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Prihodnje možnosti v livarski industriji
Izzivi in priložnosti: Primeri s področja ulivanja motorjev

Future Prospects for Foundry Technology
Challenges and Opportunities: Examples from the field of engine casting

Če se želimo ozreti v prihodnost in opisati izzive ter priložnosti v livarski industriji (z vidika tehnologij), moramo najprej razmisliti o stanju v livarski industriji iz tridesetih let prejšnjega stoletja. Dnevni red so sestavljali predvsem temne proizvodne dvorane, dim in hlapi, odprt ogenj, brizganje staljene kovine, pretežno fizično delo - kljub obstoju mehanizacije - ter slabi delovni pogoji. V modernih industrijskih državah je takšna livarska proizvodnja že postala prazgodovina. V tem času pa se niso spremenile za industrijo značilne metode obdelave naravnih materialov ter obvladovanje zakonov narave.

1 Rokovanje z naravnimi materiali in obvladovanje zakonov narave

Če si ogledamo nastanek dendrita med strjevanjem, ki je značilno za vse zlitine trdnih raztopin, kot so Al-Si-zlitine ali litoželezne zlitine, bomo opazili, da se dendrit s stene forme širi na ostanek taline (Sl. 1).

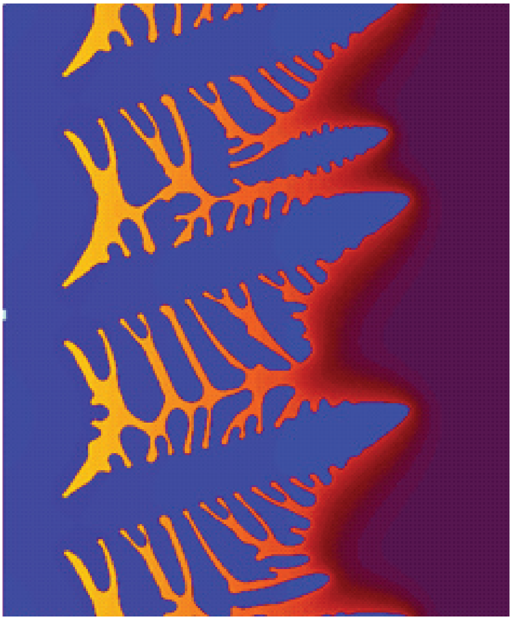
Po strjevanju nastane struktura, na podlagi katere je mogoče določiti razdaljo med dendritnimi vejami. Po eni strani to predstavlja korelacijo z mehanskimi lastnostmi materiala, po drugi pa s pričakovanim nastankom por v sestavnih delih (Sl. 2).

If we want to look ahead and describe the future challenges and opportunities for the foundry sector – from a technology point of view – it is worth contemplating the situation of the foundry industry in the Thirties of the last century first. Dark halls, smoke and exhaust fumes, glowing fires, liquid metal splashing everywhere, predominantly manual labour although mechanization already existed, and bad working and environmental conditions were all the order of the day. This archaic world of foundry production no longer exists in modern industrial nations. But what has not changed over the years are the industry-typical methods of processing natural materials and controlling the laws of nature.

1. Handling Natural Materials and the Laws of Nature

Looking at dendrite formation during solidification, which is typical for all solid-solution alloys such as Al-Si-alloys or cast irons, you can see how the dendrites grow from the mould wall to the residual melt (fig. 1).

After solidification, a structure is formed from which it is possible to deduce the dendrite arm spacing. On the one hand this correlates with the mechanical properties

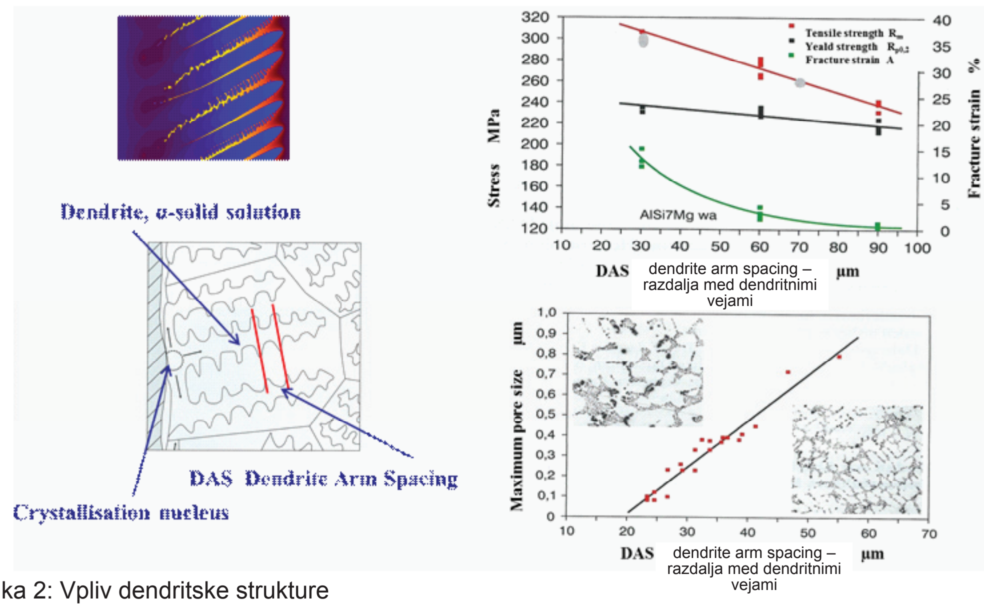


Slika 1: Nastanek dendrita med strjevanjem

Figure 1: Dendrite formation during solidification

of the material, and on the other, with the expected formation of pores in the component (fig. 2).

