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ISSN 0543-5846
METABK 49(1) 45-48 (2010)
UDC – UDK 621.74:669.131.6:621.771.073.8:536.24=111

THE EFECT OF COOLING RATE ON THE PROPERTIES OF ALLOYED CAST-IRON SIZING ROLL

Received – Prispjelo: 2008-12-24
Accepted – Prihvaćeno: 2009-03-26
Preliminary Note - Prethodno priopćenje

Directional heat transfer was investigated by temperature measurements in the casting and in the mould using thermocouples. Measurements were performed in operating conditions during pouring, solidification, and cooling of the casting. Total measurement time was 35,5 hours. After cutting, specimens were extracted for metallographic and hardness testing. Test results provided confirmation of directional heat transfer (directional cooling) that would ensure acquirement of a desired casting structure and mechanical properties.

Key words: alloyed grey cast iron, sizing roll, indefinite chill, moulding technology, thermocouple temperature measurement

Utjecaj brzine hlađenja na svojstva kalibrirnog valjka od legiranog željeznog lijeva. Usmjereni prijenos topline u odljevku i kalupu praćen je mjerenjem temperature termoparovima tijekom ulijevanja taljevine u kalup, skrućivanja i hlađenja odljevka. Ukupno trajanje mjerenja iznosilo je 35,5 sati nakon čega je odljevak izrezan i uzeti su uzorci za metalografsku analizu i mjerenje tvrdoće. Rezultati ovih ispitivanja potvrdili su usmjereno odvođenje topline (usmjereno hlađenje) što osigurava dobivanje željene mikrostrukture i mehaničkih svojstava odljevka.

Ključne riječi: legirani sivi lijev, kalibrirni valjak, nedefinirano zahlađeni sloj, tehnologija kalupljenja, mjerenje temperature termoparom

INTRODUCTION

Operational conditions in iron and steel rolling mills in Croatia have imposed the need for use of sizing rolls of own production. The rolls are characterized by a working surface depth of up to 250 mm. Rolling is done by means of the cylinder shell and lateral surfaces [1]. Because of exposure to compression stress at elevated temperatures (820–850 °C) during operation the rolls must possess a microstructure that will ensure high resistance to wear and thermal fatigue as well as good machinability of the crude cast roll.

High resistance to thermal fatigue requires high thermal conductivity which is achieved by means of the presence of flake graphite in the microstructure. The graphite presence is also essential for good machinability. On the other hand, high wear resistance calls for the presence of hard carbides in the microstructure. Bearing all this in mind and taking into account the fact that a roll of specific dimensions and weight is expected to have a machined working surface hardness of about 380 HB, which drops gradually to about 280 HB towards the roll interior, it was examined the compositions, microstructures, and hardness values of the available rolls of comparable size. Based on the test results a conclusion was reached to use alloyed grey cast iron for roll casting in order to generate an indefinite chill structure where the amount of eutectic carbides would gradually decrease going from the roll working surface to the interior, and conversely, the proportion of flake graphite would grow with the distance from the working surface. The hardness values along the roll cross-section would change accordingly [2].

The fact that the casting microstructure is directly dependent on the average cooling rate has been well documented [3–6]. It follows that to achieve an adequate coooling rate for the roll working surface suitable conditions have to be generated. The moulding technology applied in experimental casting [2] failed to ensure a sufficiently high melt cooling rate in the border zones of the casting so that the carbide content of the sizing roll working surface was too low. On the other hand, due to a lower cooling rate of the melt in the central casting zones, the concentration of carbide-forming elements increased in the last solidified melt volume. As a result, major excretion of carbon in the form of carbides took place in the direction of the thermal centre of the casting. Hardness testing carried out along the sizing roll cross-section proved the predicted solidification order to be correct. Tests showed that the recorded hardness values of the sizing roll working surface exceeded the required value (400 HB), and that, instead of becoming

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Table 1. **Chemical composition of the alloyed cast iron melt / wt.%**

Element	C	Mn	P	S	Si	Cr	Cu	Ni	Mo	V
Previous composition	2,19	0,58	0,026	0,05	0,96	0,72	0,35	1,20	0,09	-
Modified composition	2,55	0,38	0,23	0,063	1,23	0,44	0,17	1,33	0,17	0,14

lower, they grew higher towards the interior. This was taken to be the consequence of discordance between the cast iron chemical composition and the moulding technology applied.

