko zmanjšamo.

V okviru skupnega projekta so bili razviti softwer modeli za toplotno obdelavo, vključeni so bili v proces predvidevanja celotne izdelave. Za korak avstenitizacija so bile uporabnikom na voljo informacije o avstenitizacijskih časih in temperaturah. Razvit je bil tudi model, ki predvideva lokalne mikrostrukture, simulirane med procesom litja (število grafitnih nodulov in profil izcejanja), za določevanje faznih transformacij perlit/ferit v avstenit in porazdelitev ogljika v avstenitu. Namen simulacije naknadnega kaljenja je bil preprečitev nezaželjene faze kot je perlit. 16 tipičnih sestav zlitin smo preiskali in CCT diagrami so bili razviti in vključeni v softwar. Razviti so bili modeli za simulacijo končne toplotne obdelave z namenom simulirati nukleacijo in rast avsferrita v odvisnosti od časa zadrževanja na temperaturi in prejšnjih korakih procesa.

Z razvojem softwarskih prototipov so bili simulirani 3 reprezentativni deli (avtomobilski nosilec gredi, planetni nosilec, pesto kolesa



Ključne besede: optimizacija procesa, simulacijski procesi

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MATERIAL SPECIFIC PROCESS OPTIMIZATION OF ADI BY SIMULATION

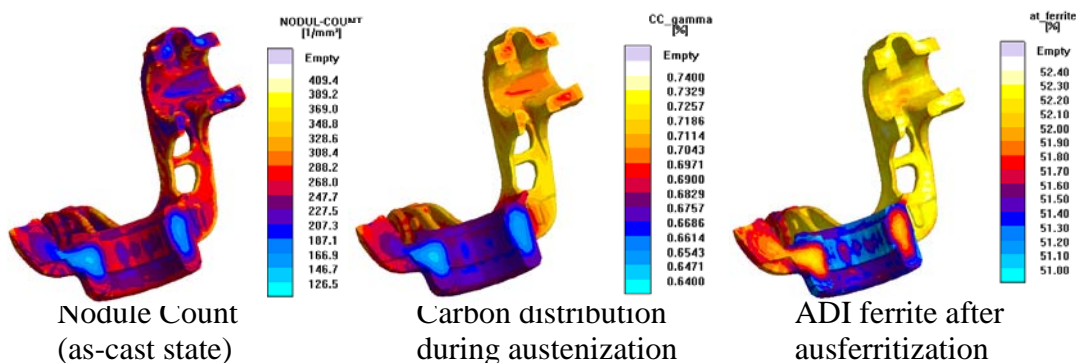
Summary

ADI materials (Austempered Ductile Iron, DIN EN 1564), offer a wide range of applications because of the advantageous combination of their mechanical properties. Their range of tensile strengths starts from 800 N/mm² and goes up to 1600 N/mm² in combination with high elongations up to 10%, a good ductility and high fatigue strengths. ADI materials have a density approx. 10% lower than steel alloys and a 3 times higher strength compared to Aluminum alloys at a 2.6 times higher weight only. This creates a considerable potential for light weight construction. Insecurities in terms of material behaviour and a reproducible process management have prevented a broad usage as construction material so far.

To achieve these favourable properties a reproducible and well controlled process management is necessary during casting and heat treatment. The goal of the simulation of the manufacturing process is to predict the influence of chemical composition and process management on the mechanical properties. Thus the process stability can be increased and cost can be decreased. Moreover it is possible to get information about production risks up-front and safety margins can be reduced.

In the frame of a common project software models for the heat treatment have been developed and integrated into the prediction of the total manufacturing process. For the austenization step quantitative information in terms of austenization times and temperatures should be available for the users. Therefore a model was developed that considers the local microstructures simulated during the casting process (number of graphite nodules and segregation profiles) to predict the phase transformation of pearlite/ferrite into austenite and the distribution of carbon within the austenite. The goal of the subsequent quenching simulation was to avoid undesirable phases such as perlite. 16 typical alloy compositions were investigated and CCT diagrams have been developed and integrated into the software. For the final tempering step models have been developed to simulate the nucleation and growth of the ausferrite depending on the holding temperature and the prior process steps.

With the developed software prototype 3 representative parts (car spindle carrier, planetary carrier and hub of a wheel) were simulated to achieve different optimizing goals.



Key words: process optimization, simulation processes



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ZNAČILNOSTI TRANSFORMACIJ PRI BAINITNO POBOLJŠANI NODULARNI LITINI Z DUALNO MIKROSTRUKTURO

Povzetek

V predavanju podajamo študijo vpliva niklja, bakra in molibdena na nizko legirano nodularno grafitno litino, ki ima tendenco poboljšanja v avstenitni stopnji, preiskali smo ulitke GJS 800-10, ki odgovarja standardu HRN-EN 1564. Nodularno sivo litino smo naredili po takoimenovanem dupleks talilnem postopku in obdelavo po sandwich metodi. Testne vzorce smo jemali iz ulitkov z debelinami 50 mm, ulitimi v sveže forme. Na osnovi kemijske sestave s programom Thermo-Calc (TCW 4) smo konstruirali ravnotežni fazni diagram in izračunali zgornje in spodnje kritične temperature, kar določa interkritični interval avstenitizacije ali interval delne avstenitizacije. Pri tej nizko legirani nodularni litini smo istočasno naredili termično analizo z metodo diferencialne scanning kalorimetrije in določili odgovarjajoče temperature evtektoidnega faznega področja (DSC). Na osnovi metalografskih analiz, narejenih s Softwarom Analysis and Materials Research Lab, smo v interkritičnem intervalu žarjenja vzorcev nodularne litine in naknadnim kaljenjem v vodi določili delež posamezne faze v odvisnosti od temperature avstenitizacije sive litine.

Ključne besede: avsfertna nodularna litina, karakterizacija transformacij, dualna mikrostruktura, interkritična temperatura avstenitizacije



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TRANSFORMATION CHARACTERISTICS OF DUAL MATRIX STRUCTURES ADI

Summary

In presented study Ni, Cu, Mo low alloyed spheroidal graphite cast iron intended to austempering and production of castings GJS grade 800-10 in according to HRN-EN 1564: 2011 was investigated. Spheroidal graphite cast iron was produced by so called duplex melting procedure and melt treatment by sandwich method. The investigations samples were taken from the casting with relevant thickness of 50 mm, which was poured in the green sand mould. On the base of chemical composition by Thermo-Calc (TCW 4) programme the equilibrium phase diagram was constructed and upper and lower critical temperatures were calculated, which define the intercritical austenitising interval or interval of partially austenitisation. Simultaneous thermal analysis of low alloyed spheroidal graphite cast iron by differential scanning calorimetry (DSC) method was also performed and the relevant temperatures of eutectoid phase region determined. On the base of metallographic analyses by Analysis © Materials Research Lab software, in the intercritical interval annealed and in water quenched samples of spheroidal graphite cast iron, the share of individual phase was determined in depending of the partially austenitised cast iron temperature.

Key words: Ausferitic spheroidal cast iron, Characteristics of transformations, Dual matrix structure, Intercritical austenitising temperature



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PRISPEVEK K VREDNOTENJU MEHANSKIH LASTNOSTI ŽELEZO-OGLJIKOVIH LIVNIH MATERIALOV

Povzetek

Izredne lastnosti železovih litin (grafitne lamele, litina z vermikularnim grafitom in nodularna litina, bela in črna temprana litina, siva litina in jeklolitina), to so osnovni razlogi za širok razpon uporabe na različnih področjih, v glavnem v avtomobilski industriji, strojništvu, gradbeništvu in elektroindustriji in še kje.

Vprašanje je, kako iz vrednotiti mehanske lastnosti v relaciji s kemijsko sestavo in pogoji ohlajevanja. Glavni namen je definirati metalurško stopnjo učinkovitosti s primerjavo merjenih lastnosti s standardnimi lastnostmi.

Detajlni primeri bodo pokazali proces. Namen je kontrolirati in optimizirati mehanske lastnosti. Na področju sive litine z lamelastim grafitom je W.Patterson leta 1958 definiral stopnjo »maturity«
RG in relativno trdoto RH. RG je razmerje merjene natezne trdnosti R_m proti normalni natezni trdnosti, kar je odvisno od nasičenja Sc in se razlikuje s pogoji ohlajevanja, na primer debelino sten ulitka ali premerov posebno ulitih vzorcev. RH je razmerje merjene trdote HB proti normalni trdoti, kar odgovarja merjeni natezni trdnosti. Normalno željene so visoke RG vrednosti (>100%) in nizke RH vrednosti (<1.0).

Modul elastičnosti E_0 odgovarja razmerju natezne trdnosti proti trdoti, po A.Collaudu 1954/55. Stopnja nasičenosti Sc je lahko zamenjana z detajlno kemijsko sestavo ali intervalom strjevanja, razlike med likvidus in solidus temperaturo.

Kar se tiče nodularne litine sta W.Siefer in K.Orths 1966 poročala o relacijah med trdoto in natezno trdnostjo. Odgovarjajoče relacije za temprano litino sta W.Patterson in R.Doepp 1969 podala v RH-diagrame za duktilne Fe-C materiale, to je nodularno in temprano litino in lito jeklo v primerjavi z originalnimi RH- diagrami za litino z lamelarnim grafitom.

H.Zeuner je že leta 1965 predlagal kot merilo za kvaliteto produkt natezne trdnosti in raztezka. To bi lahko bila uporabna možnost za vrednotenje drugih duktilnih železovih materialov, GYS, GJV, GJMW in GJMB, največ od teh je bilo raziskanih detajlno s strani W.Pattersona in R.Doeppa 1973. Novi material kot je vermikularni grafit GJV se zdi zelo podoben temprani litini. Detajlna informacija bo še podana.

Ključne besede: kontrola mehanskih lastnosti



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CONTRIBUTION TO EVALUATION OF MECHANICAL PROPERTIES OF IRON-CARBON-CASTINGS

Summary

The excellent mechanical properties of iron-carbon-castings (flake, compacted and spheroidal graphite cast iron, whiteheart and blackheart malleable cast iron and cast steel) are one basic reason for the wide range of application in different fields, mainly automotive, machinery, building and electric industry and many others.

The question is how to evaluate a distinct mechanical property in relation to chemical composition and cooling conditions. The general aim is to define metallurgical degrees of efficiency by comparing measured properties to standard properties.

Some detailed examples show the procedure. The aim is to control and optimize the mechanical properties. In the field of grey cast iron with flake graphite W. Patterson 1958 defined the degree of maturity RG and the Relative Hardness RH. RG is the ratio of measured tensile strength R_m to normal tensile strength, which depends on the degree of saturation S_c and differs with cooling conditions, for instance wall thickness of casting or diameter of separately cast specimen. RH is the ratio of measured hardness HB to normal hardness, which corresponds to the measured tensile strength. Normally wanted are high RG-values (>100%) and low RH-values (<1,0).

The modulus of elasticity E_0 corresponds to the ratio of tensile strength to hardness, following A. Collaud 1954/55. The degree of saturation S_c can be replaced by the detailed chemical composition or by the solidification range, the difference between liquidus and solidus temperature.

Concerning spheroidal graphite cast iron W. Siefer and K. Orths 1966 reported relations between hardness and tensile strength. Corresponding relations for malleable cast iron from W. Patterson and R. Doepp 1969 lead to RH-diagrams for the ductile Fe-C-materials nodular and malleable cast iron and cast steel compared to the original RH-diagram for lamellar graphite cast iron.

H. Zeuner already 1965 proposed the product of tensile strength and elongation as a measure of quality. This may be an useful chance for evaluation of the other ductile cast Fe-C-materials GJS, GJV, GJMW and GJMB, most of them discussed in detail by W. Patterson and R. Doepp 1973. The new material compacted graphite cast iron GJV is assumed to be very near to malleable cast iron. Detailed information should follow.

Key words: control of mechanical properties



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IZJEMNE TEHNOLOŠKE REŠITVE RAZIGLEVANJA IN ČIŠČENJA LIVARSKIH IZDELKOV Z AVTOMATIZACIJO, ROBOTIZACIJO IN NOVIMI TEHNOLOGIJAMI PODJETJA FERROČRTALIČ

Povzetek

Podjetje je uveljavljeno doma in v svetu na področju tehnologij in opreme za Obdelavo površin, predvsem tehnologije kontroliranega peskanja s komprimiranim zrakom in podobnih postopkov. V tem sestavku bosta predstavljena dva različna pristopa pri raziglevanju zelo občutljivih odlitkov iz zamaka in dve rešitvi čiščenja s suhim ledom oz. snegom.

Prva rešitev raziglevanja drobnih preciznih odlitkov iz zamaka za elektro in avtomobilsko industrijo je sicer konvencionalna, vendar je bilo uporabljenih kar nekaj zanimivih inovacij in popolna avtomatizacija procesa. Tu je izbran princip raziglevanja določene količine obdelovancev skupaj. Količina je določena z volumnom zaboječka, obdelovanci pa so že obrezani/odsekani od jeder, torej več sto ali tisoč posamičnih kosov v enem polnjenju stroja. Ker so kosi zelo precizni in namenjeni masovni proizvodnji telefonov, elektronskih komponent, navigacijskih naprav in varnostnih avtomobilskih ter letalskih sistemov, je potrebno z njimi zelo pazljivo rokovati. Stresanje, polnjenje in praznjenje je zelo občutljiva faza dela, zato bomo prikazali, kako smo to rešili na konkretnem primeru. Samo peskanje ter kotaljenje obdelovancev med seboj je prav tako nevarno za poškodovanje drobnih pinov ipd... Popolni nadzor in avtomatizacija procesa poteka brez operaterjeve prisotnosti, ki je o zaključenem postopku opozorjen po nekaj urah obratovanja stroja, da je potrebno paletu s 16 zaboječki obdelanih kosov zamenjati...