When using an Ishikawa diagram to look at the factors influencing the growth and formation of these dendrites (fig. 3) it is clear that the majority of the influencing parameters are not within our control, i.e. they cannot be influenced by manipulating production facilities or processes, but are to a much larger extent dependent on the natural materials used and the properties of these natural materials. In order to achieve process reliability within the production process and to ensure, for example, the appropriate mechanical properties of the material, a process-capable formation of these dendrites with accurate repeatability is required. As shown in fig. 4, this will only be successful if process control in the foundry is absolutely stable and if the properties of the natural materials used – including the preceding finishing process – have high



Slika 2: Vpliv dendritske strukture

Figure 2: Influence of dendrite structure

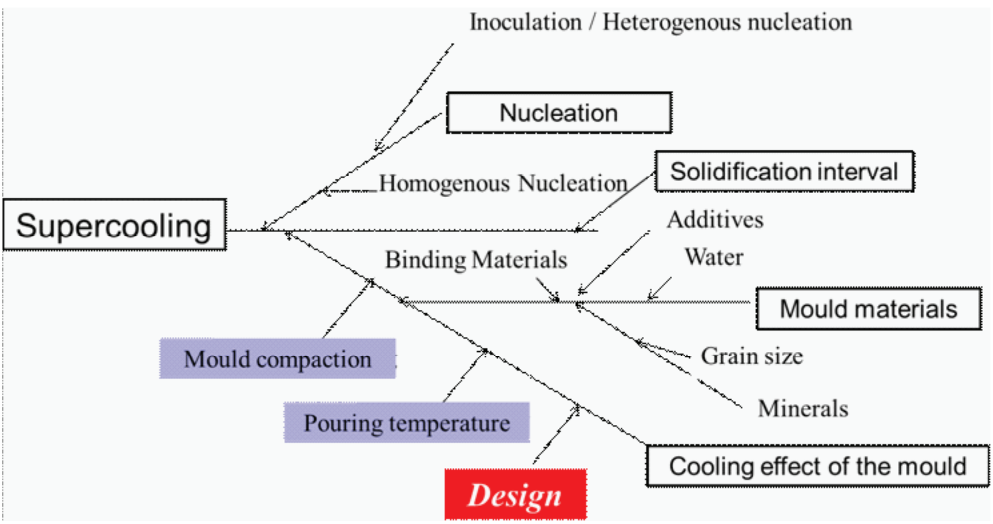
Če za proučevanje dejavnikov, ki vplivajo na rast in nastanek takšnih dendritov (Sl. 3), uporabimo diagram ribje kosti, postane jasno, da na večino parametrov, ki vplivajo na rast in nastanek dendritov, sploh ne moremo vplivati: na parametre namreč ni mogoče vplivati v proizvodnih obratih ali skozi procese, ampak so v večji meri odvisni od uporabljenih naravnih materialov ter od njihovih lastnosti. Za zanesljivost postopkov v proizvodnem procesu ter npr. ustreznih mehanskih lastnosti materiala je treba zagotoviti nastajanje takšnih dendritov v procesu z natančno ponovljivostjo. Skladno s Sl. 4 bo to mogoče zagotoviti samo, če je nadzor postopkov v livarni v celoti stabilen in če lastnosti uporabljenih naravnih materialov – med drugim tudi predhodna zaključna obdelava – zagotavljajo visoko zanesljivost. To posledično pomeni, da so za postopke v livarski industriji najpomembnejši stabilni in standardizirani postopki ter uporaba standardiziranih materialov.

process reliability. Consequently this means that stable, standardized processes and the use of standardized materials are the most important requirements for foundry processes.

2 Product Design

Component design today, particularly in the automotive industry, is driven by the demand for low-weight products – every gram or ounce counts. When high-strength materials are used, the wall thickness of the casts is reduced to a minimum. In cases where the inside wall thickness depends on the function of the component, the outer wall must be identical in shape and thickness (fig. 5).

This leads to highly complex component structures and dainty cast structures which can no longer be manufactured with the traditional moulding and casting methods used in the second half of the last century. Progress in component design and



Slika 3: Vpliv podhladitve in dendritske strukture

Figure 3: Influence of supercooling and dendrite structure

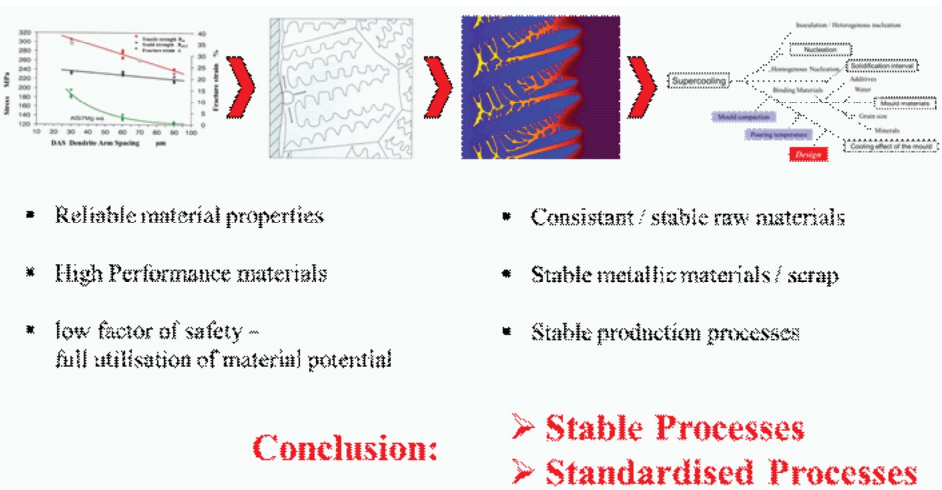
2 Zasnova izdelka

Dandanes zasnovo sestavnih delov, še posebej v avtomobilski industriji, poganja povpraševanje po izdelkih nizke teže – šteje namreč prav vsak gram. V primeru uporabe materialov z visoko trdnostjo se debelina stene ulitka zmanjša na minimum. Kadar je od debeline notranje stene ulitka odvisno delovanje sestavnega dela, mora biti identične oblike in debeline tudi zunanja stena (Sl. 5).

