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Bela železova litina za sesalne turbine

White Cast Iron for The Impellers

Izvleček

Bela železova litina z velikim deležem kroma se običajno uporablja, kadar se zahteva izvrstna obrabna trdnost, npr. za osrednje dele črpalk. Njena izvrstna obrabna trdnost je predvsem posledica mikrostrukture, dosežene pri strjevanju. Specifikacije in zahteve za sestavne dele iz bele železove litine so med najstrožjimi v livarstvu. Ena od težav pri izdelavi takih delov so lahko razpoke. Zaradi tega je na Švedskem samo nekaj livarn železove litine, ki so sposobne ulivati strojne dele zahtevanih visokih kakovosti iz bele železove litine. Prispevek opisuje raziskave sesalnih turbin za črpalke v livarni. Delo je osredotočeno na zmanjšanje razpok v delih, industrijsko ulitih v različne peščene maske. Poskusi so pokazali, da izdelava peščenih mask pomembno vpliva na nastanek razpok.
Ključne besede: bela železova litina, sesalna turbina, obrabna trdnost, razpoke, formarski pesek za izdelavo mask, ulivanje

Abstract

High chromium white cast iron is commonly used in applications requiring excellent abrasion resistance, as central parts for pumps. Their excellent abrasion resistance is mainly due to their solidification microstructures. The specifications and requirements applied for the white cast iron components are among the most stringent used within the iron foundry branch. One of the problems for the production of these components can be cracks. Because of this reason there are just a few iron foundries in Sweden that are able to cast the required high quality white cast iron components. This work has been carried out in a foundry where an impeller for pumps has been analyzed. The project work has focused on reducing cracks on casting component in a production scale using different type of shell moulding sands. The experiments showed that the shell moulding sand had an important influence on the cracks.
Keywords: White cast iron, impeller, abrasion resistance, crack, shell moulding sand and casting

1 Uvod

Evropski standard EN 12513:2011 določa kakovosti obrabno trdnih belih železovih litin [1]. Specificira kakovosti glede na kemično sestavo in trdoto. Vrste obrabno trdnih belih železovih litin, ki jih pokriva ta standard, so:

a) nelegirane ali malo legirane železove

1 Introduction

The European Standard (EN 12513:2011) defines the grades of abrasion resistant white cast irons [1]. It specifies the grades in terms of chemical composition and hardness. The types of abrasion resistant white cast irons covered by this standard are:

litine (EN-GJN-HV350),

b) z nikljem in kromom legirane železove litine, ki obsegajo naslednji glavni vrsti:
   – železove litine z 4 % Ni in 2 % Cr (EN-GJN-HV550),
   – železove litine z 5 % Ni in 9 % Cr (EN-GJN-HV600),

c) železove litine, legirane z mnogo kroma, ki pokrivajo štiri vrste takih litin:
   – 11 % < Cr ≤ 14 % (EN-GJN-HV600(XCr11),
   – 14 % < Cr ≤ 18 % (EN-GJN-HV600(XCr14),
   – 18 % < Cr ≤ 23 % (EN-GJN-HV600(XCr18),
   – 23 % < Cr ≤ 28 % (EN-GJN-HV600(XCr23)

in za vsako območje kroma še tri območja deležev ogljika.

Pomemben razred teh materialov je bela železova litina, legirana z veliko kroma, EN-GJN-HV600(XCr23). Njihova izredna obrabna trdnost je rezultat velikega deleža karbidov, ki med strjevanjem nastajajo skupaj z avstenitom kot podevtetične ali evtektične faze odvisno od sestave zlitine, predvsem od deležev ogljika in kroma. Bele železove litine z veliko kroma se značilno ulivajo kot podevtektične zlitine, kjer je primarna faza dendritni avstenit, evtektik pa je sestavljen iz avstenita in karbidov M_7C_3[2, 3, 4].