Druga rešitev raziglevanja temelji na principu: posamično, kos po kos, v milijonskih serijah... Prikazana bo popolna novost na področju čiščenja in obdelave površin iz mehkih materialov, ter opisan potek razvoja in osnovne značilnosti omenjene robotizirane rešitve. Pri izvedeni rešitvi robot odlitek iz livarskega stroja vstavi takoj v stroj za raziglevanje in poenotenje površine, nato pa taisti robot gotove obdelovance prestavi še v stroj za obsekovanje. Stroj sestavljajo štiri celice, verižni transporter, mesto za vpenjanje in izpenjanje obdelovancev na prijemala oziroma transportna gnezda verižnega transporterja, ter oprema, ki je potrebna za peskanje. V prvi celici je robot, ki s šobo za peskanje obdela samo točno določena mesta obdelovanca. V drugi celici dva seta gibljivih šob s peskanjem poenotijo površino. V tretji celici se vrši čiščenje obdelovanca in prijemal z izpihovanjem, v četrti pa robot s strojnim vidom preveri kakovost izdelka.

Na prvem primeru čiščenja s Suhim ledom bomo razložili princip in učinkovitost čiščenja modelov in kokil ter rešitvami, ki se v livarnah za tlačno litje že uporabljajo. Prikazan bo postopek čiščenja vročih kokil v Alu livarni, čiščenje kalupov za izdelavo jeder in nekaj primerov uspešne implementacije in avtomatizacije.

Drugi primer čiščenja s Suhim ledom / snegom bo prikazal primerjalno analizo čiščenja popolnoma obdelanih (postruženih, porezkanih, opremljenih z navoji utori itd...) izdelkih, ki gredo končnemu kupcu v zaključno montažo in morajo biti zato tehnično popolnoma čisti. Študije v našem podjetju so pokazale veliko prednost čiščenja z mikro peletkami iz Suhega ledu, v nekaterih primerih pa celo zelo zadovoljivo čiščenje s Suhim snegom. Primerjalna analiza bo marsikomu odgovorila na njegove dileme in morda celo podala rešitev, kaj je primernejše.

Ključne besede: čiščenje s suhim ledom, peskanje



B.Črtalič, FerroČrtalič d.o.o. Slovenia

AUTOMATIC AND ROBOTIC SURFACE TREATMENT SOLUTIONS IN FOUNDRY INDUSTRY WITH NEW TECHNOLOGIES BY FERROBLAST

Summary

The company is well known in Slovenia and also abroad on the field of technology and equipment for the treatment of surfaces, especially technology for controlled sandblasting with compressed air and other procedures. We will present two different procedures at deneedling of very sensitive castings made from zamak and two solutions for cleaning with dry ice/snow.

The first solution of deneedling of fine castings from quality zamak for electro and automotive industry is commonly conventional, but we used new interesting innovations and complete automatization of process. We decided to choose up the principle of deneedling of defined quantity of samples of castings. The quantity was defined with the volume of box, samples were already deburred/cut off from cores, we can say there were more than hundred or thousand of species in one filling. The pieces are very precise and they are designed for massive production of telephones, electronic components, navigation instruments and secure systems for automotive and aircraft systems, for these reasons it is necessary to treat them very carefully. Shaking, filling and shaking out are very sensitive phases, we presented these phases on exact example. Sand blasting and »rolling« of workpieces is also dangerous phase for different damages. Complete control and automation of process goes on without operator, he only gets the »warning« that procedures is finished after few hours of working of the machine, the pallet with 16 boxes is needed to exchange..

The second solution of deneedling based on the principle: separately, piece after piece in million series. We will present the complete novelty on the field of cleaning and surface treatment from «soft» materials and describe the development and fundamental characteristics of the mentioned robotic solution. At this solution the robot insert casting from casting machine into a machine for deneedling and making of uniform of surface, then the same robot displaces the finished pieces into a machine for »cutting«. Machine is made from four cells, chain transporter, place for clamping and declamping of pieces on the chain transport »nests«, needed for shotblasting. In the first cell is robot, which treats with nozzle for blasting the very defined places of pieces. In the second cell are two sets of moving nozzles make the surface uniform. In the third cell the workpiece is cleaned with blowing out and in the fourth the robot examines the quality of product.

On the first example of the cleaning with dry ice we will explain the principle and effectiveness of cleaning of patterns and moulds and with solutions, already existed in foundries for die casting. We will present the procedure of cleaning of hot dies in aluminium foundry, cleaning of moulds for making of cores and some examples of successful implementation and automation.

The second example for cleaning with dry ice/ snow will present the compared analysis of cleaning of complete finished workpieces, which are prepared for delivery to customers and and have to be technically complete cleaned. The studies in our company showed us the great advance of the cleaning with micro pellets made from dry ice, in some cases is even enough the cleaning with dry snow. The compared analysis will give the answers on the dilemmas and will give the solution, what is more suitable.

Key words: cleaning with dry ice, sandblasting



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MASTER DB – SISTEM UPRAVLJANJA S TEHNOLOŠKIM ZNANJEM

Povzetek

MasterDB sistem je oblikovan za monitoring pretoka informacij med odvisnimi serverji SimulacijaDB. To omogoča, da razvito tehnologijo litja v eni dejavnosti lahko hitro prenesemo v drugo dejavnost istega podjetja. Sistem MasterDB je uporabljan za učinkovito obvladovanje tehnološkega znanja v celotnem podjetju. To sestavlja subsisteme SimulacijaDB.

S tehnološkim poznavanjem osnov SimulacijeDB shranjujemo detaljne informacije iz vsakega posameznega koraka proizvodnega procesa.

SimulacijaDB – baza podatkov za livarske inženirje ima več različnih prednosti kot so:

- Tehnološki podatki so zbrani na enem mestu
- Enostaven dostop do rezultatov simulacij
- Primerjava virtualne in realne tehnologije
- Izobraževanje mladih in neizkušenih tehnologov
- Enostavno iskanje in analiza podatkov
- Kreiranje nove tehnologije na osnovi informacij iz sistema Simulacija DB

Prednosti sistema MasterDB:

- Delitev razvite tehnologije in znanja z drugimi deli podjetja
- Enostavnejši dostop do specializiranega znanja
- Izboljšanje konkurenčnosti podjetja in učinkovitosti
- Shranjevanje virov – ni potrebe vključevati različnih ekip tehnologov z namenom da bi reševali enake probleme.

Ključne besede: baza podatkov za simulacijske rezultate, baza znanja, obvladovanje proizvodnih procesov



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MASTER DB – TECHNOLOGICAL KNOWLEDGE MANAGEMENT SYSTEM

Summary

The MasterDB system is designed to monitor the flow of information between subordinate servers SimulationDB. This allows casting technology developed in one branch to be quickly applied in another branch of the company. The MasterDB system is used to efficiently manage technological knowledge in the entire casting company. It consists of SimulationDB subsystems.

A technological knowledge base SimulationDB stores detailed information from each step of the production process

SimulationDB – Database for Foundry Engineers has several advantages like:

- Technological data are gathered in one place,
- Easy access to simulation results,
- Comparison virtual and real technology,
- Training young and inexperienced technologists,
- Easy search and analyze data
- Create new technology based on information from SimulationDB system

Advantages of the MasterDB system:

- Sharing developed technological knowledge with other branches of the company,
- Easier access to specialized technological knowledge,
- Improvement of the company's competitiveness and efficiency,
- Saving resources – there is no need to involve several teams of technologists in order to solve the same issue.

Keywords: database for simulation results, knowledge base, production process management



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TEŽKI ULITKI IZ FERITNE DUKTILNE LITINE : UČINEK LOKALNE KEMIČNE SESTAVE NA MIKROSTRUKTURO IN UDARNE LASTNOSTI

Povzetek

Težki ulitki iz duktilne litine so oblikovani za uporabo v kritičnih razmerah (na primer za vetrne turbine) morajo prestati teste veljavnosti kot na primer test Charpy (V- zareza) in teste nateznih trdnosti, z namenom potrditve kvalitete ulitkov. Splošno je znano, da se lastnosti nodularne litine spreminjajo s številom nodulov, nodularnostjo in vsebnostjo perlita. To delo potrjuje, da sestava šarže vpliva pomembno na lokalno mikrostrukturo in posledično na mehanske lastnosti. To smo opazili celo pri konstantni vrednosti ogljikovega ekvivalenta. V predavanju bomo podali tudi izsledke vpliva vsote in tipa karbidov in elementov, ki pospešujejo nastanek perlita na udarno trdnost pri -20oC in - 40oC.

Ključne besede : težki ulitki iz nodularne litine, mikrostruktura



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HEAVY SECTION FERRITIC DUCTILE IRON CASTINGS: EFFECT OF THE LOCAL CHEMICAL COMPOSITION ON THE MICROSTRUCTURE AND IMPACT PROPERTIES

Summary

Heavy section ductile iron castings designed for critical applications (eg. wind mill turbines), must succeed validation tests, such as impact Charpy V-notch and tensile tests, in order to confirm the casting quality. It is well known that the properties of nodular irons vary with nodule count, nodularity and pearlite content. This work confirmed that the charge composition (quality and fraction of the charge) affects significantly the local microstructure and consequently, the mechanical properties. This was observed even for the constant C.E. values. The effect of the sum of and type of carbide and pearlite promoting elements on the impact strength at -20°C and -40°C will also be discussed.

Key words: heavy section ductile iron, microstructure



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TEM ŠTUDIJA GROBEGA IN FINEGA GRAFITA V MIKROSTRUKTURI SIVE LITINE

Povzetek

Narejena je bila TEM študija grafitnih lističev v sivi litini.

Difrakcijski eksperimenti pokažejo, da je grafit kristaliničen z zanimivo kristalograsko mikrostrukturo na dveh različnih vzorcih sive litine. Na osnovi izbranih difrakcijskih analiz, so bile identificirane in primerjane kristalografske ploskve. Razlike kot izgleda izhajajo iz dodatkov titana in lahko ugotavljamo možne vplive na nastanek in mehanizem rasti grafita.

Ključne besede: dodatek titana, vpliv titana na rast grafita



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A TEM STUDY ON THE MICROSTRUCTURE OF COARSE AND FINE GRAPHITE FLAKE

Summary

A TEM study has been carried out on graphite flakes in grey cast iron.

Diffraction experiments show the graphite to be crystalline with interesting crystallographic microstructures in two different cast iron samples. Based on the selected area diffraction pattern analysis, crystallographic planes are identified and compared. The differences appear to be related to the addition of Ti and suggest a possible influence on formation and mechanism of growth of graphite.

Key words: additions of Ti, influence of Ti on graphite growth



D.Justin, M.Gnamuš, A.Mikuž, Litostroj jeklo d.o.o., Slovenija

OPTIMIRANJE IZDELAVE GONILNIH LOPAT

Povzetek

Litostroj Jeklo d.o.o. je danes eden vodilnih proizvajalcev jeklenih kompleksnih oblik ulitkov na področju komponent za dele vodnih turbin. Le te so proizvedene iz martenzitnih in avstenitnih nerjavnih jeklenih litin z izboljšanimi mehanskimi lastnostmi.

Kvaliteta, know-how in ekonomičnost so vplivni dejavniki vsake uspešne livarne. Le s stalnimi izboljšavami proizvodnega procesa lahko uspešno nastopajo na globalnem trgu. Za doseganje večje produktivnosti, zmanjšanje potrebnega delovnega prostora, skrajšanje časa ohlajanja ulitkov v pesku/formi ter zmanjšanje pomožnih livarskih materialov je bil zasnovan izboljšan način priprave peščenih form za litje.

Pristop temelji na snovanju naprednih livarskih okvirjev s povečano sposobnostjo odvoda toplote, dobro statično stabilnostjo forme pri manjši porabi peščene mešanice. Takšen pristop omogoča prihranke na stroških in času, po drugi strani pa prinaša ponovljivost procesa izdelave form in jeder in optimizacijo delovnega procesa.

Ključne besede: izboljšanje izdelave gonilnih lopat, priprave peščenih form



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OPTIMIZATION OF RUNNER BLADES MANUFACTURING

Summary

Litostroj Steel is a leading manufacturer of complex shaped steel castings for water turbine components which are manufactured from high quality martensitic and austenitic stainless steel with improved mechanical properties.

The quality, knowhow and efficiency are influential factors of every successful foundry. Only with continuous improvements of the production process we can successfully appear in the global market. In order to increase the productivity, reduce the necessary working space, reduce the cooling time of castings in the mould and reduce the quantity of auxiliary foundry material, an improved method of preparation of sand moulds for pouring was designed.

The approach is based on the use of advanced moulding frames with increased capability of heat transfer, good static stability of the mould and smaller consumption of the sand mixture. This approach allows savings in cost and time and on the other hand, provides repeated manufacturing process of mould and cores and optimization of work process.