To pa vodi do izredno zapletenih struktur sestavnih delov in prefinjenih struktur ulitkov, ki jih ni več mogoče izdelati s tradicionalnimi livarskimi tehnikami, ki so bile v uporabi v drugi polovici prejšnjega stoletja. Napredek na področju dizajna sestavnih delov in razvoja materialov ter postopek ulivanja se dopolnjujeta. Kot je razvidno s Slike 5, je mogoče zanesljivost postopkov na področju kompleksnih sestavnih delov doseči izključno skozi uporabo popolnega paketa jeder, v katerem so vse konture izvedene z jedri, ki jih je mogoče sestaviti, ulivanje pa poteka v pokončnem položaju.

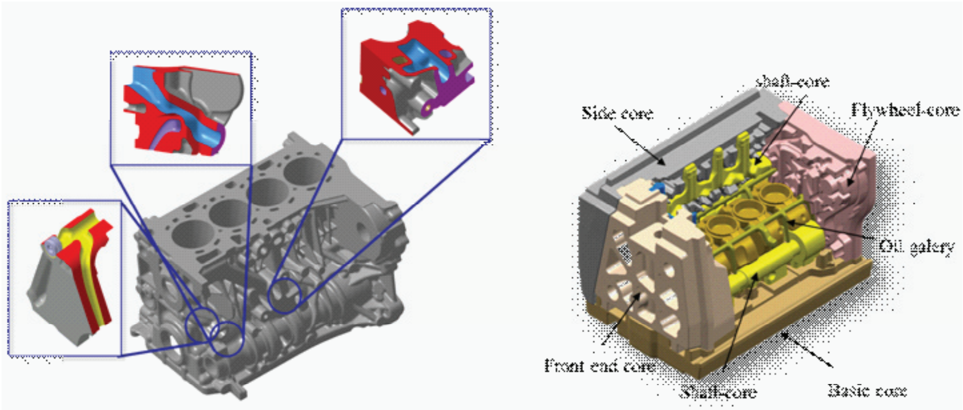
developments in casting materials and processes succeed each other. As you can see in figure 5, process reliability in the complex component areas can only be achieved by using a complete core package in which all contours are realized through cores that fit inside one another and have been cast in an upright position. Placing painted single cores in the mould is a thing of the past.

Modern castings, where the weight and local compound properties have been optimized in terms of their mechanical and thermal properties, require advanced casting techniques. A stationary and upright standing gravity cast process can not fulfill all the requirements for simultaneously preventing oxide formation and optimizing the feeding and local mechanical properties. Tilt pouring technologies, where the complete mould is tilted and cast by computer controlled systems, are state of the art. They allow customized mould filling and mould and core heating, and the hot spots can be selectively influenced (fig. 6). Die casting has the advantage of very high productivity



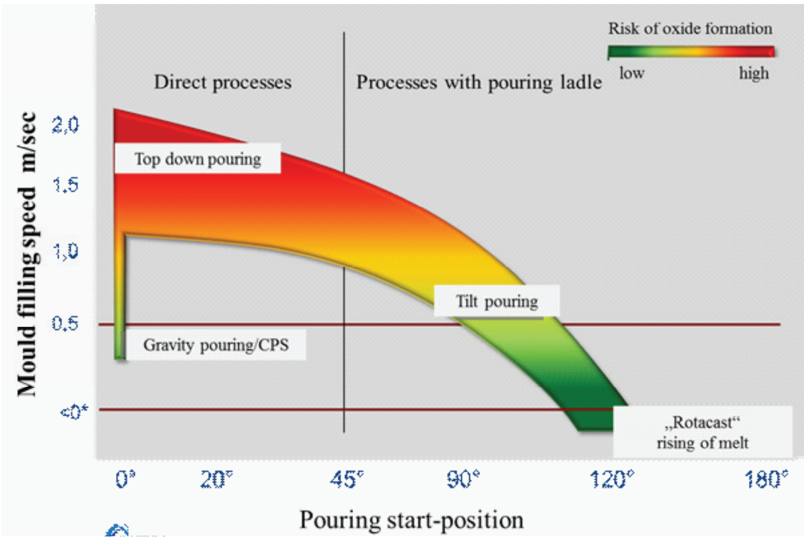
Slika 4: Vpliv dendritske strukture

Figure 4: Influence of dendrite structure



Slika 5: Optimalne tolerance jeder med njihovo izdelavo zagotavljajo ulitke optimalne teže

Figure 5: Optimal core-tolerances based on core-packing ensure weight-optimized castings



Slika 6: Moderne tehnologije litja zagotavljajo najboljšo kakovost ulitkov

Figure 6: Modern pouring technologies ensure best casting quality

Uporaba enega samega barvanega jedra je zgodovina.

Moderne ulitke, kjer so teža in lastnosti lokalnih zmesi sestavnih delov optimizirane z vidika mehanskih in termičnih značilnosti, zahtevajo uporabo naprednih livarskih tehnik. Postopki stacionarnega in pokončnega gravitacijskega litja ne morejo