Razpredelnica 1 prikazuje značilno kemično sestavo za izdelavo ulitkov v litem stanju EN-GJN-HV600(XCr23) [1].

a) unalloyed or low alloy cast irons (EN-GJN-HV350);

b) nickel-chromium cast irons covering two general types:
   - 4 % Ni 2 % Cr cast irons (EN-GJN-HV550);
   - 5 % Ni 9 % Cr cast irons (EN-GJN-HV600);

c) high chromium cast irons covering four ranges of chromium content:
   - 11 % < Cr ≤ 14 % (EN-GJN-HV600(XCr11);
   - 14 % < Cr ≤ 18 % (EN-GJN-HV600(XCr14);
   - 18 % < Cr ≤ 23 % (EN-GJN-HV600(XCr18);
   - 23 % < Cr ≤ 28 % (EN-GJN-HV600(XCr23);

and for each chromium content range, three ranges of carbon content.

An important class of these materials is high chromium white cast iron, EN-GJN-HV600(XCr23). Their exceptional wear resistance is the result of their high carbide content, which forms along with austenite during solidification as a proeutectic or eutectic phase depending on alloy composition. This is particularly depending upon carbon and chromium content. High chromium white irons are typically cast as hypoeutectic alloys having a primary phase of dendritic austenite with the eutectic made up of austenite and M7C3 carbides [2,3,4].

Table 1 presents a typical chemical composition used for the production of as-cast EN-GJN- HV600(XCr23) castings [1].

Razpredelnica 1. Kemična sestava EN-GJN-HV600(XCr23) železove litine z veliko kroma

Table 1. Chemical composition of EN-GJN-HV600(XCr23) high chromium cast iron

Kemična sestava v mas.% / Chemical composition in % (mass fraction)								
C	Si max	Mn	P max	S max	Cr max	Ni max	Mo max	Cu max
>1.8 to 2.4 >2.4 to 3.2 >3.2 to 3.6	1.0	0.5 to 1.5	0.08	0.08	23.0 to 28.0	2.0	3.0	1.2

Razpredelnica 2. Kemična sestava železovih litin v livarni XY (EN-GJN-HV600(XCr23))

Table 2. Chemical composition of the XY Foundry EN-GJN-HV600(XCr23) cast iron

Kemična sestava v mas.% / Chemical composition in % (mass fraction)						
C	Si	Mn	P	S	Cr	Ni
2.90±0.1	<1.5	<0.6	<0.08	<0.08	25.0±1.0	<1.0

Evropski standard EN-GJN-HV600(XCr23) ima status standarda livarne XY, ki velja za ulivanje sesalnih turbin za črpalke, toda livarna XY ima določene zahteve glede kemične sestave, kot kaže razpredelnica 2.

Izdelava kakovostnega ulitka zahteva, da so ulitki brez vseh napak. Ena od glavnih livarskih napak so razpoke v vročem. Te se pojavljajo v ulitku že v testastem stanju. Čeprav se v večini del smatrajo razpoke v vročem kot pojav, ki je povezan z neustreznim nadomeščanjem krčenja taline med strjevanjem ob prisotnosti toplotnih napetosti. Več vplivov lahko povzroča razpoke pri temperaturah tik nad temperaturo solidus [5, 6]. Industrijske in teoretične raziskave so pokazale, da razpoke v vročem nastajajo v zadnji fazi strjevanja, ko je delež trdne faze že nad 85—95 % in se trdna faza oblikuje v zvezno mrežo kristalnih zrn [7, 8].

V splošnem je obrabna trdnost odvisna od mikrostrukture osnove, vrste karbidov in njihovih značilnosti (velikost, morfologija, porazdelitev in usmerjenost), kot rudi njihovega prostorninskega deleža ter trdote zlitin [9]. Zahtevana zgradba in trdota obrabno obstojnih železovih litin se doseže z izbiro primerne kemične sestave in načinom izdelave.

Cilji tega prispevka so:

- prikazati oris razvoja bele železove litine v livarni XY,
- dati opis glavne vloge, ki jo ima bela železova litina kot konstrukcijski material pri črpanju tekočin in kako je lahko ta

The European standard EN-GJN-HV600(XCr23) has the status of the XY Foundry standard in relevant cast impeller for pumps., but the XY Foundry has some requirements on the chemical composition as shown in table 2.