Key words:: improvement of making of runner blades, preparing of sand molds



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MODEL AKTIVNEGA POSKUSA ZA OCENJEVANJE STANJA BENTONITNE FORME PRED LITJEM SIVE LITINE

Povzetek

Kompleten razvoj mehanizma širjenja in krčenja med strjevanjem sive litine je bolj kompleksen kot samo sprememba volumna ulitka. Še več, geometrija ulitka zakomplicira strjevanje (plinska poroznost kritičnih presekov), bentonitnih form. Testiranje fizikalnih in kemijskih lastnosti komponent bentonitnih mešanic: peska, bentonita, mešanica krožnega peska in dodatkov pred izdelavo mešanice je bilo narejeno v preiskovalnem laboratoriju. Pogoje v formi, narejeni ročno in strojno, nismo mogli pretestirati pred ulivanjem, in to je čas, v katerem se istočasno prepletajo fenomeni strjevanja in tok taline. V poročilu podajamo tehniko jemanja majhnih vzorcev iz mešanice v kritični coni forme, v področju erozije in penetracije v formo, kar lahko učinkovito popravimo, določimo pa tudi količino vlage in stopnjo nabijanja. Za analiziranje baze podatkov testnih rezultatov mehanskih lastnosti mešanice, narejene v livarni, si postavimo aktivni eksperimentalni model mehanskih lastnosti: propustnost, stisljivost, strižna trdnost in trdnost kondenzacijske cone.

Profil fronte forma – ulitek je privzet iz rezultatov MAGMASOFT simulacije kritične cone za posamezne replike test forme. Na koncu poteka 3D funkcije, katere minimum preferira erozijo in loči primere erozije in penetracije taline v formo.

Analiza kvalitete sive litine (fitingi) pokaže bistveno zmanjšanje napak in ni pojava zgodnjega razpada forme ali penetracije taline v formo, če mešanica vsebuje 3 – 3.5% vlage, z 30-40% stopnjo zgoščevanja v kritičnih področjih forme.

Ključne besede: siva litina, trajnost bentonitne mešanice, vlaga, stopnja zgoščevanja, penetracija taline, erozija forme



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THE MODEL OF ACTIVE EXPERIMENT TO ASSES THE STATE OF BENTONITE MOLD BEFORE CASTING OF CAST IRON

Summary

Complete development of mechanisms for expansion and shrinkage during the solidification of gray cast iron is more complex than just a change of volume of the casting. In addition, the casting geometry has complicated its solidification (gas porosity critical section), and making bentonite molds and endurance. Testing of physical and chemical properties of bentonite mixture components: sand, bentonite, a mixture of circular and supplements prior to making a mixture whose mechanical properties of the lab exam. Condition of the mold, made by hand and machine can not be checked prior to pouring the metal, and this is the period in which the fragments drawn solidification phenomena and flow of metal mold and decay occur simultaneously. In this paper, the technique of taking small samples from a mixture of the critical zone of the mold, the region of erosion or penetration of metal into the mold, which can be effectively repaired, determines the amount of moisture and degree of ramming. To analyze a database of test results of mechanical properties of the mixture in the foundry set an active experiment model of mechanical properties: permeability, compressive, shear and condensation zone strength.

Profile front mold - casting is adopted from the results MAGMASOFT simulation, the critical zone for single mold replica tests. At the end of running 3D function whose minimum preference erosion separates cases of erosion and penetration of metal into the mold.

Analysis of quality gray iron castings (fittings) shows a significant reduction in defects and the absence of cases of early destruction of the mold or the penetration of metal into the mold if a mixture containing 3 – 3.5% moisture, with 30 – 40% degree of ramming in the critical zones of the mold.

Key Words: gray iron, durability bentonite mold, moisture, degree of ramming, metal penetration, mold erosion.



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KONTROLA IN KRMILJENJE IZDELAVE SIVE LITINE S KROGLASTIM GRAFITOM

Povzetek

Strjevanje sive litine s kroglastim grafitom je kompleksen mehanizem, ki brez dosledne kontrole krmiljenja procesa vodi k livarskim napakam. Sam podatek o kemijski sestavi taline je nezadovoljiv za razlago strjevalnih procesov, saj prikazuje le celotno količino in tip kemijskih elementov vzorca. Že relativno majhne variacije pri taljenju, odstajanju, obdelavi in cepljenju taline pri proizvodnji sive litine s kroglastim grafitom imajo močan vpliv na mehanizem strjevanja. Članek opisuje vpliv obdelave taline s spremenjeno količino FeSiMg na kakovost taline, ki smo jo pri ohlajanju skozi področje evtektske premene kvantitativno opredelili z uporabo programskega paketa za termično analizo. Raziskovalna metoda nam omogoča vpogled v obnašanje taline med samimi strjevanjem.

Ključne besede: siva litina s kroglatim grafitom, termična analiza, FeSiMg



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CONTROL AND MANAGING OF PRODUCTION OF NODULAR GRAPHITE IRON

Summary

Solidification of nodular graphite iron is a complex mechanism, because of this fact, it leads without consistent control of the process often to casting defects. The data about chemical composition of melt is not enough to explain the solidification processes, this is only the description of the complete quantity and type of chemical elements. Already the relatively small variations at melting, treatment of melt, inoculation at the production of nodular graphite iron, these parameters have a great influence on the mechanism of solidification. The report presents influence of treatment of melt with changeable quantity of FeSiMg on the quality of melt. Melt was quantitatively defined at cooling through the eutectic plane with the use of a programme package for thermal analysis. The research method enables us to look at the behaviour of melt at solidification.

Key words: nodular graphite iron, thermal analysis, FeSiMg



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TEHNIČNA IN STROŠKOVNA UČINKOVITOST LINIJE ZA PROIZVODNJO SIVE LITINE

Povzetek

Za izboljšanje dobička v livarni, je med drugim potrebno zmanjšati proizvodne stroške, ki nastajajo zaradi različnih izgub v proizvodnem procesu. Stroškovno učinkovitost livarske linije lahko povečamo s tehnično učinkovitostjo, ki jo izrazimo z OEE (Overall Equipment Effectiveness), stroškovno učinkovitost pa z zmanjšanjem razmerja med dejanskimi povprečnimi stroški (AC) in optimalnimi povprečnimi stroški (AC*). Ocenili smo matematični model, s katerim lahko opišemo razmerje med navedenima spremenljivkama OEE in AC/AC*.

Ključne besede: OEE, Overall Equipment Effectiveness, stroški, izkoristek, proizvodna linija



B.Čuk, Eta Cerkno d.o.o., Slovenia

TECHNICAL AND COSTS EFFICIENCY OF THE PRODUCTION LINE FOR GRAY IRON

Summary

To improve the net profit in foundry, we have to lower production costs, originating because of different losses in the production line. Cost efficiency of the foundry production line can increase with technical efficiency, that we express with so called OEE (Overall Equipment Effectiveness), cost efficiency can we lower with the proportion between actual average costs (AC) and optimal average costs (AC*). We estimated the mathematical model, we can describe proportion between these variables OEE and AC/AC*.

Key words: OEE, Overall Equipment Effectiveness, costs, yield, production line



S.Babarci, Analysis doo, Thermo Scientific, Beograd, Srbija

ANALIZA VKLJUČKOV V JEKLU

Povzetek

Optična emisijska spektrometrija (OES) je stroškovno učinkovita in robustna analitska tehnika, ki je zelo hitra, od enostavne elementarne analize trdnega železa in jekla od proizvodnje do reciklaže in od livarne do servisnih laboratorijev. ThermoScientific ARL 4460 Metals Analyzer z TRS in CCS možnostmi je visoko uporaben OES spektrometer z najboljšo občutljivostjo, natančnostjo in zanesljivostjo na tržišču.

Spark-DAT (Spark Data Acquisition and Treatment) pridobivanje signala korak po korak nudi še nedosežene možnosti za kontrolo vključkov med izdelavo jekla: samo ena aparatura omogoča določitev elementarne koncentracije in število vključkov, velikosti in sestavo. Z Spark-DAT uporabo lahko izračunamo celotno koncentracijo kisika direktno iz količine kisika v oksidnih vključkih. Metoda je kvantitativna in določa koncentracije kisika pod 30 ppm, z samo eno tehniko z uporabo te aplikacije lahko danes zmanjšamo uporabo nekaterih dragih tehnik (in povezanih z vzorčenjem) kot je optična mikroskopija, SEM, AAS, analiza zgorevanja...

Priprava vzorcev, vzdrževanje in servisiranje vse ostaja enako kot pri standardnem spektrometru ARL 4460, ta rešitev zagotavlja minimalne stroške delovanje in časa (tipično 30 vzorcev na uro za vse analize, celo več, če uporabimo avtomatizacijo)

Ključne besede: OES,vključki, Spark-DAT,ARL 4460



S.Babarci, Analysis doo, Thermo Scientific, Beograd, Serbia

ANALYSIS OF INCLUSIONS IN STEEL

Summary

Optical emission spectrometry (OES) as cost-effective and robustness analytical technique is a very fast, simple elemental analysis of solid iron and steel samples from production to recycling and from foundries to service laboratories. The Thermo Scientific ARL 4460 Metals Analyzer with TRS and CCS options is a high performance OES spectrometer with best sensitivity, precision and accuracy on the market.

The Spark-DAT (Spark Data Acquisition and Treatment) acquisition of the signal spark by spark offers unequalled perspectives for controlling inclusions during steel production: single instrument provides elemental concentrations and inclusion number, sizes and composition. With Spark-DAT application the total oxygen concentration can be also calculated directly from the amount of oxygen contained in the oxide inclusions. The method is quantitative and determines the oxygen concentration below 30ppm. With only one technique using this application today we can reduce usage of some costly techniques (and related sampling) such as optical microscopy, SEM, AAS, combustion analyzers,...

As the sample preparation, maintenance and service remain the same as for the standard ARL 4460 spectrometer, this solution ensuring minimal operation cost and time (typically 30 samples per hour for all analysis, even more using automation)

Key words: OES, inclusion, Spark-DAT, ARL 4460



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UČINEK ELEKTRO MAGNETNEGA POLJA MAJHNIH FREKVENC NA IZDELAVO IN LASTNOSTI DIREKTNO ULITE ALUMINIJEVE ZLITINE 6060

Povzetek

V študiji smo preiskali vpliv nizkofrekvenčnega elektromagnetnega polja med vertikalnim polkontinuirnim procesom litja aluminijeve zlitine 6060. Rezultate smo primerjali s tistimi, ki smo jih dobili pri konvencionalnem polkontinuirnem litju. Na osnovi primerjalnih analiz rezultatov je bilo ugotovljeno, da litje v nizkofrekvenčnem magnetnem polju nudi mnoge prednosti kot na primer gladko površino gredic, manjše velikosti kristalnih zrn po preseku, bolj drobno mikrostrukturo in enakomerno porazdelitev intermetalnih faz v zlitini z enakimi ali celo boljšimi mehanskimi lastnostmi. Zaradi tega je uporaba tega livnega procesa lahko opcija za ekonomsko upravičenost oziroma prihranke.

Ključne besede: nizkofrekvenčni elektromagnetni proces (LFEC), direktno litje v kokilo, (DC), aluminijeva zlitina, mikrostruktura, mehanske lastnosti



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EFFECT OF USE OF LOW-FREQUENCY ELECTROMAGNETIC FIELDS ON THE PRODUCTION AND PROPERTIES OF DIRECT CHILL CAST 6060 ALUMINIUM ALLOY

Summary

In this study, the effect of low frequency electromagnetic fields during the vertical semi-continuous casting process of 6060 aluminum alloy billets was investigated. The results were compared with those obtained by conventional semi-continuous casting. Based on comparative analysis of the results, it was found that casting in a low frequency electromagnetic field offers many advantages, such as smooth surface of the billets, smaller grain size in the cross section, finer microstructure and a uniform distribution of inter-metallic phases in the alloy, with the same or even slightly better mechanical properties. For these reasons, the employment of this casting process is considered an option for obtaining economic savings.

Keywords: low frequency electromagnetic casting process (LFEC), direct chill casting process (DC), aluminum alloy, microstructure, mechanical properties



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ANALIZA STRJEVANJA ZLITINE $AlSi9MgMn$ S TERMIČNO ANALIZO

Povzetek

Ker se aluminijeve zlitine uporabljajo v zelo širokem obsegu v različnih vejah industrije, jih seveda moramo razdeliti glede na zahteve po kvaliteti na mikrostruturne, mehanske in tehnološke lastnosti. Multikomponentno zlitino, $AlSi9MgMn$, ki je namenjena za visokotlačno litje smo preiskovali glede na njeno neobičajno kemijsko sestavo. Ker ta zlitina ni bila klasificirana v mednarodnih normah, ampak samo kratko opisana glede na norme izdelave, predstavlja to izziv za razumevanje njenega mehanizma strjevanja. Glavne karakteristike zlitine so povezane z visoko vsebnostjo mangana in nizko vsebnostjo železa in zaradi tega ima visoke mehanske lastnosti, predvsem duktilnost.