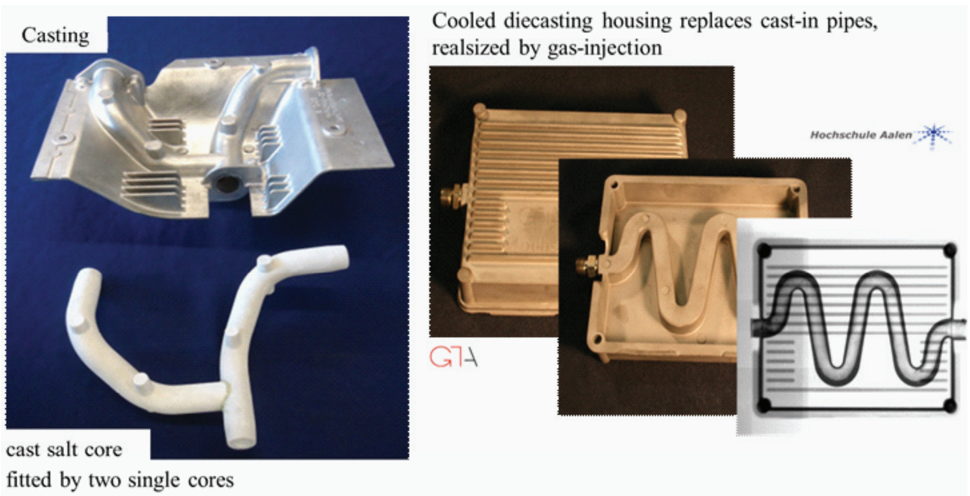
and precision and is the preferred method for typical die cast components where high quantities are needed. This technology harbours design limitations, however: interior cavities, back drafts and pared-down components, such as the one shown in figure 5, cannot be produced per die casting because the necessary cores (lost več izpolniti vseh zahtev za sočasno preprečevanje nastanka oksidacije ter optimizacijo napajanja in lokalnih mehanskih lastnosti. Tehnologije ulivanja pod naklonom, kjer je forma v celoti nagnjena, ulivanje pa izvaja računalniško nadzorovan sistem, predstavljajo najnovejši napredek na področju. Omogočajo prilagojeno ulivanje v forme ter segrevanje form in jeder, na vroče točke pa je mogoče vplivati posamezno (Sl. 6). Prednost tlačnega litja je izredno visoka storilnost ter natančnost. Je najbolj priljubljena metoda za tlačno litje sestavnih delov v velikih serijah. Vendar pa je ta tehnologija omejena z vidika zasnove ulitkov: utorov v notranjosti ulitkov, obratne koničnosti negativnih naklonov in prirezanih sestavnih delov, kot npr. tistih, prikazanih na Sliki 5, ni mogoče izdelati s tlačnim litjem, saj potrebna jedra (izguba form) ne prenesejo dinamičnih sil postopka tlačnega litja. Razvoj, npr. proizvodnja jeder iz soli (Sl. 7), je zelo obetaven. Pričakuje se, da bo tehnološki napredek še večji, ko bodo takšna jedra končno primerna za serijsko proizvodnjo.

moulds) can not withstand the dynamic forces of the die casting process. New developments such as salt core production (fig. 7) are very promising and are expected to create a considerable technology leap when they finally become suitable for mass production.

3 Environmental Aspects

The foundry industry is a very energy-intensive sector. As illustrated in figure 8, about 50% of the energy demand is needed for the melting process.

It is a typical feature of the casting process that the melting energy is needed for the liquefaction of the metallic parts. Technologies for recovering the waste heat from the melting process are state of the art. The Sankey diagram in figure 9 uses a mass production iron foundry as an example to illustrate the energy losses in melting caused by losses of materials alone. Classic casting process improvements to reduce the machining allowance as well as the



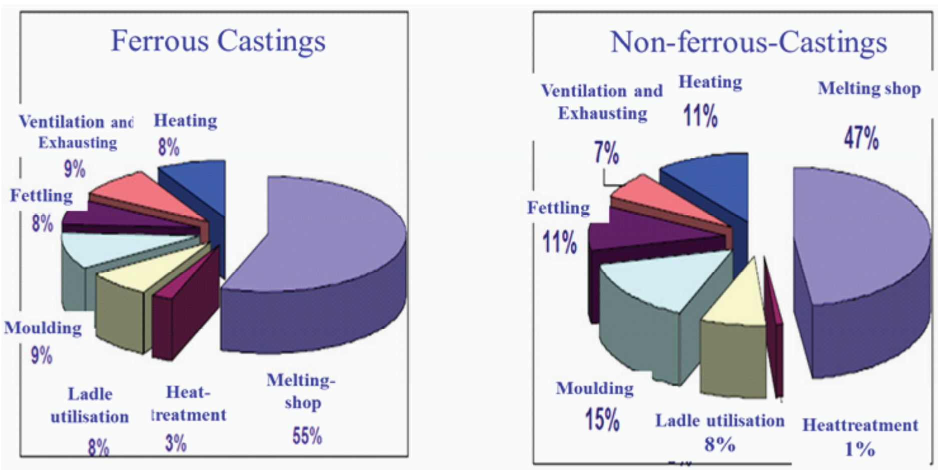
Slika 7: Jedra iz soli in polnjenje s plinom bosta omogočila dodatne možnosti v postopku kokilnega litja

Figure 7: Salt-cores and gas-injection will increase design-freedom in diecasting process

3 Okoljevarstveni vidiki

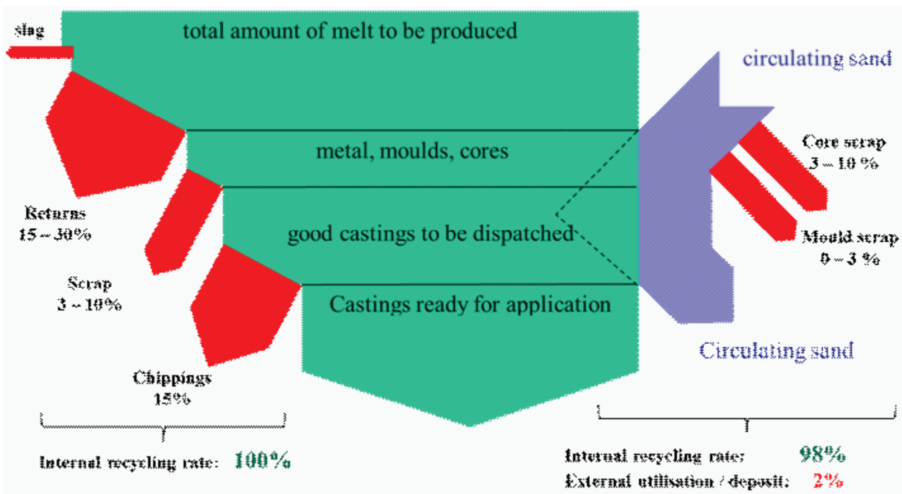
Livarska industrija je energetsko izredno intenzivna panoga. Kot je prikazano na Sliki 8, se v postopku taljenja porabi pribl. 50 % vse energije.

amount of returns and scrap have always an impact on energy consumption! Modern simulation technologies provide plenty of possibilites for this, even in foundries working with very traditional methods.



