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Vpliv ohlajevalne hitrosti na livarske napake v beli litini z mnogo kroma za sesalne turbine

Effect of Cooling Rate on the Casting Defects of High Chromium White Cast Iron for the Impellers

Izvleček

Kadar je delež kroma v beli železovi litini 23 – 28 %, predstavlja ta eno najstarejših trgovskih belih visoko legiranih železovih litin. Visoko legirane bele železove litine so izvrstno abrazijsko odporne in se učinkovito uporabljajo za črpalke za gošče, forme za opeke, mline za mletje premoga, valje valjalnih strojev, opremo za peskanje in sestavne dele naprav v kamnolomih za pridobivanje in mletje trdih kamnin.

Specifikacije in zahteve glede uporabe sestavnih delov iz bele železove litine so med najbolj strogimi na področju litja železovih litin. Ena od največjih težav pri izdelavi teh sestavnih delov so razpoke v vročem ali pokanje v vročem oziroma krhkost v vročem. Ne glede na poimenovanje ta pojav predstavlja nastanek nepovratnih napak (razpok) v še ne popolnoma strjenem ulitku.

Ta prispevek prikazuje raziskavo vpliva ohlajevalne hitrosti na pokanje. Obravnavali smo en ulit sestavni del, sesalno turbino črpalke, pri izdelavi v industrijskem merilu, s tem da smo uporabili različne ohlajevalne hitrosti po litju. Pokazali smo, da ima hitrost strjevanja močan vpliv na pokanje v vročem.

Ključne besede: bela železova litina, sesalna turbina, ohlajevalna hitrost, pokanje v vročem, litje

Abstract

One of the oldest high alloys white cast irons is produced commercially when the chromium content is between 23 and 28 %. The high-chromium white irons have excellent abrasion resistance and are used effectively in slurry pumps, brick moulds, coal-grinding mills, rolling mill rolls, shot blasting equipment, and components for quarrying, hard-rock mining and milling.

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 biggest problems for the production of these components is hot tearing or hot cracking, or hot shortness. Irrespective of the name, this phenomenon represents the formation of an irreversible failure (crack) in the still semisolid casting.

This paper will show a study of the effect of cooling rate on the cracks. The procedure to achieve this was to study one casting component, impeller, in a production scale using different cooling rate after pouring. In this work it has been shown that the solidification rate has a strong effect on the hot cracking.

Keywords: white cast iron, impeller, cooling rate, hot cracking and casting.

1 Uvod

Pridobivanje in predelava mineralnih surovin se vsakodnevno uporablja na vseh celinah. Industrijske črpalke so na splošno posebej konstruirane tako, da izpolnjujejo najvišje zahteve glede transporta v industriji. Te črpalke se zlahka uporabljajo za različne materiale: materiale, ki se mažejo, so abrazivni, kemično nevtralni ali korodirni, dodatno pa še za vlaknate snovi in gošče trdnih delcev. V rudarski industriji velik delež trdnin in veliki delci močno povečujejo stroške zaradi obrabe ter slabo vplivajo na delovanje črpalke [1,2].

Glede na evropski standard EN 12513:2011 [3] obstajajo trije različni razredi železovih litin:

a) nelegirane in nizkolegirane železove litine,
b) nikelj-kromove železove litine,
c) železove litine z velikim deležem kroma.

Bele železove litine z veliko kroma predstavljajo kombinacijo izvrstne abrazijske odpornosti, še kar dobre žilavosti in možnosti žarjenja, da se izboljša obdelovalnost [4,5,6]. Različne vrste bele železove litine so se v preteklosti uporabljale različno uspešno. Značilnosti in lastnosti teh materialov so objavljene v številnih priznanih publikacijah [7,8,9].

Specifikacije in zahteve za uporabljene sestavne dele iz bele železove litine so med najstrožjimi v livarstvu železovih litin. Ena od največjih težav pri izdelavi takih strojnih delov so razpoke v vročem ali pokanje v vročem ali krhkost v vročem. Ne glede na poimenovanje ta pojav predstavlja nepovratne napake (razpoke) v ulitku že med strjevanjem [10].