The production of quality casting requires the castings to be free from any defects. One of the main casting defects is hot tearing (hot cracking or hot shortness). Irrespective of the name, this phenomenon represents the formation of an irreversible failure (crack) in the still semisolid casting. Although in most works hot tearing is considered as a phenomenon linked to the inadequate compensation of solidification shrinkage by melt flow in the presence of

thermal stresses, there are more factors that could be involved in the formation of cracks at supersolidus temperatures [5,6]. Industrial and fundamental studies show that hot tearing occurs in the late stages of solidification when the volume fraction of solid is above 85 to 95 % and the solid phase is organized in a continuous network of grains [7,8].

Generally, wear resistance depends on matrix microstructure, carbide type and characteristics (size, morphology, distribution and orientation) as well as the volume fraction, and hardness of the alloys [9]. The required structure and hardness of abrasion resistant cast irons are obtained by the selection of a suitable chemical composition and the manufacturing method.

koristna za livarne bele železove litine,
- prikazati analizo, kako različne vrste izdelav peščenih mask vplivajo na napake pri litju v industrijskem merilu.

Poskusi so bili narejeni v livarni XY na južnem Švedskem.

2 Materiali in metode

Različne vrste livarskega peska, prevlečenega z umetno smolo, so bile preizkušene z litjem značilnih ulitkov, imenovanih »sesalna turbina« (slika 1) in enim ulitkom, pritrjenim na modelno ploščo. Masa »sesalne turbine« je bila 7,5 kg, njen premer pa 260 mm. V prejšnjem poskusu [10] se je enaka sesalna turbina uporabila za preizkus vpliva deleža molibdena in livne temperature na livarske napake.

Slika 1. Ulitek »sesalna turbina«

Figure1. The casting component "Impeller"

Ulivalo se je v maske, narejene iz osem vrst peskov različnih dobaviteljev, kot kaže razpredelnica 3. Povprečna velikost zrn vsakega peska je bila 0,18 mm.

Z vsako vrsto peska je bilo izdelanih 25 mask. Čas strjevanja maske pri izdelavi iz vsakega peska je bil 70 s in čas utrjevanja

The objectives of this paper are to present;
- An outline of the development of white cast iron in the XY Foundry.
- To describe the major role played by white cast iron as a construction material in pumping liquids and how it could benefit white cast iron foundries.
- Analyze how different type of shell moulding sands influences the casting defects on a casting component in a production scale.

The experiments were carried out at one foundry (XY Foundry) in South part of Sweden

2 Materials and Methods

Different type of resin coated sand were tested using a typical casting component named "Impeller", illustrated in figure 1, and one casting was mounted on the pattern plate. The weight of the "Impeller" is 7.3 kg and the diameter of 260 mm. In the earlier experiment [10], the same impeller was used to test how Molybdenum content and pouring temperature affected the casting defects.

The castings were made in shell moulding using eight different types of sand from different suppliers, as is shown in table 3. Average grain size of each sand was 0.18 mm.

For each different type of sand, 25 shell were moulded. The setting time for shell manufacturing was 70 s and the curing time was also 70 s for each type of sand. After moulding each shell was weighed and table 4 shows the average weight for different type of sand.

Melting was done in high frequency furnace. The chemical composition was determined by the light emission spectrometer - ARL 3460. The chemical composition of the base melts for the

Razpredelnica 3. Tehnične specifikacije peskov

Table 3. Technical specification of the sands

Tehnična specifikacija / Technical specification	Vrsta peskov / Type of sand							
	A	B	C	D	E	F	G	H
Natezna trdnost v vročem / Hot tensile strength (N/cm^2)	175	280	170	180	175	215	200	200
Upogibna trdnost v hladnem / Cold bending strength (N/cm^2)	900	1085	815	900	850	930	970	1050
Temperature lepljenja / Sticking point (°C)	77	79	79	79	77	79	80	81
Izgube pri žarjenju / Loss on ignition (%)	4.70	4.70	4.80	4.80	4.63	4.81	4.93	5.07
Čas izdelave maske / Shell forming time (s)	15	15	15	16	13	14	14	13

Razpredelnica 4. Povprečna masa maske iz posameznega peska

Table 4. The average weigt of shell mould for each type of sand.