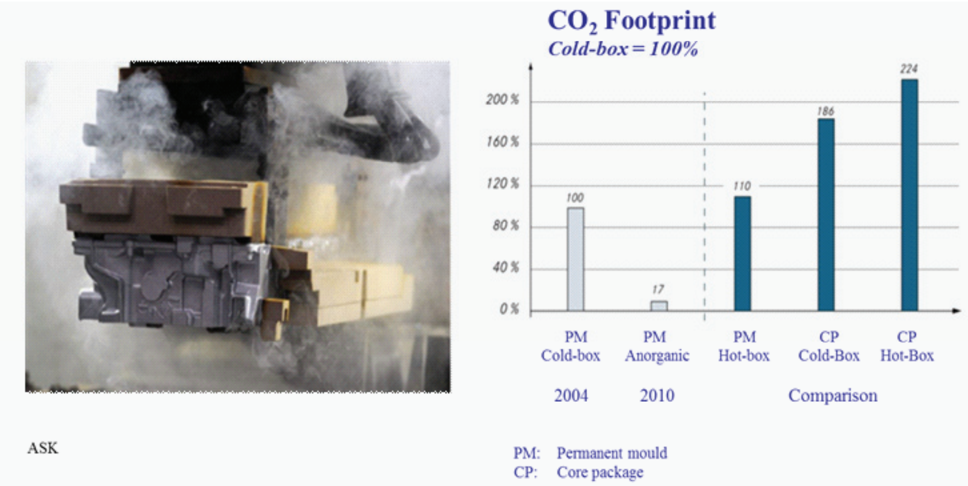
Slika 8: Večina energije se porabi med taljenjem

Figure 8: Most energy is expended in melting shop



Slika 9: Znatne izgube materiala in energije v postopkih ulivanja (ponazorjeno na primeru železolivarne z masovno proizvodnjo)

Figure 9: Substantial losses of material and energy during casting process (illustrated by mass production iron foundry)



Slika 10: Anorganska vezivna sredstva izboljšujejo delovne in okoljske pogoje

Figure 10: Anorganic binders improve working- and environmental conditions

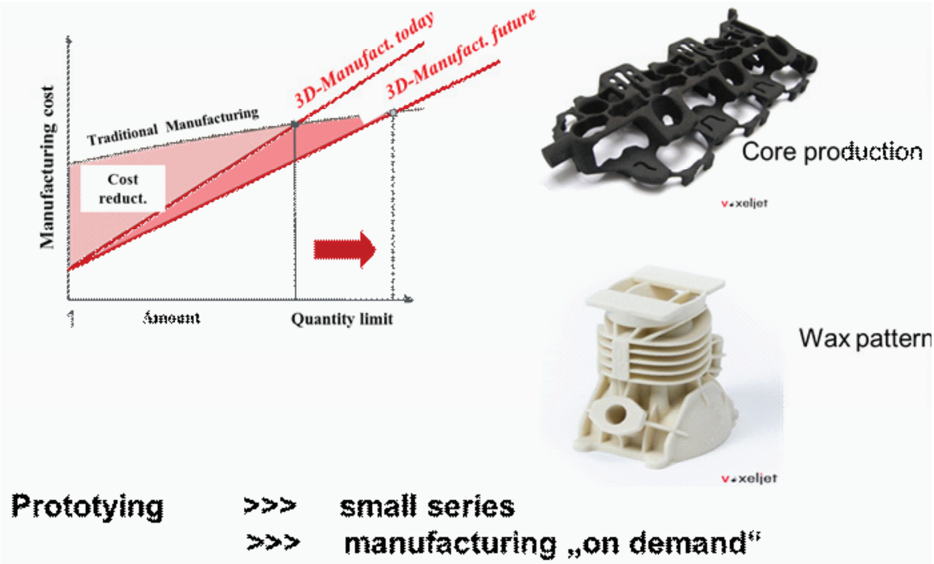
To je povsem običajna lastnost postopka ulivanja, kjer je energija potrebna za taljenje kovinskih delov. Najnovejši razvoj na področju predstavljajo tehnologije za rekuperacijo odpadne toplote. Sankeyjev diagram na Sliki 9 na primeru železolivarne s serijsko proizvodnjo prikazuje energetske izgube pri taljenju, ki so posledica izključno izgub materiala. Izboljšave tradicionalnih postopkov ulivanja z namenom zmanjševanja potrebe po mehanski obdelavi ter količine vračil krožne litine in odpadkov izmetnih ulitkov, vedno vplivajo tudi na porabo energije! Moderne simulacijske tehnologije ponujajo ogromno možnosti tudi livarnam, ki se zanašajo na precej tradicionalne metode.

Na Sliki 10 je prikazano, kako običajno nastaja dim pri ulivanju glav valjev v stalno formo s cold box jedrom. Glavne slabosti uporabe organskih vezivnih sredstev, potrebnih za delovanje sistema, so »koktejli«, ki so posledica različnih faz sežiga vezivnih sredstev med ulivanjem ter posledičnim nastankom kondenzata

Figure 10 illustrates the typical development of smoke when casting a cylinder head in a permanent mould using cold-box-cores. Major disadvantages of organic binders – which are inherent to the system – are the "cocktail" that ensues from the different combustion stages of the binders during casting and the subsequent condensate formation in the sand and in the pipes of the exhaust air purification systems. As a result, inorganic binders are gradually becoming more popular. These binders not only reduce the critical exhaust gases such as benzene, toluene and xylene and the amounts of condensate generated during casting, but also contribute to the reduction of greenhouse gases by considerably reducing the CO2 footprint (fig. 10).

4 Additive-generative Processes

Additive-generative manufacturing methods have been used in the field of rapid prototyping for around 15-20 years now.