Namen tega prispevka je dokazati oziroma prikazati sekvenco strjevanja zlitine $AlSi9MgMn$ z visokim dodatkom mangana z numeričnim izračunom ravnotežnega faznega diagrama in z diferencialno scanning kalorimetrijo in „prepoznavanjem“ termodinamičnih parametrov z dobljeno mikrostrukturo. Termodinamični izračuni so pokazali sekvenco strjevanja z odgovarjajočimi temperaturami kot: izločanje visokotemperaturne $Al_xMn_yFe_2Si_u$ faze, razvoj primarne dendritne mreže, glavne evtektske reakcije in končno, v trdnem stanju sekundarno evtektsko fazo Mg_2Si . Diferencialna scanning kalorimetrija omogoča določitev eksaktne temperature faznih transformacij. Termodinamične preiskave ne dajejo indikacij o kakršnikoli reakciji v trdnem stanju. Mikrostruturne preiskave z optičnim elektronskim mikroskopom indicirajo prisotnost delnih faz: primarnih aluminijevih dendritov (α_{Al}), visokotemperaturne $Al_{15}(MnFe)_3Si_2$ in Al_5FeSi faze, največ evtektika $\alpha_{Al} + \beta_{Si}$, interemetalne železo-magnezijeve faze $Al_8Mg_3FeSi_6$, razvite iz igličastih Al_5FeSi faz in sekundarne evtektske faze na osnovi magnezija v obliki binarnega evtektika ($\alpha_{Al} + Mg_2Si$).

Sinergija teh narejenih termodinamičnih in mikrostruturnih preiskav omogoča določitev oziroma „dokaz“ strjevalne sekvence z reakcijo in odgovarjajočimi temperaturami.

Ključne besede: $AlSi9MgMn$ zlitina, strjevalna sekvenca, termična analiza, mikrostruktura



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INVESTIGATION OF AlSi9MgMn ALLOY SOLIDIFICATION BY THERMAL ANALYSIS

Summary

Since aluminium alloys have found their wide application in numerous industries, quality requirements allocated new features regarding microstructural, mechanical and technological properties. Novel multicomponent AlSi9MgMn alloy intended for high pressure die casting has been investigated due to unusual chemical composition. Since this alloy has not been classified in international norm, only briefly described in manufacturer norm, it represents challenge for understanding of its solidification mechanism. Main characteristics of an alloy are related to high manganese and low iron content, and in spite of this, high mechanical properties, first of all, ductility.

The aim of this article was to establish solidification sequence of AlSi9MgMn alloy with high Mn addition by numerical calculation of equilibrium phase diagram and differential scanning calorimetry and reconnection of thermodynamic parameters with obtained microstructure. Thermodynamic calculation revealed solidification sequence with corresponded temperatures as follows: precipitation of high temperature $Al_xMn_yFe_zSi_u$ phase, development of primary dendrite network, main eutectic reaction and finally, in solid state, secondary eutectic phase Mg_2Si . Differential scanning calorimetry enables exact temperatures of phase transformations determination. Thermodynamic investigation does not indicate any reaction in solid state. Microstructure investigation by optical and electron microscopy indicates presence of particular phases: primary aluminium dendrites (α_{Al}), high temperature $Al_{15}(MnFe)_3Si_2$ and Al_5FeSi phases, main eutectic $\alpha_{Al}+\beta_{Si}$, intermetallic iron-magnesium phase $Al_8Mg_3FeSi_6$ developed from needle-like Al_5FeSi phases and secondary eutectic phase on the magnesium base in a form of binary eutectic ($\alpha_{Al} + Mg_2Si$).

Synergy of performed thermodynamic and microstructural investigation enables exact solidification sequence establishment with reaction and corresponding temperatures.

Key words: AlSi9MgMn alloy, solidification sequence, thermal analysis, microstructure



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UPORABA »JET COOLING« SISTEMA ZA LOKALNO USMERJENO STRIJEVANJE ULITKOV IZ AL ZLITINE

Povzetek

Tlačni ulitki iz aluminijevih zlitin imajo v veliko primerih funkcionalnost nosilnega elementa ali tesnilnega elementa. Zaradi tega je potrebno ulitkom iz visokotlačnega litja zagotoviti kakovostno strukturo materiala. Pri oblikovanju izdelkov ni možno vedno zagotoviti obliko, ki bi bila tudi najboljša za proces tlačnega litja. Posledica tega je nastajanje poroznosti v ulitkih. Le te z klasičnimi metodami ni mogoče vedno odpraviti, zaradi tega se lahko poslužimo lokalno usmerjenega strjevanja, ki v posamičnih delih ulitka izboljša kakovost materiala.

Uvajanje lokalno usmerjenega strjevanja smo izpeljali v sledečih korakih:

1. S ciljem zagotavljanja ustrezne temperature jeder v tlačnem orodju in odpravo poroznosti, so se analizirali parametri procesa tlačnega litja z implementiranimi prisilno hlajenimi jedri. Izdelana je bila simulacija ohlajevanja zlitine pri uporabi prisilno hlajenih jeder.
2. Izvedeni so bili testi tlačnega orodja z implementiranim sistemom prisilnega hlajenja jeder. Izvedeni so bili primerjalni testi in ovrednotene razlike v primerjavi z klasičnim tlačnim litjem.

Implementacija prisilno hlajenih jeder »Jet Cooling« je pokazala izboljšanje kakovosti materiala na področju okoli jeder, pri čemer se je zmanjšala poroznost okoli jeder, struktura materiala pa je postala bolj fino zrnata.

Ključne besede: Tlačno litje, usmerjeno strjevanje, Jet Cooling, simulacija, optimizacija procesa, orodje za tlačno litje



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»JET COOLING« OF SYSTEM FOR LOCAL DIRECTED SOLIDIFICATION OF CASTINGS FROM AL ALLOY

Summary

Die castings from aluminium alloys have in many cases functionalism of supporting or tightly element. Because of that it is necessary that castings from high pressure die casting have to have a quality structure of material. At designing of products it is not possible always to assure the shape, which is the best for the process of die casting. The consequence of that is the originating of porosity in castings. These it is not always annuled only with classic methods, because of that we can use the local oriented solidification, that in single parts of casting improves the quality of material.

Introducing of local oriented solidification we made in such steps:

1. with the aim of assuring of suitable temperature of cores in die casting tool and lowering of porosity, we analysed parameters of processes of die casting with implemented forced cooled cores. We made the simulation of cooling at the use of forced cooled cores.
2. The test of die casting tool were made with implemented system of forced cooling of cores. We made the comparative tests and differences in the comparison with classic die casting were valued.

Implementation of forced cooled cores »jet cooling« showed the improvement of quality of material on the field around cores, there was the lowering of porosity around cores, the structure of material was grainrefined.

Key words: die casting, oriented solidification, Jet Cooling, simulation, optimization of process, tool for die casting



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TERMODINAMIČNO MODELIRANJE KOT POMOČ PRI OPTIMIRANJU ALUMINIJEVIH MATERIALOV IN TEHNOLOGIJ

Povzetek

Termodinamska karakterizacija livarskih Al zlitin z izračunanimi in eksperimentalno pridobljenimi podatki povečuje razumevanje zlitin na osnovi aluminija, ki se uporabljajo za ulitke z majhno maso v industrijskih aplikacijah. Nova generacija termodinamskih podatkovnih baz je osnova za razvoj novih ulitkov, možnosti uporabe, modeliranja itd. Vsekakor je eksperimentiranje še vedno potrebno za potrjevanje in optimiziranje obstoječih termodinamičnih podatkovnih baz. Pomembna je uporaba različnih kombinacij elementov v določenih temperaturnih področjih za pridobivanje informacij tvorbe različnih faz (trdne raztopine, intermetalne spojine). Določali smo sestavo, tip in delež posameznih faz ter poteke ravnotežnih in neravnotežnih procesov in karakterističnih temperatur za lahke zlitine. Termična analiza daje nove informacije o termodinamičnih lastnostih, faznih premenah in izločanju faz, ki jih lahko uporabimo za podatkovne baze in simulacije ulitkov. Namen tega dela je pridobiti natančne termodinamične lastnosti preiskovanih zlitin kot osnovo za nadaljnje preiskave in industrijske aplikacije.

Ključne besede: termodinamično modeliranje, aluminijeve zlitine, termična analiza



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THERMODYNAMIC MODELING AS A SUPPORT FOR OPTIMIZATION OF ALUMINIUM MATERIALS AND TECHNOLOGIES

Summary

Thermodynamic characterization of castable Al-alloys with the predicted and experimental determined data will increase the basic understanding of Al-alloys that can be used as lightweight castings alternatives for real industrial applications. The new generation of the thermodynamic database is important for further development of new castings, applications, modeling etc. The various computational techniques exist to reduce the amount of experimental effort required for formation of data bases. Nevertheless, the experimenting is still needed to confirm or to optimize the already existent thermodynamic database. Using the different combinations of elements in specific temperature regions the information of which specific phase (solid solution, intermetallic compound) is formed is important. Determination of composition and types of phases, amount of phase and study of equilibrium and non-equilibrium processes, the characteristic temperatures for lightweight alloys will be done. Thermal analysis provides us new information about thermodynamic properties, phase transitions and phase precipitation used further for database simulations in the castings. The aim of this work is to gain accurate thermodynamic properties of investigated alloys as a basis for other investigations and industrial applications.

Key words: thermodynamic modelling, aluminium alloys, thermal analysis



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UPORABA METODE PREMKAJOČIH MREŽ PRI NUMERIČNI SIMULACIJI PROCESOV LITJA S STAR-CAST

Povzetek

Korektno predvidevanje toka taline med procesom polnjenja forme pri litju je velikega pomena pri izbiri najboljših livnih parametrov in optimalnim oblikovanjem ulivnega sistema. Industrijska aplikacija numerične simulacije je postala standardno orodje, ki pomaga doseči te cilje. Nadaljni razvoj numeričnih tehnik vodi k še boljši zanesljivosti simulacijskega softvera in to v praksi, podpira pa inovativni način razmišljanja v livarni.

V predavanju smo predstavili simulacije različnih livnih procesov, ki vsebujejo ali premikajoče meje ali premične domene, pojasnjene so pa tudi numerične tehnike v STAR-Cast. Procesi so kontrolirani s časovno odvisnimi parametri kot je hitrost vrtenja v primeru centrifugalnega litja, krivulja „streljanja” v primeru visokotlačnega litja, krivulja nagibanja pri litju z nagibanjem. Dekompozicijska metoda domene je uporabljena za premikajoče mreže. Polnjenje forme in strjevalni procesi so simulirani na popolnoma „združen” način z uporabo multifaznega/multi-fizikalnega približka. Izračunana je točna in zanesljiva fronta kovina/plin z uporabo najnovejše HRIC sheme mejnih ploskev.

Ključne besede: premikajoče mreže, numerična simulacija,



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APPLICATION OF MOVING MESHES IN NUMERICAL SIMULATION OF CASTING PROCESSES WITH STAR-CAST

Summary

Correct prediction of the melt flow pattern during the mould filling process in casting production is of great importance in selection of the best casting process parameters and optimal gating system design. Industrial application of numerical simulation did become a standard tool which helps to achieve these goals. Further development of numerical techniques leads to even higher reliability of the simulation software used in practice and supports an innovative way of thinking in a foundry.

In this work simulations of various casting processes containing either moving boundaries or moving domains are presented and the numerical techniques in STAR-Cast necessary to obtain these results are explained. The processes are controlled by time dependent parameters like rotation speed profile in case of centrifugal casting, shot curve in case of high pressure die casting, or tilt curve in case of tilt casting. A domain decomposition method is used for moving meshes applications. Mould filling and solidification processes are simulated in a fully coupled way using a multi-phase/multi-physics approach. A sharp and accurate metal-gas front is calculated using the state-of-the-art HRIC interface capturing scheme.

Key words: moving meshes, numerical simulation



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RAČUNALNIŠKA SIMULACIJA NAPETOSTI TER DOLOČITEV ZAČETNE ORTODONTSKE SILE NA ORTODONTSKEM SISTEMU Z UPORABO NUMERIČNIH METOD

Povzetek

Namen našega razvojno raziskovalnega dela je bil razviti 3D računalniški model za predel zgornjih sprednjih zob, ki so izpostavljeni ortodontski sili pri začetnem ortodontskem zdravljenju. Pri tem 3D modelu smo parametre nastavili tako, da smo se čim bolj približali geometrijskim velikostim posameznih segmentov v ustih (čeljust, zobje, obzobno tkivo). Pri simulaciji smo uporabili metodo, ki se običajno uporablja v ortodontski praksi za poravnavanje krivo zraščениh zob. To je t.i. fiksni ortodontski aparat, kjer ima glavno funkcijo ortodontska žica, ki preko pritrjenih nosilcev na zobe po celotnem zobnem loku deluje na krive zobe z blago in konstantno silo. Ta sila povzroča na obzobnem tkivu mehanske napetosti, kar posledično privede do biološkega odziva oz. preoblikovanja čeljusti in s tem pomika zoba v pravilni položaj. Pri uspešnem in za paciente čim manj bolečem pomikanju zob ima pomembno vlogo pravišnja napetost v obzobnem tkivu oziroma ustrezna velikost sile na zob. Sile, ki so višje od optimalnega območja delovanja sile, lahko namreč povzročijo prevelike bolečine pri pacientih. Nasprotno temu, pa s premajhno silo ne dosežemo potrebnega učinka oz. gibanja zob.