Cilji tega prispevka so predstaviti:

- kratek prikaz razvoja bele železove litine v livarni XY,
- opis glavne vloge bele železove litine,

1 Introduction

The extraction and processing of minerals takes place daily on every continent. Industrial pumps in general are especially designed to meet the highest conveying requirements for the use within the industry. These pumps are capable of handling different materials; lubricating, abrasive, chemically neutral, or corrosive product plus fibrous matter and matter containing solids with great ease. In the mining industry, high solids content and large particles can dramatically increase wear costs and have a negative impact on the pump's operation [1,2].

According to European Standard EN 12513:2011 [3], three distinct classes of irons exist:

a) unalloyed or low alloy cast irons,
b) nickel-chromium cast irons and
c) high chromium cast irons.

The high-chromium white cast iron possesses a combination of excellent abrasion resistance together with a reasonable degree of toughness and the possibility of annealing to facilitate machining operations [4,5,6]. Different types of white cast iron have been used in the past with varying success. The characteristic features and properties of these materials have been reviewed in a lot of excellent publications [7,8,9].

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 biggest problems for the production of these components is hot tearing or hot cracking, or hot shortness. Irrespective of the name, this phenomenon represents the formation of an irreversible failure (crack) in the still semisolid casting [10]

The objectives of this paper are to present:

ki jo ima kot konstrukcijski material pri črpanju tekočin in kako je to lahko koristno za livarne bele železove litine,
- analizo, kako hitrost ohlajevanja vpliva na livarske napake pri ulivanju ulitega strojnega dela, sesalne turbine, pri industrijski izdelavi ob uporabi različnih ohlajevalnih hitrosti po litju.

2 Materiali in metode

Poskuse, opisane v tem prispevku, smo naredili v livarni XY v južnem delu Švedske. Vpliv različnih hitrosti ohlajevanja po litju smo preskušali na značilnem ulitem strojnem delu, imenovanem »sesalna turbina«, ki je prikazan na sliki 1. En ulit del je montiran na modelni plošči. Masa sesalne turbine je bila 7,3 kg, njen premer 260 mm. Pri prejšnjih poskusih [11,12] smo enako sesalno turbino uporabili pri ugotavljanju, kako delež molibdena in temperatura litja vplivata na livarske napake [11] in kako različne vrste livarskih mask vplivajo na livarske napake [12].

Ulitki so bili izdelani na stroju Laempe LFB25 v formah iz kremenovega peska, vezanega s fenolno smolo na osnovi vode, in utrjenih s CO_2. En prilagodilni člen

- 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 the effect of cooling rate influences the casting defects on a casting component, impeller, in a production scale using different cooling rate after pouring.

2 Materials and Methods

The experiments in this work were carried out at the XY Foundry in the South part of Sweden. Different cooling rates after pouring 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 is 260 mm. In the earlier experiments [11,12], the same impeller was used to test how molybdenum content and pouring temperature affected the casting defects [11] and how different types of shell moulding sand influence the casting defects [12].

The castings were made using silica sand and a water based phenolic resin system cured by the use of CO_2 gas by Laempe machine LFB25. One “adapter” is manufactured to use the same pattern which is used for the shell moulding in the earlier experiments [10,11], see figures 2 and 3.

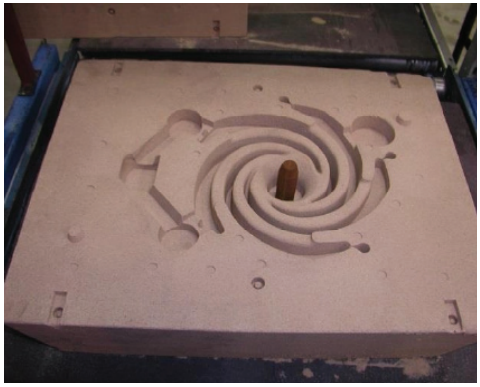
The silica sand with particle size (MK) of 0.27 mm (AFS 57) was mixed with a resin (content of 2.3 % based on the weight of the sand). Table 1 shows some parameters

Slika 1. Ulit strojni del – sesalna turbina

Figure 1. The casting component "Impeller"

Slika 2. Adapter z modelom

Figure 2. Adapter with the pattern



Slika 3. Spodnji okvir forme

Figure 3. The lower mould

(adapter) je bil izdelan v enaki obliki, kot se je uporabila pri prejšnjih poskusih formanja v maski [10, 11], sliki 2 in 3.