Slika 11: Aditivni in generativni postopki so že na voljo

Figure 11: Additive-generative technologies are already established

v pesku ter v izpušnih ceveh sistema za čiščenje zraka. Tako postopoma postajajo anorganska vezivna sredstva vedno bolj priljubljena. Takšna vezivna sredstva zmanjšujejo nastajanje kritičnih izpušnih plinov, kot so benzen, toluen in ksilen, ter količino kondenzata, ki nastaja med ulivanjem, hkrati pa zaradi bistveno manjšega ogljičnega odtisa prispevajo tudi k zmanjševanju učinka toplogrednih plinov (Sl. 10).

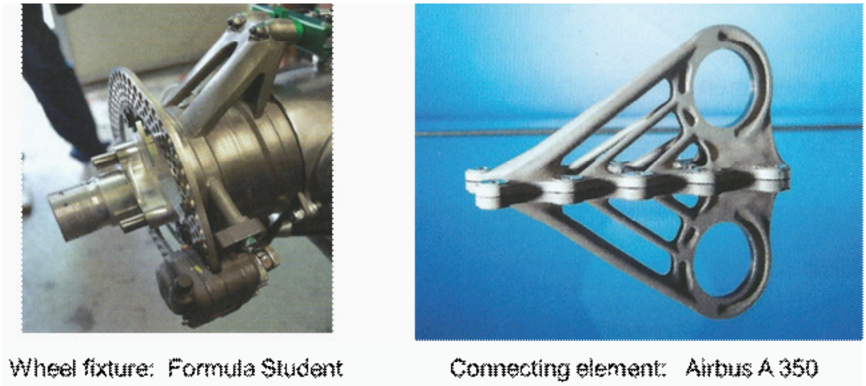
4 Aditivni in generativni postopki

Aditivne in generativne proizvodne metode se na področju hitre izdelave prototipov uporabljajo že 15 –20 let. Ti postopki, ki so se sprva uporabljali za krajšanje časa, potrebnega za izdelavo prvega sestavnega dela, tako, da izdelava orodja ni bila potrebna, so se medtem dobro uveljavili in

These processes, originally used to reduce the time needed for manufacturing a first component by omitting tool manufacturing, have meanwhile established themselves and are now the method of choice for small series in core and mould production.

Figure 11 shows the expected shift of quantities when printed moulds can be produced more cost-effectively than castings. In this way, complex cores such as the water jacket core shown can be produced. Additive-generative processes have many advantages: economical production of very small quantities, facilitation of design changes at short notice, and greater freedom of design. Wax patterns created by generative processes prove that this technology will play out its strength in investment casting, too.

Additive-generative methods for metallic components are so far limited to single item (“on demand“) production and to cases where component weight is an issue, e.g. in



Slika 12: Trenutno se proizvajajo posamezni kovinski kosi (»na zahtevo«) nizke teže (letalska industrija)

Figure 12: Metallic components are so far limited to single item (on-demand) production and to lowest weight (aircraft prod.)

so postali priljubljena izbira za proizvodnjo majhnih serij jeder in form.

Slika 11 prikazuje pričakovano gibanje količin v trenutku, ko bo proizvodnja tiskanih form stroškovno učinkovitejša od ulitkov. Na takšen način bo mogoče proizvesti tudi bolj kompleksna jedra, kot npr. jedra za ulivanje blokov motorjev na sliki. Aditivni in generativni postopki prinašajo številke prednosti: gospodarnejšo proizvodnjo zelo majhnih količin, poenostavljajo spremembe zasnove v zadnjem trenutku, nudijo pa tudi več svobode pri dizajniranju. Voščeni modeli, ustvarjeni skozi generativne postopke, dokazujejo, da bo ta tehnologija zasedla pomembno mesto tudi v precizijskem litju.

Aditivne in generativne metode za kovinske sestavne dele so trenutno omejene na proizvodnjo posameznih delov (»na zahtevo«) ter na proizvodnjo lahkih sestavnih delov, npr. za letalsko industrijo. Na Sliki 12 je prikazan nosilec pnevmatike in vezni element, ki se uporablja v izdelavi letal. Ni prav verjetno, da se bodo kovinski sestavni deli, proizvedeni skozi aditivne in generativne postopke, kadar koli uporabljali za masovno ulivanje, kot npr. v proizvodnji blokov motorjev.

the aircraft industry. As an example, figure 12 shows a wheel carrier and a connecting element used in aircraft construction. It is unlikely that metallic components made with additive-generative processes will be used for mass castings, like those needed for engine crankcases.

5 Industry 4.0

Industry 4.0 or the “Internet of Things” are current issues with a high priority on many agendas. Even though the term is not used officially, Industry 4.0 has already arrived in modern foundries with robot-assisted production lines and cross-linked systems. Taking fully automated core production in mass production as an example (fig. 13), you can see how the relevant information is processed from one production stage to the next and how changes within the production flow, such as type changes, largely occur automatically.

Linking up production areas that are locally separated, e.g. in a national/international production network, networks between suppliers and the foundry, direct