Pri določanju dejanske sile, ki deluje na zob, je bilo v preteklosti opravljenih veliko raziskav, pri katerih so na zato posebej zgrajenih modelih izven ust merili s pomočjo merilnih celic začetne sile, ki jih povzročijo ortodontske žice. V naši raziskavi smo določali začetne ortodontske sile, ki jih povzročijo žice z različnimi materialnimi parametri in to z numerično metodo po metodi končnih elementov (MKE). Za simulacijo smo uporabili komercialno dostopni program za numerične analize po MKE - Abaqus. S tem programom smo zgradili numerični model z robnimi pogoji podobnim tistim, ki so v ustih. Velik poudarek smo namenili izbiri materialnih parametrov in biološkemu segmentom na samem numeričnem modelu. Za segmenta kot sta čeljust in zob obstajajo natančni podatki za modul elastičnosti in Poissonovo razmerje, medtem ko je za obzobno tkivo to neznanka. Vzrok temu je v tem, da je to tkivo zelo tanko in da obdaja koren zoba. Zaradi navedenega pri sami meritvi materialnih parametrov nastajajo velike težave. V zadnjih letih je bilo opravljenih veliko raziskav na to temo, rezultati pa so le delni približki realnemu stanju.

V našem 3D računalniškemu modelu ortodontskega sistema predstavljamo napetosti na obzobnem tkivu in na zobu stranski sekalec. Rezultati simulacij kažejo, da so na obeh segmentih nastale kompleksne napetosti zaradi različnih komponent sil na zob. Sočasno je bil opravljen tudi izračun posameznih komponent sil in določena rezultanta oziroma ortodontska sila, ki deluje na zob. Ta izračun smo opravili s komponentami napetosti (normalne in strižne) na določenem delu nosilca. Rezultati so pokazali, da so izračunane sile v območju, ki so sicer teoretično predvidene kot optimalne sile za premikanje zob v ortodontskem sistemu. Prikazane napetosti simulacije na obzobnem tkivu so pomembne predvsem zaradi razumevanja obremenitev, ki so posledica delovanja sile na zob.

Z numerično simulacijo na kompleksnem biološkem sistemu smo prikazali napetosti in sile. Čeprav so pri numeričnih simulacijah potrebne precejšnje poenostavitve numeričnih modelov, nam le-te dajejo dokaj realne rezultate. S to raziskavo smo se želeli čim bolj približati realni ortodontski praksi. Za nadaljnje uspešno simuliranje določitev napetosti in pomikov na različnih ortodontskih primerih, bo potrebno upoštevati še bolj realne podatke



materialnih parametrov in kontaktnih problemov med samimi biološkimi in nebiološkimi segmenti.

Ključne besede: računalniški model ortodontskega sistema,



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USING THE FINITE ELEMENT METHOD FOR SIMULATION OF THE STRESSES AND FORCE DURING ORTHODONTIC TOOTH MOVEMENT

Summary

The purpose of this study-was to develop a 3D computer model of upper anterior teeth that are exposed to orthodontic forces during the initial stage of orthodontic treatment. 3D computer model was design to resemble the real malocclusion. Parameters were given for that region of the mouth (bone, teeth, periodontal ligament). In real life, fixed orthodontic appliance would be used for the correction of malocclusion. Fixed orthodontic appliance consists of brackets that are bonded to teeth and arch wires that are inserted into the brackets. NiTi wires are ideally preformed in order to achieve desired alignment of the teeth in the dental arch by expressing their superelasticity and shape memory effect. NiTi wires are used in the initial stages of orthodontic treatment. The force from the reversely deformed NiTi wire tied in the brackets is constantly applied to teeth moving them in desired position. Continuous force causes mechanical stresses on the periodontal ligament which, consequently, leads to the biological response and remodeling of the supporting bone. Remodeling of the bone enables movement of the teeth in desired position. The optimal force in orthodontic treatment is the one that moves teeth in the fastest manner with the least damage to supporting tissues. Optimal force level is important for an adequate biological response in the periodontal ligament. Forces below optimal level cause no reaction in the periodontal ligament. Excessive forces would lead to areas of tissue necrosis, preventing normal bone remodeling.

In the past, numerous studies have been carried out to determine the actual level of force applied to the teeth, in which the initial force caused by orthodontic wires was measured by means of load cells on specially constructed models.

In the present study the level of orthodontic forces caused by the initial NiTi wire was determined using the Finite Element Method (FEM). For the simulation we used commercially available software for numerical simulation by FEM - Abaqus. Numerical model with boundary conditions similar to those in the mouth was constructed. Much emphasis was placed on the choice of material parameters and biological segment in the numerical model.

Material parameters such as, an elastic module and Poisson's ratio for the bone and teeth were available. Determination of material parameters of periodontal ligament was difficult due to the small space of the ligament that surrounds tooth. In the present 3D computer model, simulating the force system in simple orthodontic case, we presented the stresses on the periodontal ligament. The results of simulation showed that complex stresses were created due the various components of the forces applied to the tooth. Calculation of individual and resultant forces was done at the same time taking into consideration two components of the force applied to the brackets on the tooth: normal and tangential. The results indicated that the calculated force is in the range of predicted optimal force for orthodontic tooth movement.

In this paper, the numerical simulation of a complex biological system with applied orthodontic forces was shown. Although, the numerical simulation required substantial simplification of real life situation, results are clinically relevant. The future of numerical



model lies in the ability to introduce more relevant parameters into the successful simulation of more complex orthodontic problems.

Keywords: orthodontic force, simulation of stresses, 3D computer model, numerical method



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OBDELAVA, LASTNOSTI IN UPORABA NAPREDNIH MATERIALOV ZA ELEKTRIČNE KONTAKTE

Povzetek

Električni kontakti na osnovi srebra so v široki uporabi v elektro in elektronski industriji in predstavljajo pomembno skupino funkcionalnih materialov. Osnovne lastnosti teh materialov, ki so potrebne, so visoka električna in toplotna prevodnost, visoka odpornost pri varjenju, nizek upor kontakto, visoka trdnost in trdota. Desetleje dolgo je bil material Ag-CdO tista izbira kot aplikacija za stikalne naprave. To je zaradi tega, ker ima izredne lastnosti pri varjenju in odpornosti na obrabo, primerno trdnost, ki omogoča dobro obdelovalnost in visoko električno prevodnost. Če pa vzamemo v obzir visoko toksičnost kadmija in zelo strogo zakonodajo (RoHS, WEEE), pa je razumljivo, da so bili številni materiali kot nadomestni materiali preiskani kot možni in okolju bolj prijazni. Med temi, Ag-SnO₂ in Ag-ZnO so se pokazali kot najbolj obetajoči „kandidati“. Ker oba materiala večkrat ne nudita enakega „učinka“ kot Ag-CdO, so bil različni poskusi za povečanje učinkovitosti v glavnem z dodatkom manjših količin različnih kovinskih oksidov (In₂O₃, CuO, Bi₂O₃ ali WO₃). Drugi pomemben faktor je razpršenost (disperzija) kovinskih oksidov v srebrni osnovi in na splošno je bilo sprejeto, da je uporaba teh materialov boljša, če je disperznost bolj fina. Če upoštevamo, da je disperzija oksidov direktno povezana s procesno tehniko, so bile razvite različne poti za proizvodnjo. Dve prevladujoči komercialno uporabljeni tehniki sta prašna metalurgija in interna oksidacija srebrnih zlitin. Ker tako suho in mokro mešanje prahov dosega limit za aplikacijo pri delcih okrog 1 – 2 μm, če hočemo dobiti homogeno mikrostrukturo drobnih kovinskih oksidov in interno oksidacijo, smo uporabili reakcijsko valjanje ali kemijsko izločevanje. „Pot“ interne oksidacije se začne s procesno metalurgijo z ingotom, za izdelavo osnovne zlitine srebra s taljenjem in litjem. Pripravljeni uliti slabi so običajno valjani z vmesnim žarjenjem in naknadno oksidacijo z ogrevanjem v kisikovi atmosferi. Nadaljni napredek pri homogenizaciji in boljšemu dispergiranju lahko dobimo z metodo, ki ima za osnovo kemijsko izločevanje kot dual jet ali v zadnjem času z bio litjem ali metodo nastanka anorganskih kompozitov z dodatkom polimerov. Predstavljena študija podaja kratek pregled eksperimentalnih rezultatov preiskav različnih proizvodnih tehnologij in njihov vpliv na lastnosti osnovnih materialov na bazi srebra (za električne kontakte), s poudarkom na v tem trenutku prevladujočem materialu Ag-SnO₂. Najbolj splošno uporabna prašna metalurgija in metode interne oksidacije sta prikazani na primeru materialov Ag-CdO in Ag-SnO₂. Prikazali smo tudi vpliv nano delcev kovinskih oksidov in metoda njihovega „vnašanja“ v osnovo srebra in sicer na enakomernost mikrostrukture in fizikalne lastnosti kot so: gostota, poroznost, trdnost in električna prevodnost Ag-SnO₂ materialov. Podali smo tudi kot dodatek nekatere najbolj splošne uporabe električnih kontaktnih materialov na osnovi srebra.

Ključne besede: srebro-kovinski kontakti, procesiranje, lastnosti, nano delci kovinskih oksidov



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PROCESSING, PROPERTIES AND APPLICATION OF ADVANCED ELECTRICAL CONTACT MATERIALS

Summary

The silver based electrical contact materials are widely used by electrical and electronics industry and represent a significant group of functional materials. Basic properties required for these materials are high electrical and thermal conductivity, high resistance to arcing, high welding resistance, low contact resistance, high hardness and strength. For several decades Ag-CdO has been the material of choice for application in wide range of switching devices. This is due to its superior anti welding properties and wear resistance, suitable hardness that enables good machineability and high electrical conductivity. Taking into consideration toxic nature of cadmium and strict environmental legislation (RoHS, WEEE) numerous materials have been investigated as a possible more environmentally friendly substitutes. Among those, Ag-SnO₂ and Ag-ZnO have emerged as the most promising candidates. As both materials do not always offer the same performance as Ag-CdO various attempts were carried out to enhance their performance mainly by introduction of small amounts of different metal oxides (In₂O₃, CuO, Bi₂O₃ or WO₃). The other important factor is dispersion of metal oxides in silver matrix as it is generally accepted that the performance of these materials can be improved by finer dispersion. Considering that the oxide dispersion is directly related to applied processing technique, a variety of production routes have been developed. The two dominant commercially used techniques are powder metallurgy and internal oxidation of silver alloys. As both wet and dry mixing of powders reach the limit of applicability at particle sizes about 1-2 μm, in order to obtain homogenous microstructures containing fine metal oxide particles, internal oxidation, reactive milling or chemical precipitation are used. The internal oxidation route relies on ingot metallurgy processing to produce starting silver alloys by melting and casting. The prepared cast slabs are usually rolled with intermediate annealing and subsequently subjected to internal oxidation by heating in oxygen atmosphere. Further improvement in homogeneity and more fine dispersion can be achieved by methods based on chemical precipitation such as dual-jet or more recently bio casting or polymer assisted inorganic composite formation methods. The presented study provides brief overview of the experimental results of investigations of different production technologies and their influence on properties of silver based electrical contact materials, with emphasis on currently dominating Ag-SnO₂ materials. The most commonly used powder metallurgy and internal oxidation methods are illustrated on example of Ag-CdO and Ag-SnO₂ materials. The influence of metal oxide nanoparticles and method of their introduction in silver matrix on uniformity of microstructure and physical properties, such as: density, porosity, hardness and electrical conductivity of Ag-SnO₂ materials are presented as well. In addition, some of the most common applications of the silver based electrical contact materials are given.

Keywords: silver-metal oxide contacts, processing, properties, metal oxide nanoparticles



J. Dul, M.Toth, Z.Lesko, Univerza v Miškolcu, Oddelek za livarski inženiring, Madžarska

ANALIZA TOPLOTNEGA STANJA ORODJA ZA TLAČNO LITJE

Povzetek

Toplotno ravnotežje livnega cikla lahko zagotovimo pri kratkih ciklih z žarjenjem orodja za tlačno litje, ker dobro konstruiran in dobro delujoč hladilni sistem lahko poveča produktivnost. Nepravilno hlajenje pa lahko vodi do toplotnega neravnotežja v orodju in tako pride do zmanjšanja kvalitete ulitkov, zmanjšanja življenjske dobe orodja in ireverzibilne proizvodnje – zmanjšanja. Poleg teoretičnih preiskav konstrukcije in delovanja hladilnega sistema ima tudi vrednotenje učinkovito odstranjene količine toplote velik pomen (te toplotne vrednosti so »vodene« glede na konstrukcijo hladilnega sistema). Predavanje predstavlja analizo delovanja hladilnega sistema ulivanja zlitine AlSi9Cu3 v primeru različnih parametrov hlajenja. Na osnovi izmerjenih rezultatov temperatur na vstopu in izstopu in hitrosti pretoka hladilnega sredstva, so bile določene količine toplote v krogu hlajenja in predlagana je bila optimizacija hladilnega sistema. Izsledke analize lahko uporabimo za konstruiranje in optimizacijo hladilnega sistema za tlačno litje.