Kremenov pesek z velikostjo zrn (MK) 0,27 mm (AFS 57) je bil zmešaqn z 2,3 % smole glede na maso peska. Razpredelnica 1 kaže nekatere parametre smole, ki se je uporabila za poskusne ulitke.

Forma je bila 508 mm dolga in 455 mm široka, toda višini spodnje in zgornje sta bili različni, kot se vidi iz razpredelnice 2.

of resin used for preparing the examined castings.

Each mould had length of 508 mm and width of 455 mm but the height of the lower and upper mould were various, see Table 2. The reason to have different height of the lower and upper mould was to have different cooling rates.

For each different height of the mould 25 castings were moulded. To have a better emission of gases from the mould, two air

Razpredelnica 1. Lastnosti smole, ki se je uporabila za izdelavo poskusnih ulitkov

Table 1. Properties of the resin used for preparing the examined castings

Ime smole / Resin name	Tehnične lastnosti / Technical specification				
	viskoznost / viscosity @ 25°C, cps	gostota / density [funti na galono / pounds per gallon]	pH	prosti formaldelhid / free formaldelhyde [%]	prosti fenol / free Phenol [%]
XXX	620	13.00	14.00	<0.1	<1.0

Razpredelnica 2. Višina form pri poskusih.

Table 2. The height of the mould used in the experiments

Ime / Name	Poskus / Experiment								
	A	B	C	D	E	F	G	H	I
Spodnja forma / Lower mould [cm]	11	16	11	16	20	16	20	11	20
Spodnja forma / Upper mould [cm]	11	11	16	16	16	20	20	20	11

Razpredelnica 3. Kemijske sestave osnovnih talin. Ogljikov ekvivalent v % = 12.33(% C)+0.55(% Cr)-15.2

Table 3. The chemical composition of the base melt. %E.C. = 12.33(% C)+0.55(% Cr)-15.2

Talina / Melt	Element v mas. % / Element in % (mass fraction)							C ekv. / %E.C. [%]	razmerje / ratio Cr/%C	litje temp. / pouring temp [°C]
	C	Si	S	P	Mn	Ni	Cr			
I	2,93	1,60	0,03	0,03	0,28	0,26	25,52	34,96	8,71	1540
II	2,91	1,59	0,03	0,03	0,29	0,27	25,50	34,71	8,76	1542
III	2,90	1,60	0,03	0,03	0,30	0,27	25,51	34,59	8,80	1538

Vzrok, da sta bili uporabljeni različni višini spodnje in zgornje forme, je bila različna ohlajevalna hitrost.

V vsaki formi različnih višin je bilo zaformanih 25 ulitkov. Za boljše odzračenje forme sta bila v vsak napajalnik zvrtana dva zračnika premera 15 mm. Zgornja in spodnja forma sta bili zlepljeni skupaj z lesnim lepilom.

Vložek se je talil v visokofrekvenčni peči. Napravili smo tri serije poskusnih ulitkov. Kemično sestavo smo ugotavljali s svetlobnim emisijskim spektrometrom ARL 3460. Kemične sestave talin in livne temperature prikazuje razpredelnica 3. Talina I se je uporabila za ulitke A, B, C, talina II za poskuse D, E in F in talina III za poskuse G, H in I.

Vseh poskusnih ulitkov je bilo 225, da smo dobili solidno statistično osnovo za ovrednotenje učinka različnih ohlajevalnih hitrosti na livarske napake.

directions are drilled in each feeder with a drill of 15 mm in diameter. The gluing of the lower and upper mould was made with wood glue.

Melting was done in high frequency furnace. A three series of casting experiments were carried out. The chemical compositions were determined by the light emission spectrometer - ARL 3460. The chemical compositions of the base melts for the castings and pouring temperature is shown in Table 3. The Melt I was used to cast the experiment A, B, C. The Melt II was used to cast the experiment D, E and F. The Melt III was used to cast the experiment G, H and I.