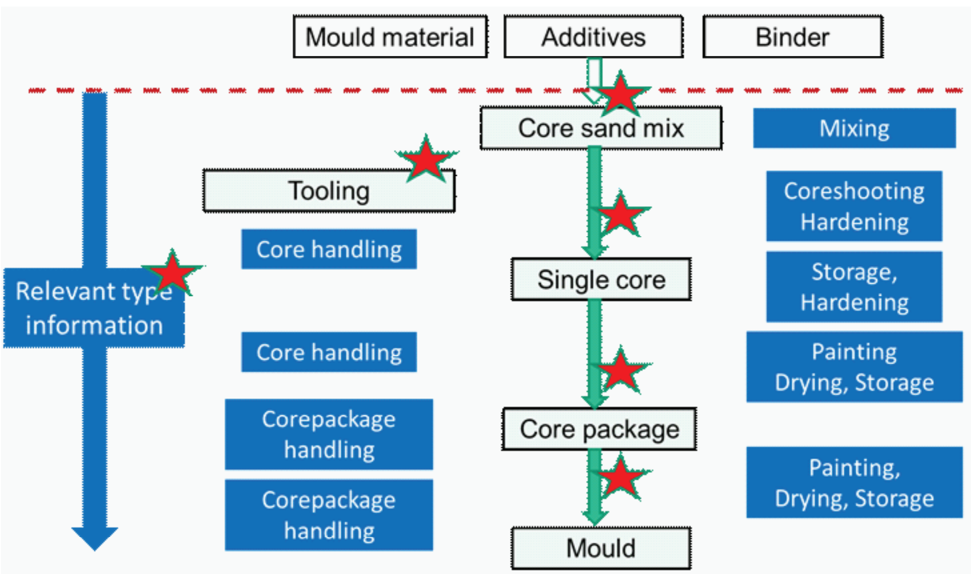
5 Industrija 4.0

Industrija 4.0 oz. »internet stvari« predstavlja trenutne težave s poudarkom na različnih vidikih. Industrija 4.0, čeprav ta izraz še ni uradno priznan, je že postal del modernih livarn z robotskimi proizvodnimi linijami in med seboj povezanimi sistemi. Na primeru popolnoma avtomatizirane serijske proizvodnje jeder (Sl. 13) je prikazano, kako se v zaporednih fazah proizvodnje obdelajo pomembne informacije ter kako se spremembe poteka proizvodnje, npr. tipske spremembe, v večji meri izvedejo samodejno.

Povezovanje lokalno ločenih proizvodnih področij, npr. v nacionalnem oz. mednarodnem proizvodnem omrežju, omrežja med dobavitelji in livarnami, neposredne podatkovne povezave med modelnimi delavnicami, konstrukcijo ulitkov in oddelki za zagotavljanje kakovosti ter ustreznimi oddelki za stranke so že izvedeni data connections between the pattern shop casting design and QA divisions and the respective customer departments have already been implemented or are in the pipeline. Whether the applications already implemented in the foundry industry actually correspond to the Industry 4.0. standards is a matter of personal opinion. The foundry industry has a relaxed attitude to this issue.

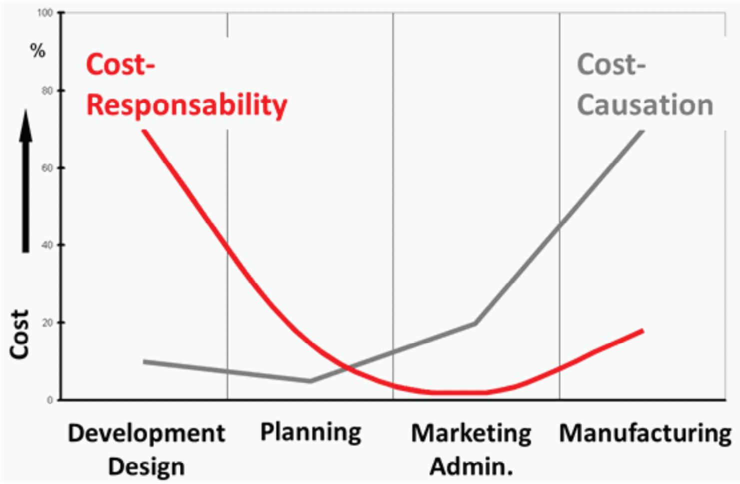
6 Cooperation between Foundrymen and Designers

Figure 14 compares cost responsibilities and cost causation at the individual stages of component development and production. It is evident that omissions or lapses in the component development stage have negative effects on the production costs in mass production and that corrections are complex and expensive. As such, foundrymen and designers need to cooperate closely during



Slika 13: Med seboj povezani proizvodni procesi

Figure 13: Production processes are cross-linked

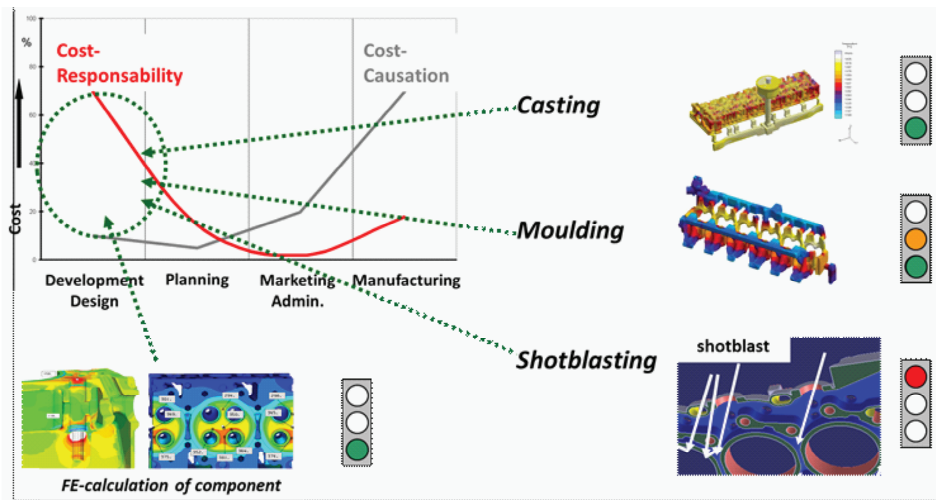


Slika 14: Pravočasno načrtovanje in razvoj pomagata pri manjšanju stroškov v začetnih fazah procesa

Figure 14: Frontloading at planning and development process helps avoid costs at initial stage of process

oziroma že predstavljajo pomembne elemente oskrbovalne linije. Ali že uvedene aplikacije v livarski industriji dejansko ustrezajo standardu Industrija 4.0, pa je subjektivno mnenje. Livarska industrija

the development and construction stages. The available simulation tools have to be optimally employed for recurring tasks in order to eliminate risks during production or



Slika 15: Orodja za načrtovanje in razvoj: sedanjost in prihodnost

Figure 15: Planning and development tools: today and future

namreč glede tega vprašanja nima ravno strogega mnenja.