Ključne besede: toplotno stanje, orodje za tlačno litje, optimizacija hladilnega sistema



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THE ANALYSIS OF HEAT BALANCE OF THE DIE CASTING TOOL

Summary

The heat balance of a casting cycle can be ensured in short cycles by the annealing of the die-casting tool, by which the well-constructed and well-functioned cooling system can enhance productivity. Incorrect cooling, however, can lead to heat unbalance in the die casting tool, thus causing the destruction of casting quality, the reduction of the lifetime of die casting tool and irreversible production-reduction. Beside the theoretical examination of construction and function of cooling system, the evaluation of the effectively removed heat quantities has great importance. (These heat-quantities are conducted by the built in die casting tool cooling system) The paper presents an analysis of the function of the cooling system of a scraggy thin casting of AlSi9Cu3 alloy, in case of different cooling parameters. Based on the measured results of the entering and leaving temperatures and the flow rates of the coolants, the heat quantities belonging to the cooling circles are determined and an optimization of the cooling system is proposed. The findings of the analysis can be utilized for the construction and optimum operation of die-casting cooling systems.

Key words: heat balance, die casting tool, optimization of cool system



B.Lovšin, L. Palmer, Siapro d.o.o., Slovenija

PREDNOSTI CCD SENZORJA ZA KEMIČNO ANALIZO KOVIN

Povzetek

CCD senzor je naprava namenjena pretoku električnega naboja na mesto, kjer se lahko obdeluje, na primer za pretvorbo v digitalno vrednost. Tehnologija zaznavanja svetlobe CCD senzorjev se uporabljajo v profesionalnih aplikacijah, kjer se zahteva visoko kakovost slike in podatkov. Analizo kovine s pomočjo CCD tehnologije omogoča majhna, a robustna naprava za merjenje celotnega svetlobnega spektra, ki je potreben za analizo kovinskih materialov. Najustreznejši del analitične ali spektralne linije se izbere s programsko opremo tako, da MetalScan spektrometri niso omejeni s številom elementov, ki jih je mogoče analizirati. Za primerjavo tipičen konvencionalni spektrometer, ki uporablja foto-multiplikator detektorje (PMT), doseže do 30 analitičnih kanalov, omejuje ga draga strojna oprema. CCD senzor ima dostop do več kot 1000 kanalov izbranih s programsko opremo. CCD elektronika se lahko uporablja za iskanje peakov in tako preprečuje morebitne toplotne ali mehanske premike spektra, ki so pogosto vir težav pri običajnih enotah.

Arun Tehnology je kot pionir vpeljal sisteme CCD analize v hitro rastoči trg prenosnih in namiznih analizatorjev za kovine ali metalurške aplikacije. Združuje nizko ceno CCD tehnologije, z visoko natančnostjo iskre in laboratorijsko analitično programsko opremo. V zadnjih 25 letih je bila paleta Arunovih izdelkov razširjena in izboljšana raven zmogljivosti. Trenutne serije PolySpek spektrometrov ponujajo optiko, ki se izpira z argonom brez uporabe optičnih vlaken. Nova serija prenosnih spektrometrov "A" ponuja izmenično iskro, enosmerni oblok, ali oboje vrste vzbujanja. Oblok omogoča hitro prepoznavanje kakovostnega razreda materiala, medtem ko iskra zagotavlja boljše prepoznavanje sestave materiala, kot je na primer nizek ogljik v nerjavnih jeklih. Skratka, prednosti CCD senzorjev pri analizi kovinskih materialov je kar veliko.

Ključne besede: analiza materialov, spektrometri



B.Lovšin, L. Palmer, Siapro d.o.o., Slovenia

BENEFITS OF CCD SENSORS BY CHEMICAL ANALYSED OF METALS

Summary

A charge-coupled device (CCD) is a device for the movement of electrical charge to an area where the charge can be manipulated, for example conversion into a digital value. CCD image sensors are widely used in professional applications where high-quality image data is required. In metals analysis the Charge Coupled Device (CCD) technology, enables a small, yet robust instrument to measure the whole spectrum necessary for the analysis of all the common metal bases. In fact the most appropriate analytical or spectral 'lines' can be chosen by software rather than hardware such that MetalScan spectrometers are not limited in the number of elements that can be analysed. For example a typical conventional spectrometer incorporating Photo-Multiplier Tube (PMT) detectors might have about 30 analytical channels fixed by expensive hardware, while a CCD based unit would have access to over 1000 channels, all selectable by software. The CCD electronics can be used to search for line peaks and counteract any thermal or mechanical shifts, which are often the source of problems with conventional units.

ARUN Technology pioneered and has led the world in the fast growing market for portable and desktop CCD-array analysis systems for metal or metallurgical applications, combining low cost CCD array technology with a high precision spark source and laboratory analytical software. Over the last twenty five years, the range of products offered by ARUN Technology and the performance levels available have both increased. The current PolySpek series spectrometers offer direct view argon flushed optics, no fibre optics are used. A new range of portable spectrometers the 'A' Series has also been introduced offering AC spark, DC Arc, or both types of excitation. The DC Arc mode offers rapid grade identification while the spark mode provides low-level carbon determination, typically separating stainless L non-L grades.

Key words: analysis of material, spectrometers



S.Holger, StrikoWestofen, GmbH, Nemčija

PAMETNA UPORABA VIROV. ZA MANJŠE STROŠKE NA ENOTO IZDELKA

Povzetek

STRIKOMELTER[®] postavlja nove „meje“ v svojem spektru ponudbe. Skoraj kompleten izkoristek pri istočasni učinkoviti uporabi energije in največji življenjski dobi: STRIKOMELTER[®] je v mnogih pogledih edinstven proizvod in ponuja livarnam vseh velikosti natančne pogoje ekonomične proizvodnje.

Zaradi tega učinkovitost zelo dobro znanega STRIKOMELTERJA[®] lahko takoj izboljšamo s celovitim pristopom do peči oziroma obzidave peči in oblikovanja gorilcev v peči.

Zmanjšanje porabe energije, največji izkoristek materiala, nizka obraba, enostaven koncept polnjenja: linija PUREFFICIENCY[®] ponuja edinstvene prednosti za učinkovito proizvodnjo.

V časih, ko se cene materiala in energije zvišujejo, postaja recikliranje bolj pomemben ekonomski regulator v livarni. Neodvisno od sistema za taljenje povratnega materiala, kar že obstaja, je procesiranje aluminijevega odpadka dobilo veliko na pomenu. S proizvodnjo ulitih delov iz aluminija je recikliranje ena od poti za inteligentno uporabo metariala.

Ključne besede: recycling, učinkovita poraba energije



S.Holger, StrikoWestofen, GmbH, Germany

USE RESOURCES INTELLIGENTLY. FOR LOWER UNIT COSTS

Summary

The **STRIKOMELTER**® sets new yardsticks in its power spectrum. Almost complete metal yield with at the same time efficient energy use and highest longevity: The **STRIKOMELTER**® is in many respects a singular product and offers to foundries of all sizes particularly economic production conditions.

Hence, the efficiency of the well-known **STRIKOMELTER**® could be substantially improved by a holistic view of the furnace body, refractory lining and burner design.

Reduced energy consumption, highest material yield, lower wear, simplified feed concept: The **PUREFFICIENCY**® line offers singular advantages for an efficient production.

In times of rising raw material and energy prices, recycling becomes more important for the economic adjustment of a foundry. Apart from the systems for melting return material, existing so far, the processing of aluminum chips wins increasingly in meaning. With the production of aluminum cast parts inhouse recycling of chips is one way to intelligent material use.

Key words: recycling, efficient energy use



D.Tomažič, Chem-Trend[®] HERA[™] GmbH/ Feal -inženiring, Nemčija, Slovenija

PREDNOSTI TLAČNEGA LITJA Z VLOŽKOM KONCENTRATOV LOČILNEGA SREDSTVA NA OSNOVI VODE

Povzetek

Mikro nanašanje mazivnega sredstva je process tlačnega litja, ko ločilno sredstvo v koncentrirani obliki nanašamo v majhni količini, samo toliko da naredimo film na površini livne votiline.

Prednosti uporabe HERA proizvodov so:

- Krajši čas cikla
- Izboljšana produktivnost
- Izredno omočenje in nastanek filma
- Dolga življenjska doba kokile/ livne "votline" (zaradi manjših temperaturnih razlik)
- Ni odpadne vode
- Proizvodi brez biocidov in drugih dodatkov
- Za težke in kompleksne ulitke iz tlačnega litja tako za aluminij kot za magnezij, kjer je potrebna dobra kvaliteta in zmožnost varjenja

Ključne besede: mikro nanašanje ločilca, HERA proizvodi – izboljšanje ulitkov tlačnega litja



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CHEM TREND INTRODUCE NEW SERIES WATER BASE CONCENTRATE RELEASE AGENTS FOR MICRO SPRAYING

Summary

Micro spraying is process of die casing when lubricant is used in concentrated form and spraying in low quantity just to make an film on cavity surface.

The Benefits of using HERA products

- Shorter cycle time
- Improved productivity
- Excellent wetting and film building
- Long mould/ cavity life time (regarding less temp. differences)
- No waste water
- Products with no Biozid and other Additives
- For difficult and complex pressure die castings for both Aluminium and Magnesium where a good finish, welding and high performance is required

Key words: micro spraying, HERA product – improvements of die castings



J.Trojan, DISA Industries A/S, Švica

PREDSTAVITEV INOVATIVNIH REŠITEV V LIVARNI S STRANI DISA

Povzetek

Že desetletja servisira DISA svetovno livarsko industrijo s formarskimi tehnologijami v sami kvalitetni “špici” oziroma vrhu. Ko je sredi šestdesetih let podjetje uvedlo Disamatic vertikalno formarsko linijo, je bil to preboj v običajno livarsko prakso. Metoda formanja Disamatic je postala kmalu vodilna za proizvodnjo ulitkov za velike in srednje količine ulitkov. Od tedaj je bilo pri Disi narejenih veliko število inovacij, ki so izboljšale v osnovi vse aspekte procesa formanja v svežem pesku. Eno pa ostaja nespremenjeno – Disamatic je nepremagan glede na kvaliteto in ekonomičnost izdelave.

Zadnje inovacije pri vertikalnem formanju – danes DISA ponuja široko paleto vertikalnih formarskih linij. Na voljo je veliko število form različnih velikosti v različnih variantah. Nazadnje razvit specialni Dvojni Index sistem za prenos form dovoljuje povečanje časa litja kjer je proces „moten”. Od tod ulivni sistem, ki polni dve formi istočasno in je lahko uspešno uporabljen. Povečanje izkoristka formarske linije je pomembno, povečanje izkoristka in kvaliteta ulitkov je višja. Kot skupen razvoj podjetij Foseco in DISA je nova tehnika napajanja. Inovacija je stransko napajanje, kar uspešno izboljša eventuelano krčenje notranjosti ulitka, z možnostjo, da imamo eksotermne napajalnike v formi z njihovo postavitvijo direktno na vrtljivii modelni plošči.

Najnovejše inovacije pri horizontalem formanju – v zadnjem desetletju dobiva DISA zahteve za opremo, kjer imajo izkušnje z Disamaticom, samo po nižjih kapacitetah in fleksibilni proizvodnji. Korak za korakom pa so bile uvedene formarske linije s podložnimi ploščami, različnih velikosti form. Najnoveši dosežek je DISA MATCH 20/24 formarski stroj, ki je horizontalno deljen, brez okvirjev, uporablja enoten princip DISAMATIC pihanja & stiskanja. S formami velikosti 508 x 610 mm in maksimalno težo ulitka 364 kg je maksimalna kapaciteta 160 form/uro brez jeder ali 120 form/uro z jedri. Izredna je natančnost formanja. Rešitev je primerna za manjše livarne ali tiste, ki zahtevajo zelo fleksibilno spremembo modelov, s težnjo po visoki kvaliteti ulitkov in nizkimi stroški.

Različne tehnike streljanja Wheelabradorja – pod Wheelabradorjem so koncentrirane vse tehnike streljanja pri Norican skupini, materinski firmi DISE in Wheelabradorja. Strokovnjaki podjetja razpolagajo z izrednim know howom pri čiščenju ulitkov, so takoj pripravljene predlagati primeren stroj za čiščenje s streljanjem in zahtevami za proizvodnjo vsake posamezne livarne in različne načine litja in proizvodnje, v veliko velikostih in aplikacijskih variantah.

Ključne besede: inovacije pri formarskih linijah in metodah



J.Trojan, DISA Industries A/S, Swiss

DISA – INNOVATION POTENTIAL IN FOUNDRIES

Summary

For several decades DISA serves world's foundry industry with cutting edge moulding technologies. When in mid 60's company introduced Disamatic vertical moulding, it has been real break-through in then foundry habits. Disamatic moulding method became soon preferred for high and mid volume casting production. Ever since, many innovations have been introduced by DISA, that improved basically all aspects of green sand moulding process. One stays however unchanged - Disamatic unbeatable for its performance, quality and manufacturing economy.

Latest innovation in vertical moulding - Today DISA offers widest range of vertical moulding lines ever. Available are many mould sizes at several performance variants. Lately developed special Double Index system for mould transport, allow increase of pouring time to foundries where this is process bottle neck. Hence pouring systems that fill two moulds at a time may be successfully used. Increase of mould line utilization is thereafter significant, side by increased yield and casting quality. As a common development of company Foseco and DISA is a new riser technique. Innovation is in side feeding, which successfully improve eventual shrinkage of inner casting areas, by possibility to have exothermic sleeves in mould volume by setting them directly on swing pattern plate.