All the casting experiments yield a total 225 castings, thereby providing a sound statistical basis for evaluation of the effect of different cooling rates on the casting defect.

3 Rezultati in razprava

3.1 Livarske napake

Po peskanju smo ulitke preiskali najprej vizualno, nato s tekočino po standardu EN 1371-1:2011. Rezultate prikazuje razpredelnica 4.

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 4.

Razpredelnica 4. Statistični pregled livarskih napak na ulitkih

Table 4. Statistical listing of casting defects found on the castings.

Livarska napaka / Casting defect	Poskus / Experiment								
	A	B	C	D	E	F	G	H	I
Razpoke v vročem / Hot tearing	16 %	12 %	12 %	4%	8%	8%	4%	8%	12 %
Žilaste razpoke / Veining	-	-	-	4%	8%	12 %	16 %	12 %	8%

Slika 4. Ulita sesalna turbina z žilastimi razpokami

Figure 4. The casting component "Impeller" with the casting defect veining

Vroče razpoke so se pogosto pojavile na istih mestih strojnega dela kot pri prejšnjih poskusih. [10,11]. Pri poskusih, ko smo preiskovali vpliv ohlajevalne hitrosti na vroče pokanje, smo opazili, da je nastala druga vrsta livarskih napak – žilaste razpoke (slika 4).

The hot tearing often occurs in same locations on the component like earlier experiments [10,11]. In the experiments made to investigate the influence of the cooling rate on the hot tearing, another type of castings defect had seen to be formed, called veining, see figure 4.

3.2 Mechanical Testing

The hardness tests were performed on each casting component in according to SS-EN ISO 6508:2006. In table 5 the average value for all measurements are shown.

3.3 Casting Simulation

A series of simulations were performed with the casting simulation programme MagmaSoft® using the add-on module MagmaIron®, especially developed for cast iron simulation. The “Impeller” with its gating system was modeled for the simulation. In the simulation, the mould filling sequence as well as the solidification sequence was

Razpredelnica 5. Povprečna vrednost trdote po Rockwellu, HRC

Table 5. The average value of hardness measurements in Rockwell, HRC

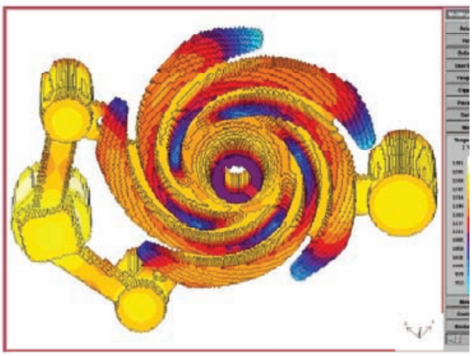
Stanje / Condition	Preskus / Experiment								
	A	B	C	D	E	F	G	H	I
Neobdelano / Untreated	52	51	51	50	49	48	45	46	46

3.2 Mehanski preizkusi

Trdoto vsakega ulitka smo izmerili po standardu SS-EN ISO 6508:2006. Razpredelnica 5 prikazuje povprečne vrednosti vseh meritev.

3.3 Simulacija litja

Napravili smo vrsto simulacij s programom MagmaSoft® za simulacijo litja ob uporabi dodatnega modula MagmaIron®, ki je bil posebej razvit za simulacijo železove litine. Za to simulacijo smo izdelali poseben model sesalne turbine z ulivnim sistemom. S simulacijo smo zasledovali potek zapolnjevanja forme in potek strjevanja. Slika 5 kaže 3-D posnetek iz simulacije, ko je bilo strjeno 50 % taline v formi.