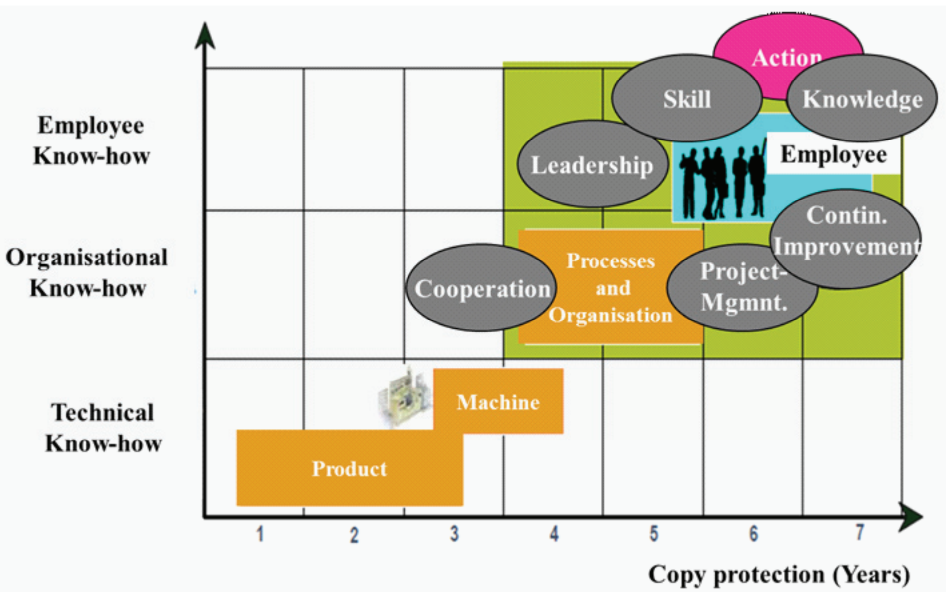
6 Sodelovanje med livarji in konstrukterji

Na Sliki 14 je prikazana primerjava med odgovornostjo za kritje stroškov in njihovim izvorom v različnih fazah razvoja ter proizvodnje sestavnih delov. Očitno je, da opustitve in napake v fazi razvoja sestavnih delov negativno vplivajo na proizvodne stroške serijske proizvodnje, rešitve pa so zapletene in drage. Zato morajo livarji in konstrukterji v fazi razvoja in konstrukcije sodelovati tesneje. Razpoložljiva simulacijska orodja je treba optimalno izkoristiti za ponavljajoča opravila in odpraviti tveganja med proizvodnjo oziroma v življenjski dobi sestavnega dela (Sl. 15).

Energijo, čas in denar je učinkoviteje vložiti v razvojno in proizvodno fazo kot pa preiskovati zapletene postopke in odpravljati during the operating life of the component (fig. 15).

It is more efficient to invest more energy, time and money in the development and construction stages than to go through complicated processes to correct mistakes – if this is at all possible. Although that seems like stating the obvious, it nevertheless often falls prey to stringent cost reduction programmes.

In this context the question arises on how to maintain a technological leading edge. To finish, figure 16 illustrates how long a copy protection may last. While technical know-how about products and machines can be copied within a very short period of time, organizational know-how in processes and organizations enjoy a higher copy protection and can temporarily lead to competitive advantages. The expertise, skills and knowledge of employees as well as their capabilities for successful



Slika 16: Veljavnost zaščite pred kopiranjem

Figure 16: Copy protection validity

napake – seveda, če je to mogoče. Čeprav je lahko zgoraj opisano popolnoma očitno, pogosto postane žrtev neizprosnih programov zmanjševanja stroškov.

S tega vidika pa se poraja vprašanje, kako ohranjati tehnološko dovršenost. Za zaključek je na Sliki 16 prikazano obdobje veljavnosti zaščite pred kopiranjem. Tehnično znanje o izdelkih in strojih je dovoljeno kopirati že po zelo kratkem obdobju, organizacijsko znanje s področja postopkov in organizacij pa je deležno daljše zaščite ter lahko predstavlja začasno konkurenčno prednost. Znanje in veščine zaposlenih ter njihove zmožnosti uspešne interakcije in inteligentno vodstvo so deležni največje stopnje zaščite pred kopiranjem.

7 Sklep

Možnosti v livarski industriji ter priložnosti in izzivi so bili opisani na podlagi primerov s področja ulivanja motorjev. Čeprav je mogoče rezultate raziskav in razvoja, t.j. izdelke in zadevne proizvodne procese, preprosto kopirati, mora biti organizacija sposobna prilagoditi se novim izzivom, če želi ohraniti več kot pomembno tehnološko prednost. Rezultat uspešnega sodelovanja med delavci v livarnah ter njihovimi strankami v zgodnji fazi razvoja sestavnih delov je primeren izdelek. Moderne tehnologije na področju ulivanja in uporaba prefinjenih materialov omogočajo proizvodnjo inovativnih sestavnih delov, kar opravičuje slogan »napredek skozi tehnologijo«.Energetska učinkovitost in okoljska uspešnost proizvodnih procesov predstavljata glavna vidika prav vsake livarne v dobavni industriji. Industrija 4.0: v modernih livarnah po vsem svetu že uvajajo metode, čeprav se ta izraz še ne uporablja prav pogosto. Aditivni in generativni postopki so v nekaterih delih livarske industrije že uvedeni. Livarska industrija tako uspešno sledi izzivom.

interactions and intelligent leadership have the highest level of copy protection.

7 Conclusion

The future prospects of foundry technology and its opportunities and challenges were described on the basis of examples taken from the field of engine casting.

Whereas the results of research and development, i.e. products and their respective production processes, can easily be copied, it is vital that an organization is capable of adapting to new challenges if the all-important technological advantage is to last.

Successful cooperation between foundry workers and their customers at an early stage of component development ensures mature products as an outcome. Modern casting technologies and sophisticated materials enable the production of innovative components, which justify the “progress through technology” slogan.

Energy efficiency and the environmental performance of production processes are focal issues for each and every foundry and the supplier industry.

Industry 4.0: Methods are already being applied in modern foundries even though this term is not yet widely used.

Additive-generative processes have already been implemented in parts of the foundry industry. The industry is taking up this challenge.