Latest innovation in horizontal moulding - In last decade DISA notably hear of the foundries requesting equipment as they experienced with Disamatic, just for lower capacity and flexible production. Stepwise, match plate moulding machines, of different mould sizes, has been introduced. Latest arrival is DISA MATCH 20/24 moulding machine, which is horizontally parted flask-less moulding system, uses unique DISAMATIC blow & squeeze principle. With mould size 508x610mm and maximum poured weight 36kg is maximum capacity 160 m/h coreless or 120m/h cored. Exceptional is moulding accuracy and uptime. Solution is suitable for smaller foundries or those requesting very flexible pattern change, while aiming for high castings quality and low finishing costs.

Different shot blast techniques of Wheelabrator - Under Wheelabrator are concentrated all shot-blasting activities of Norican group, parent company of DISA and Wheelabrator. Company experts dispose of extensive know how in castings cleaning, ready to suggest suitable shot blast machine fit to casting and production requirements of individual foundries, such as batch, hanger type or various throughput machines, in many size and application variants.

Key words: innovations of moulding lines and methods





POSTERJI



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MOŽNOSTI PROCESA ELEKTROPRETALJEVANJA POD ŽLINDRO ZA DOSEGANJE NESPREMENJENE KEMIČNE SESTAVE SUPERZLITINE S KRMILJENJEM PRETALJEVANJA OSTRUŽKOV ENAKEGA MATERIALA

Povzetek

Proizvodnja ulitkov v peščene mešanice ima svoje ekonomske in kvalitetne karakteristike. Vendar pa z večjimi močmi strojev in rotacijskim litjem, visokimi delovnimi temperaturami in pritiski lahko izboljšamo in razvijamo kvaliteto ulitkov. To lahko dosežemo samo z uvajanjem novih tehnoloških faz ali livarske opreme. Pri nekaterih vrstah opreme kot je elektropretaljevanje pod žlindro ali vakuumsko taljenje in pečeh lahko bistveno izboljšamo kvalitene karakteristike. Na ta način izboljšamo čistost, zmanjšanje vsebnosti plinov in nečistoč, izboljšamo mikrostruturo, mehanske lastnosti ali nekatere fizikalne karakteristike. Na ta način so kupci zadovoljni s sprejemljivimi cenami ulitkov. Na drugi strani pa je proces elektropretaljevanja pod žlindro možno uporabiti za pretaljevanje odpadka pri strojni obdelavi ali prahu iz procesov odrezovanja. S tem uspešno „obnovimo“ oziroma dosežemo isto kemijsko sestavo za visoko Ni-Cr zlitino brez izgube elementov kot sta titan in aluminij brez dodatka teh elementov, ki so po klasičnem postopku „izgubljeni“ oziroma odgorijo. Istočasno je možno iz rekonstrukcije in taljenja super-zlitin izdelati ulitke z dobrimi karakteristikami s primerno žlindro. Na ta način je možno dobiti dobre ulitke iz krožnega materiala, to je cenovno seveda ugodno.

Z raziskavami in razvojem dela na elektropretaljevanju pod žlindro, posebno na pilotni napravi, smo izboljšali aplikacijo tega procesa. Zaradi boljše kvalitete ulitkov ulitih po postopku EPŽ ulivamo lahko ulitke od nekaj kilogramov do nekaj ton od visokolegiranih materialov z možnostjo, da ne pride do spremembe vsebnosti elementov med procesom ali legiranjem.

Ključne besede: ulitki, elektropretaljevanje, super zlitina



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POSSIBILITIES OF ESR PROCESS TO OBTAIN SAME CHEMICAL ANALYSIS OF SUPER-ALLOY CASTINGS BY GOVERNING OF REMELTING OF MACHINING CHIPS

Summary

Castings produced in sand mixtures there are their economic and quality characteristics. But with higher machine power and rotating speeds of castings, higher working temperatures and pressures it has to be improved and developed castings quality characteristics. It can be reached only by introducing new technology phases or equipment by foundry-men. By some equipment as electro-slag re-melting process (ESR) or electron beam vacuum melting and casting furnace can be significantly improved castings quality characteristics. On that way are improved cleanness, decreased contents of gases and impurities, improved micro-structure, mechanical properties or some physical characteristics. On that way customers are satisfied in a spite of higher castings prices. In the other hand ESR process is possible to use for re-melting machining process chips or sawdust and to successfully reconstruct same chemical analysis for high Ni-Cr super-alloy without losing some elements as Ti or Al, as well as without addition mentioned elements as at classical processes of lost elements. In same time it is possible from reconstructed and melted super-alloy to produce castings of high characteristics value properties by suitable slag. On that way it is possible to make useful high quality castings from rejected material, what is rather low cost production processes.

Therefore, by research and development work of ESR castings especially on pilot plant scales is improved application of ESR process. Because of better quality characteristics of ESR-castings from a few kilos to a few tons from high alloyed materials with possibilities of not changing elements content or alloying.

Keywords: castings, electro-slag re-melting, super-alloy



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OPREDELITEV NUKLEACIJSKEGA POTENCIALA IN STOPNJE GRAFITIZACIJE S TERMIČNO ANALIZO IN NUMERIČNO SIMULACIJO

Povzetek

ATAS je sistem za termično analizo kvalitete taline sivih litin. Pokaže nam vpliv vseh elementov in njihovih spojin v zlitini. Da bi izboljšali in kontrolirali kvaliteto taline v vsakdanji proizvodnji, je potrebno testirati bazno in končno talino, izvesti korekcijo aktivnega ogljika (ACEL), uporabljati modul za dinamično dodajanje cepiva in določiti procesno okno z ATAS podatki. ATAS iz ohlajevalne krivulje izmeri količino aktivnega ogljika ACEL, rekalcenco R (nukleacijski potencial, evtektična rast), grafitizacijski faktor GRF1 (podhladitev, hitrost precipitacije, količino izločenega grafita), grafitizacijski faktor GRF2 (oblika in količina grafita), temperature likvidus, solidus in evtetske temperature. Pri izračunih simulacij je za kvalitetne izračune potrebno vse te parametre upoštevati. V programu za izračun livarskih procesov ProCAST in QuikCAST so parametri katere je potrebno prilagoditi kvaliteti taline. V novejši verziji QuikCAST-a se pripravlja modul v katerega bi lahko že uvozili ohlajevalno krivuljo iz termične analize in program bi sam odčital potrebne in značilne parametre iz ohlajevalne krivulje.

Ključne besede: termična analiza, kvaliteta taline, simulacija livarskih procesov



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CRARACTERIZATION OF NUCLEATION POTENTIAL AND DEGREE OF GRAPHITISATION BY THERMAL ANALYSIS AND NUMERICAL SIMULATION

Summary

Adaptive thermal analysis system is a system which gives us informations about cast iron melts quality. It shows us influence of elements and their compounds. To improve and control the melt quality in daily praxis, you need to investigate base and final alloy, do the corrections of active carbon (ACEL), use module for dynamic addition of inoculants and define process window with ATAS informations. System can define ACEL, recalescence R (nucleation potential, eutectic growth), graphitization factor GRF2 (shape and size of graphite), liquidus, eutectic and solidus temperatures. When calculating foundry simulations it is necessary to include such results to obtain good results. In simulation programs such as ProCAST and QuickCAST we need to define parameters obtained by ATAS in such manner that the simulated solidification way is the same as in the reality. In future version of QuickCAST it will be possible to directly import cooling curve into the program and parameter of solidification will be set automatically.

Key words: thermal analysis, melt quality, foundry process simulation



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FSW LIVARSKIH ALUMINIJEVIH ZLITIN

Povzetek

FSW v kombinaciji z visokotlačnim litjem aluminijevih ulitkov odpira nove možnosti v konstruiranju visokotlačnih ulitkov. Ulitki spojeni s FSW postopkom imajo lahko zelo zapletene oblike in lastnosti. Ulitke lahko spojimo tako, da imajo različne lastnosti, kjer je to potrebno, saj lahko spajamo različne zlitine. Vnos energije v spoj s FSW je neprimerno manjši, kot s klasičnimi postopki varjenja. Zaradi tega so manjše tudi zaostale napetosti in deformacija po spajanju. Namen tega dela je predstaviti FSW spajanje tehnično čistega aluminija in livarske zlitine AA413.0. Prikazano je izračunano temperaturno polje z metodo končnih elementov. Izračunane temperature so bile eksperimentalno preverjene. Okarakterizirane so tudi mehanske lastnosti spoja.

Ključne besede: FSW postopek, aluminijeve zlitine



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FSW OF CAST ALUMINIUM ALLOYS

Summary

FSW used in combination with high pressure die casting aluminium castings got new possibilities in construction and design of high pressure die castings. Castings joined with FSW can be very complex in shape and in alloy. This kind of part has different properties in place where these, usually better, properties are needed. Also the heat input into the joint with FSW is significantly smaller than conventional welding therefore the deformation of the joint after joining is small. The aim of recent research papers in FSW are orientated in joining of wrought aluminium alloys which are difficult for welding. The aim of this article is to investigate FSW joint of two different aluminium alloys. The investigation was done on joining of cast aluminium alloy (AA413.0) and wrought aluminium alloy (AA1050). Temperature distribution during FSW was measured and calculated with finite element model. Mechanical properties of joint was also investigated.

Key words: FSW procedure, aluminium alloys



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LIVNOST ALUMINIJEVIH LIVNIH ZLITIN

Povzetek

Poster podaja vpliv temperature ulivanja, udrobnjavanje zrn in modificiranje na livnost zlitine AlSi9Cu3 in zlitine AlSi12. Aluminijeve zlitine smo preiskali v različnih »stanjih«, kot osnovna zlitina in z dodatki AlTi5B2 in AlSr10 »glavne« zlitine. Vzorci so bili uliti v Sippovo livno spiralo pri različnih temperatura litja, ki so bile 640oC, 670oC, 700oC in 710oC. Obnašanje pri strjevanju smo preiskovali z uporabo »in situ« termične analize in mikrostrukture so bile analizirane z optičnim mikroskopom Olympus BX61. Livnost se povečuje z višjo temperaturo litja, udrobnjavanje zrn zniža livnost in modifikacija prav tako zniža livnost AlSi12 zlitine in poveča livnost AlSi9Cu3.

Ključne besede: livnost zlitin, mikrostrukture zlitin, termična analiza



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FLUIDITY OF ALUMINIUM CASTING ALLOYS

Summary

This poster describes the influence of pouring temperature, grain refining and modification on the fluidity of AlSi9Cu3 and AlSi12 casting alloys. The aluminium alloys were tested in the different states, as basic alloy and with additions of AlTi5B1 and AlSr10 master alloys. Samples were casted into Sipp spiral probe at the different pouring temperatures which were 640 °C, 670 °C, 700 °C and 710 °C. The solidification behavior of alloys was investigated using “in situ” thermal analyses and the microstructures were analyzed by optical microscope Olympus BX61. The fluidity increases with higher pouring temperature, grain refinement lowers the fluidity and modification lowers the fluidity of AlSi12 alloy and increases the fluidity of AlSi9Cu3 alloy.

Key words: fluidity of alloys, microstructure, thermal analysis



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SIMULACIJA STRJEVANJA PRI RAVNOTEŽNIH IN NERAVNOTEŽNIH POGOJIH V ALUMINIJEVIH ZLITINAH

Povzetek

Za razumevanje termičnih efektov posnetih z diferenčno termično analizo (DTA) ali diferenčno vrstično kalorimetrijo (DSC), predvsem vezanih na segregacijo primarnih zmesnih kristalov v aluminijevih zlitinah, je bila narejena simulacija segrevalnih DTA/DSC krivulj. Simulacija je potekala pod Lever in Scheil pogoji. Za primerjavo med eksperimentalnimi in izračunanimi rezultati je bil uporabljen model toplotnega toka [1,2]. DTA in DSC segrevalne krivulje predstavljajo pomemben vir informacij o zgodovini strjevanja, v tem primeru, aluminijevih zlitin. Za izračune so se uporabile entalpijske krivulje za primer ravnotežnega in neravnotežnega stanja termodinamsko optimiziranega binarnega faznega sistema aluminij-cink. Tako je v tem prispevku poudarek predvsem na monotektoidne (evtektoidne) in evtektске aluminijeve zlitine, kot tipičen primer livarskih zlitin. Ugotovljeno je bilo dobro ujemanje tako med izračuni kot eksperimentalnimi rezultati.

Ključne besede: Al-Zn zlitine, Termična analiza, Termodinamika



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SIMULATION OF SOLIDIFICATION UNDER EQUILIBRIUM AND NONEQUILIBRIUM CONDITIONS IN ALUMINIUM-BASED ALLOYS

Summary

To understand the thermal effects recorded with the DTA (differential thermal analysis) or DSC (differential scanning calorimetry) and phenomena of dendritic segregation in Al-based alloys a simulation of DTA melting curves was done under Lever and Scheil conditions. It is important to study the melting processes, for example by using DTA/DSC heating curves, knowing that DTA/DSC curves contain the information about the history of previously solidified alloys. The so-called heat transfer model [1, 2] was used to compare the experimental data. The temperature-enthalpy curves for both equilibrium state and non-equilibrium were calculated using an example of thermodynamic evaluation of the aluminium-zinc system. In this paper a focus was given on the monotectoid (eutectoid) and eutectic alloys as most common foundry alloys. A good agreement was achieved between the calculations and experimental results.