Povprečna masa / Average weigt (kg)	Vrsta peskov / Type of sand							
	A	B	C	D	E	F	G	H
	12.15	14.45	11.75	12.40	13.35	14.25	13.75	12.90

Razpredelnica 5. Kemična sestava osnovne taline. % E.C. = 12.33(% C)+0.55(% Cr)-15.2

Table 5. The chemical composition of the base melt. %E.C. = 12.33(% C)+0.55(% Cr)-15.2

Talina / Melt	Element v mass % / Element in % (mass fraction)							%E.C.	razmerje / ratio %Cr/%C	livna temperatura / pouring temp (°C)
	C	Si	S	P	Mn	Ni	Cr			
I	2.89	1.58	0.03	0.03	0.29	0.27	25.42	34.41	8.79	1550
II	2.88	1.59	0.03	0.03	0.28	0.27	25.41	34.29	8.82	1550

tudi 70 s. Po izdelavi se je vsaka maska tehtala, razpredelnica 4 pa kaže povprečne mase maske iz vsakega peska.

Za taljenje se je uporabila visokofrekvenčna peč. Kemična sestava se je ugotavljala s svetlobnim emisijskim spektrometrom ARL 3460. Kemične sestave osnovnih talin in livne temperature prikazuje razpredelnica 5. Talina I se je uporabila za ulivanje v maske iz peskov A, B, C in D in talina II za ulivanje v maske iz peskov E, F, G in H.

Vsi poskusi litja so obsegali skupaj 200 ulivanj, da se je dobila dobra statistična osnova za ovrednotenje vpliva različnih vrst peskov na livarsko napako.

castings and pouring temperature are shown in table 5. The Melt I was used to cast the shell from the sand type A, B, C and D. The Melt II was used to cast the shell from the sand type E, F, G and H.

All the casting experiments yield a total 200 castings, thereby providing a sound statistical basis for evaluation of the effect of different type of sand on the casting defect.

3 Rezultati in razprava

3.1 Livarske napake

Po peskanju smo vse ulitke pregledali najprej s prostim očesom nato v skladu s standardom EN 1371-1:2011 preiskali še s tekočino, ki pronica v material. Rezultate prikazuje razpredelnica 6.

Razpoke v vročem se pogosto pojavljajo na istih mestih v ulitku. Ta mesta prikazuje slika 2.

3.2 Simulacija litja

Simulacije litja smo pripravili s programsko opremo MagmaSoft® in dodatnim modulom MagmaIron®, posebej razvitim za simulacije z železovo litino. »Sesalno turbino«

3 Results and Discussion

3.1 Castings Defects

After sand blasting all castings were investigated first by an ocular inspection, and then with the liquid penetrant testing in accordance with EN 1371-1:2011. The results are given in table 6.

The hot tearing often occurs in same locations on this casting. These locations are shown in figure 2.