Slika 5. 3-D posnetek iz simulacije, ko je bilo strjeno 50 % taline v formi

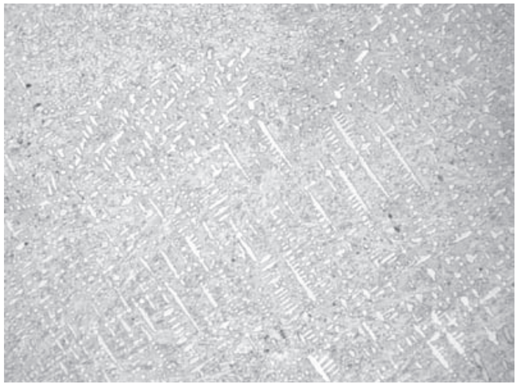
Figure 5. 3-D result from the simulation showing temperature when 50 % of the mould is solidified

3.4 Mikrostrukturna analiza

Da bi preiskali, če se je mikrostruktura spremenila pri posameznih preskusih ulivanja, smo iz vsakega ulitka vzeli vzorec

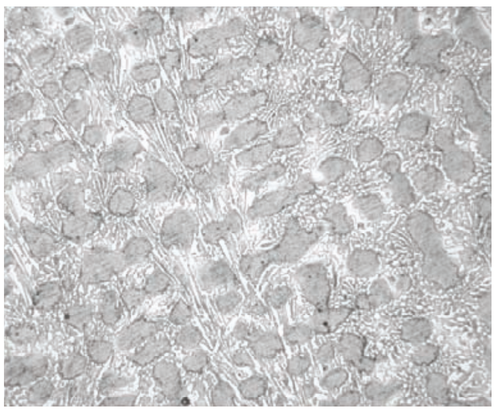
considered. Figure 5 shows 3-D result from the simulation showing temperature when 50% of the mould is solidified.

3.4 Microstructure Analysis



Slika 6. Mikrostruktura sesalne turbine iz poskusa D (povečava 100 x)

Figure 6. The microstructure of the “Impeller” from experiment D (magnification 100X).



Slika 7. Mikrostruktura sesalne turbine iz poskusa G (povečava 200 x)

Figure 7. The microstructure of the “Impeller” from experiment G (magnification 200X).

To investigate whether there were differences in microstructures between different test castings, an example from za mikroskopsko preiskavo. Obruse smo pripravili z brušenjem in poliranjem ter jih preiskali s svetlobnim mikroskopom. Jedkali smo z Kallingovim jedkalom št. 2 (5 g $CuCl_2$, 100 ml klorovodikove kisline in 100 ml etanola) pri sobni temperaturi. Slika 6 kaže značilen primer mikrostrukture iz poskusa D in slika 7 značilen primer mikrostrukture iz poskusa G.

4 Sklepi

Poskusi so pokazali, da ohlajevalna hitrost nima pomembnega vpliva na pokanje v vročem.

Najhujši primeri pokanja v vročem so bili pri poskusu A.

Rezultati kažejo, da smo najboljše rezultate, kar se tiče pokanja v vročem, dobili pri poskusih D in G, le 4 % pri obeh poskusih. Pri poskusu G z najvišjo spodnjo in zgornjo formo smo ugotovili veliko nagnjenost k nastajanju drugih livarskih napak, nastajanju žilastih razpok.

S simulacijo je možno ugotoviti območja, kjer je verjetnost nastajanja razpok v vročem.

Mikroskopska preiskava ni pokazala razlik med različnimi poskusnimi ulitki.

5 Zahvale

Avtor se želi zahvaliti Linnaeus univerzi, Tehnološki fakulteti, Oddelku za strojništvo, Växjö, Švedska.

Zahvala tudi moji čudoviti ženi Muvehidi in najinima sinovoma Mahirju in Eminu za njihovo neskončno potrpežljivost in znatno podporo v času raziskave. Brez njihovega spodbujanja tega dela ne bi bilo možno narediti.

each casting was 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 (CuCl2 5 g, Hydrochloric acid 100 ml and Ethanol 100 ml) at room temperature. Figure 6 shows some typical examples of the microstructure from the experiment D. Figure 7 shows some typical examples of the microstructure from the experiment G.

4 Conclusions

The experiments showed that the cooling rate has an important influence on hot tearing. The worst cases of hot tearing were obtained with experiment A.

The experiments show that the best results regarding hot tearing have been obtained in experiments D and G, only 4 % for both two experiments. However, in experiment G with the highest lower and upper mould is obtained a large tendency to other casting defect, veining.

By simulation it is possible to detect the areas where hot tearing is likely to be formed.

The microscopic examination doesn't show any deviations between the different test castings.

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