Key words: Al-Zn based alloys, Thermal analysis, Thermodynamics



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MERITVE ELEKTRIČNE UPORNOSTI ČISTEGA ALUMINIJA MED STRJEVANJEM

Povzetek

Poster prikazuje "in situ" meritev električne upornosti aluminija z 99,99 in 99,9 % deležem Al. Električna upornost kovin se s segrevanjem praviloma povečuje v skladu temperaturnim koeficientom električne upornosti. Do povečanja električne upornosti pri povišanih temperaturah pride zaradi bolj intenzivnega nihanja kristalne rešetke in nastanka večjega števila napak v kristalni mreži. Na teh napah se elektroni sipajo, kar pomeni, da je njihov prehod skozi material otežen in je njihova pot daljša, kar pomeni večjo električno upornost. Pri temperaturi tališča se s taljenjem začne rušiti periodičnost kristalne rešetke, kar za približno dvakrat poveča upornost, ki nadalje v tekočem s temperaturo še narašča.

Merilna celica je narejena iz opeke iz kalcijevega silikata. V celici smo merili temperaturo na dveh mestih. Električno upornost smo merili s štiri točkovno metodo. Uporabljene elektrode so bile iz 99,5 % čistega aluminija, kar je preprečilo kontaminiranje vzorca z drugimi elementi in zagotovilo kvaliteten kontakt med elektrodo in vzorcem.

Ključne besede: aluminij, električna upornost, štiri točkovna metoda



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ELECTRICAL RESISTIVITY MEASUREMENT OF PURE ALUMINIUM DURING SOLIDIFICATION

Summary

This poster is showing “in situ” measurement of electrical resistivity of 99,99 % and 99,9 % pure aluminium. Electrical resistivity is increasing with higher temperature in accordance with thermal coefficient. Reason for this is stronger vibration of crystal lattice at higher temperatures and more defects in material. Electrons are scattered on these defects which means that their path through material is disturbed and longer which cause higher electrical resistivity. Periodicity of lattice is disturbed at melting point and the scattering of electrons is even stronger which causes increment of resistivity by approximately two and then in liquid state is increasing with higher temperature again.

Measuring cell is made of calcium silicate ceramic. Temperature was measured on two places in the cell. Electrical resistivity was measured by four-probe technique with electrodes from 99,5 % pure aluminium wires for ideal contact and not to introduce impurities into specimen.

Key words: aluminium, electrical resistivity, four-probe technique



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“TEHNIČNA ČISTOST V AVTOMOBILSKI INDUSTRIJI (ISO 16232)”

Povzetek

Zahteva po tehnični čistosti je relativno nova karakteristika kvalitete za komponente v avtomobilski industriji. Razvoj tehnične čistosti se je začel v letu 2001 z VDA (Verband der Automobilindustrie). Prvi standard VDA 19 je bil narejen v letu 2004, standard ISO 16232 pa je bil uveden v letu 2007 in zadnji standard VDA 19- 2 -del je bil uveden v letu 2010. LTH Ulitki (specializiran za visokotlačno litje Al in Mg tlačnih ulitkov) je začel s prvim projektom z zahtevo po tehnični čistosti v letu 2003.

Karakteristika kvalitete tehnične čistosti ima vsaj tri pomembne komponente; kako to definirati, kako to meriti in kaj rabimo da to izpolnimo. Tehnična čistost je izražena s količino nečistoč (komtaninacija) na komponenti, definirano z maso in številom, velikostjo in materialom delcev. Napačna definicija ali razumevanje zahteve po čistosti ima lahko za posledico, da te zahteve vodijo proizvajalca v veliko investicijo, da bi dosegel zahteve po čistosti. Merilni sistem v tehnični čistosti je definiran v VDA 19 – prvi del in ISO 16232. Tu je veliko število detajlov, ki lahko „pokvarijo“ rezultate meritev. Dobra laboratorijska praksa je usklajevanje metod s kupci (obiski v laboratorijih kupca, primerjalne analize). Analitični postopki so časovno zahtevni, meritve direktno na liniji v proizvodnji niso možne in referenčni material (komponente s certificiranim nivojem čistosti) ni na voljo. Dobri stroj za „pranje“ ni dovolj, da zadostimo zahtevam po čistosti. Na nivo čistosti lahko vpliva prejšnji proizvodni proces, logistika, pakiranje in na koncu proces sestavljanja.

Po 10 letih prvega projekta z zahtevami po čistosti v LTH Ulitki ni nobenih novih projektov brez specifikacij čistosti in imamo vedno konstanten pritisk s strani kupcev za izboljševanje nivo čistosti komponent. Tehnična čistost je postala značilna karakteristika komponent iz tlačno ulitih delov. V zadnjem času je LTH Ulitki startal projekt za akreditacijo zahtev v področju tehnične čistosti z metrološkim laboratorijem LOTRIČ Metrologija, ki ima preko 20 let izkušenj v metrologiji.

Ključne besede: LTH Ulitki, LOTRIČ Metrologija, VDA 19, ISO 16232, tehnična čistost, metrologija, laboratorij



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"TECHNICAL CLEANLINESS IN THE AUTOMOTIVE INDUSTRY (ISO 16232)"

Summary

The technical cleanliness requirement is relative young quality characteristic for components in the automotive industry. The development of technical cleanliness started in 2001 by VDA (Verband der Automobilindustrie). First standard VDA 19 was released in 2004, standard ISO 16232 was released in 2007 and the last standard VDA 19-part 2 was released in 2010. LTH Castings (specialist for high pressure Al and Mg die-casts) started with first project with technical cleanliness demands in 2003.

The technical cleanliness quality characteristic has at least three important components; how to define it, how to measure it and what do we need to fulfil it. The technical cleanliness is expressed by amount of dirt (contamination) on the component defined by mass and number, size and material of particles. Wrong definition or understanding of cleanliness demands can lead to customer claims or company invest too much money to reach cleanliness demands. Measuring system in technical cleanliness is defined in VDA 19 – part 1 and ISO 16232. There are a lot of details that can affect the result of measurements. Good laboratory practice is harmonising methods with customers (visits at customer laboratory, comparison analysis). Analytical procedures are time consumable, direct in line measuring in production is not possible and reference material (component with certified cleanliness level) is not available. The good washing machine is not enough to fulfil the cleanliness demands. Cleanliness level can be influenced by previous production processes, logistic, packaging and at the end further assembly processes.

After 10 years of the first project with cleanliness demands in LTH Castings there are no new projects without cleanliness specification and there is constant pressure from customers to improve the cleanliness level of components. Technical cleanliness became significant quality characteristic of die-cast components. In last period LTH Castings has started project of accreditation the requirement in the field of technical cleanliness with metrology laboratory LOTRIČ Metrology, which has over 20 years of experience in metrology.

Keywords: LTH Castings d.o.o., LOTRIČ Metrology l.t.d, VDA 19, ISO 16232, technical cleanliness, metrology, laboratory



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VODOTOPNA VEZIVA JEDER ZA PRECIZIJSKO LITJE ALUMINIJEVIH ZLITIN

Povzetek

Izdelava notranjosti oziroma „votlin“ pri ulitkih iz aluminijava po postopku precizijskega litja ni enostavna naloga. Danes se to dela z uporabo vodotopnih voskov. To je seveda laboratorijsko in ne dovoljuje proizvodnje tankih presekov in/ali dolgih kanalov, ker ni enostavno odstraniti kompletno keramično maso iz notranjosti. Običajna keramična jedra, ki bazirajo na taljenem kremenu, je v široki uporabi za jeklo in super zlitine, kar pa ne moremo uporabiti za aluminij zaradi kemisjke agresivnosti hidroksidov, ki so uporabljeni za leaching. Mehansko odstranjevanje (s peskanjem) ne moremo uporabiti brez nevarnosti erozije ulitkov.

Predstavljen poster se na kratko ukvarja z razvojem materiala za vodotopna jedra, ki ga lahko uporabimo za litje aluminija. Med razvojem smo izbrali primerno vezivo in ognjevzdržni material, njuno najboljše razmerje in postavili smo cikel žarjenja in našli primerno impregnacijo. Trikotnik treh povezanih parametrov je bil končno rešen: TRDNOST – KRČENJE – TOPNOST v optimalnem razmerju. Poskusi uporabe so bili narejeni v različnih livarnah za precizijsko litje z usmeritvijo na odstranjevanje voska (avtoklavi ali MW peči), žarjenjem lupine, ulivanjem, odstranjevanjem jedra in gostoto ulitkov. Metalurške raziskave so bile narejene po tem, da bi iz vrednotili interakcije med materialom jeder in površinsko hrapavostjo.

Ključne besede: precizijsko litje, vodotopna jedra, aluminijeve zlitine



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WATER SOLUBLE CORES FOR ALUMINIUM INVESTMENT CASTINGS

Summary

Making cavities in aluminium castings produced by the method of investment casting is not an easy task. Cavities are nowadays produced by applying water soluble waxes. However this is quite laborious and does not allow to produce thin cross sections and/or long channels, as it is not easy to remove the complete ceramic mass out of the cavities. Usual ceramic cores based on fused silica, widely used for steel and superalloy castings, cannot be used for aluminium casting due to chemical aggressiveness of hydroxides which are used for its leaching. Mechanical removal (sand blasting) cannot be used either without the risk of casting erosion.

The presented poster shortly deals with development of a water soluble core material which can be used for aluminium castings. During the development a suitable binder and refractory material has been chosen, their best ratio and firing cycle settled and a suitable impregnation solution found. Triangle of three mutually interconnected parameters has been resolved finally: STRENGTH – SHRINKAGE – SOLUBILITY, to find its optimal balance. Application trials were run in several investment casting foundries with focus on wax removal (autoclave or MW oven), shell annealing, pouring, core removal and casting soundness. Metallurgical research was carried out afterwards to evaluate interaction between the core material and aluminium alloy and surface roughness of the casting.

Key words: investment casting, water soluble cores, aluminium alloys



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SIMULACIJA PROCESA CENTRIFUGALNEGA LITJA V KERAMIČNO FORMO

Povzetek

Namen prezentacije je podati rezultate procesa centrifugalnega litja na primeru računalniške simulacije in realnih poskusov.

Proces centrifugalnega litja uporablja sile, ki vplivajo na tok taline v formo, in potem povečamo pritisk, ki vpliva na talino in strjevanje. Hitrost vrtenja forme 500 obratov/minuto in razdaljo med osjo rotacije, ki je enaka 0.2 m, daje vrednost centrifugalne sile, ki je 50 krat večja kot je sila težnosti. Zato so sile velike, in često opazimo neenakomernost v ulitkih, ki so narejeni v centrifugalnih indukcijskih pečeh iz razlogov, ki jih še do sedaj ne poznamo.

Analiza ulitkov z napakami in njihovega ulivnega sistema pokaže, da med polnjenjem forme pride do nastanka velike Coriolisove sile in ti efekti so jasno vidni v ulivnem sistemu. Talina ne zapolni ulivni sistem, „lebdi“ oziroma teče na površini talilnega lonca in forme.

Izvedli smo serijo poskusov z uporabo izbranih livnih konfiguracij, da bi lahko opazovali geometrijo toka taline in polnjenja forme.

Simulacije smo izvedli z računalniškim programom Flow3D. Z uporabo tega programa smo dobili dobro ujemanje rezultatov s poskusi.

Kot rezultat so bili narejeni poskusi za izvedbo numeričnih izračunov za skupen sistem talilni lonec/keramična forma, uporabljen za izdelavo precizijskih ulitkov.

Ključne besede: centrifugalno litje, keramična forma, precizijsko litje, Coriolisov efekt, računalniška simulacija, centrifugalne indukcijske peči



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SIMULATION OF CENTRIFUGAL CASTING PROCESS IN THE CERAMIC MOULDS

Summary

The aim of the presentation is to disclose the results of the centrifugal casting process on the example of computer simulation and actual experiments.

The centrifugal casting process uses the centrifugal force effect on the flow of molten metal in a mould, and then on pressure increase in the liquid and solidifying metal. The mould spinning speed of 500rev/min and the distance from the axis of rotation equal to 0.2m give the value of the centrifugal force 50 times greater than the force of gravity. Despite the force so large, misruns are often observed in castings made in the centrifugal induction furnaces for reasons which have been unexplained so far.

Analysis of castings with defects and of their gating systems has indicated that during pouring of moulds, the strong Coriolis force occurs, and its effects are clearly visible in the gating system. The liquid metal does not fill the gating system, but keeps flowing on the surface of the crucible and mould.

A series of experiments was carried out using specially selected casting configurations to allow observations of the flow geometry and mould filling pattern.

Simulations were performed with a Flow3D computer programme. Using this programme, good compliance with the results of the experiments was achieved.

As an outcome, attempts were made to carry out numerical calculations for a common crucible/ceramic mould system used to manufacture precision castings.

Keywords: Centrifugal casting, ceramic mould, investment casting process, Coriolis effect, computer simulation, centrifugal induction furnaces