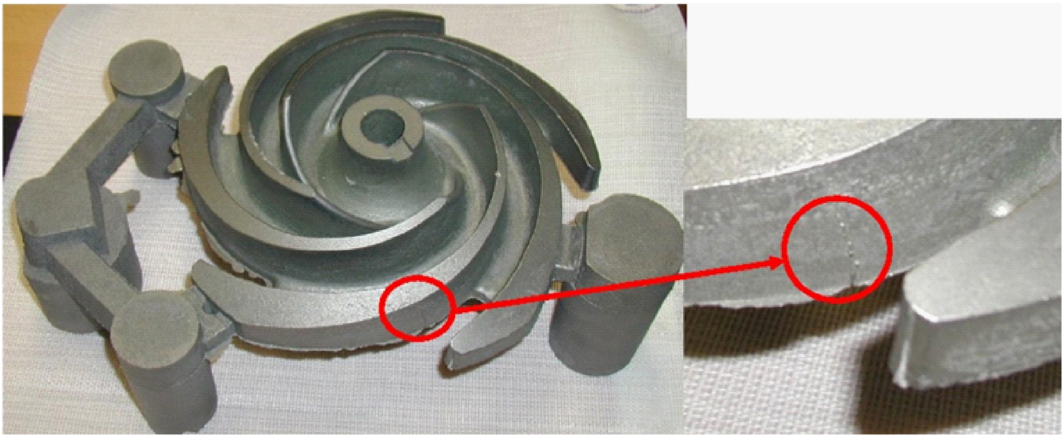
3.2. Casting Simulation

A series of simulations were performed with the casting simulation programme MagmaSoft® using the add-on module MagmaIron®, especially developed for cast

Razpredelnica 6. Statistično navajanje livarskih napak na ulitkih

Table 6. Statistical listing of casting defects found on the castings

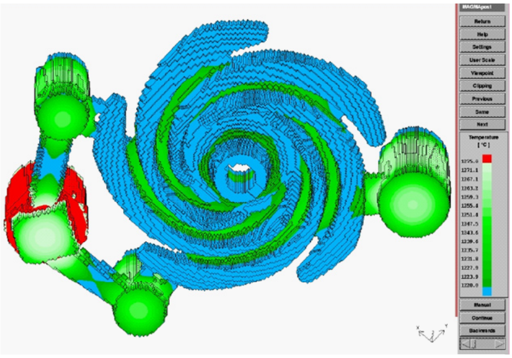
Livarska napaka / Casting defect	Poskus / Experiment							
	A	B	C	D	E	F	G	H
Razpoke v vročem / Hot tearing [%]	28.00	12.00	32.00	32.00	36.00	24.00	4.00	8.00



Slika 2. Ulitek »sesalna turbina« in njegov ulivni sistem. Krogi kažejo območja, kjer se pojavljajo razpoke v vročem

Figure 2. The casting component “Impeller” and its gating system. The circles show the areas where the hot tearing usually occurs

z ulivnim sistemom smo modelirali s simulacijo. Pri simulaciji smo upoštevali potek zapolnjevanja forme kot tudi potek strjevanja. Slika 3 prikazuje rezultat 3-D simulacije pri temperaturi, ko je bilo 50 % forme strjenih.



Slika 3. Rezultat 3-D simulacije pri temperaturi, ko je bilo 50 % forme strjene

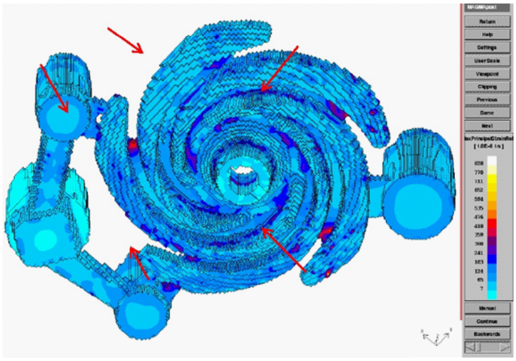
Figure 3. 3-D result from the simulation showing temperature when 50% of the mould is solidified

Slika 4 prikazuje rezultat 3-D simulacije porazdelitve napetosti, ko je bilo 50 % forme strjene. Napetosti so večje na zaokrožitvah (puščice kažejo ta območja). Material še ni bil strjen, zato je bila nevarnost nastanka razpok v vročem.

3.3 Mikrostrukturna analiza

Za ugotavljanje, če se pojavljajo razlike v mikrostrukturah med različnimi poskusnimi ulitki, je bil vzet vzorec iz vsakega ulitka za mikroskopsko preiskavo. Vzorci so bili brušeni, polirani, mikrostruktura pa se je preiskovala s svetlobnim mikroskopom. Obrusi so bili jedkani s Kallingovim reagentom št. 2 ($CuCl_2$ 5 g, klorovodikova kislina 100 ml in etanol 100 ml) pri sobni temperaturi. Slika 5 prikazuje nekaj značilnih

iron simulation. The “Impeller” with its gating system was modelled for the simulation. In the simulation, the mould filling sequence as well as the solidification sequence were considered. Figure 3 shows the 3-D result from the simulation showing temperature when 50% of the mould is solidified.



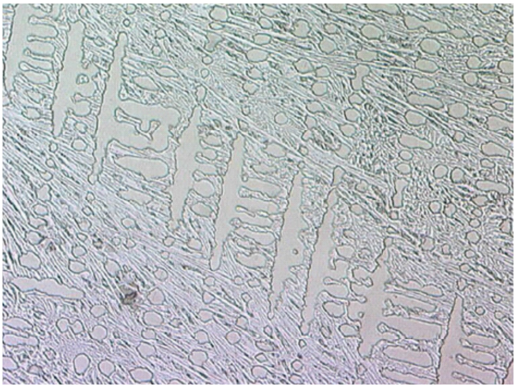
Slika 4. Rezultat 3-D simulacije porazdelitve napetosti, ko je bilo 50 % forme strjene

Figure 4. 3-D result from the simulation showing strain ratio when 50% of the mould is solidified

Figure 4 shows the 3-D result from the simulation, showing strain ratio when 50% of the mould is solidified. Strain rate is elevated at radius (the arrows show the areas). The material has not solidified there yet and there is a risk of hot cracking.

3.3. Microstructure Analysis

To investigate whether there were differences in microstructures between different test castings, an example from each casting is taken for microscopic examination. The samples were grinded and polished and the microstructure was investigated by optical microscope. The etching was performed by Kalling’s No.2 etching solutions ($CuCl_2$ 5 g, hydrochloric acid 100 ml and Ethanol 100 primerov mikrostrukture iz poskusa s peskom E, in slika 6 s peskom G.



Slika 5. Mikrostruktura »sesalne turbine« iz poskusa litja E (povečava 200 x)

Figure 5. The microstructure of the "Impeller" from pouring E (magnification 200X).

4 Sklepi

Poskusi so pokazali, da ima pesek za izdelavo mask velik vpliv na razpoke v vročem. Najbolj neugodni primeri razpok v vročem so bili pri pesku vrste E. Tedaj je bil delež livarskih napak 36 %.

Najboljše rezultate smo dosegli s peskom vrste G, ko je bilo livarskih napak le 4 %.

S simulacijo je bilo možno odkriti območja, kjer je nastanek razpok v vročem verjeten. Mikroskopska preiskava ni pokazala razlik med različnimi poskusnimi ulitki.

5 Zahvale

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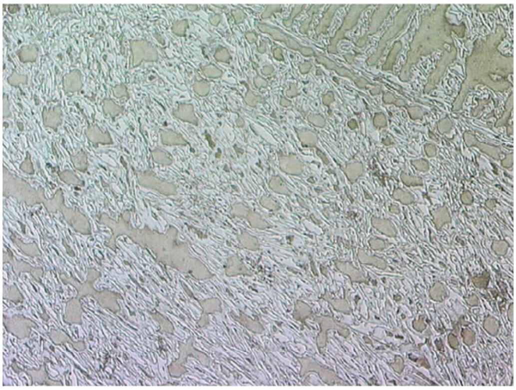
ml) at room temperature. Figure 5 shows a typical example of the microstructure from the experiment with sand type E. Figure 6 shows a typical example of the microstructure from the experiment with sand type G.



Slika 6. Mikrostruktura »sesalne turbine« iz poskusa litja G (povečava 200 x)

Figure 6. The microstructure of the "Impeller" from pouring G (magnification 200X).

4 Conclusions

The experiments showed that the shell moulding sand had an important influence on hot tearing. The worst cases of hot tearing were obtained using the sand type E. When we used this type of sand, the castings defects were 36 %.

The best results were obtained using the sand type G with only 4 % castings defects.

By simulation it is possible to detect the areas where hot tearing is likely to be formed. The microscopic examination does not show any deviations between the different test castings.

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