The aim of the investigation was to examine, by experimental casting, an altered composition of alloyed grey cast iron and a modified moulding technology in comparison with those refered to in [2], and also to identify the changes that had taken place in the microstructure and in the hardness of the the sizing roll working surface.

CASTING TECHNOLOGY MODIFICATION

Modifications of the casting technology related to those of the mould. The chromite sand core was reduced to only one half of the sizing roll circumference (Figure 1).

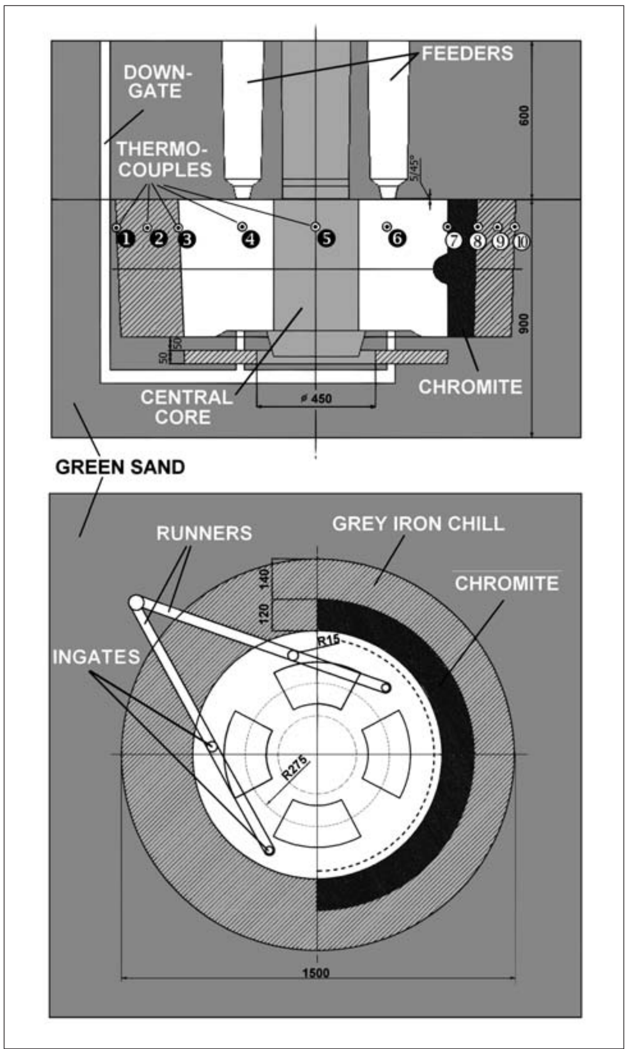

Figure 1. Schematic view of the sizing roll mould and thermocouple positions

The core thickness was also diminished. At the opposite side of the sizing roll circumference there was an external metal core – a chill. A direct contact of the melt with the chill was supposed to enhance the cooling effect by producing a heat release that would help directional solidification and thus make a better control of the microstructure possible [7]. In addition to mould modification the chemical composition of alloyed grey cast iron was also altered. The chemical compositions of the melt, the one used earlier [2] and the altered one, are comparatively shown in Table 1. The idea was to promote further the formation of carbides.

MEASURING EQUIPMENT AND RESULTS

For temperature measurements a NI4350 high-precision temperature and voltage meter of the plug-and-play type was used. It was connected to a computer with the Windows 2000 operating system and a Virtual Bench software package for data processing, displaying and storing. Thermocouples were connected to a NI4350 Data Logger. Table 2 shows their characteristics and locations in the mould. All thermocouples were in direct contact with the melt (TC3, TC4, TC6, TC7) were inserted in ceramic tubes for protection against damage and to ensure steady measurement during the entire period of solidification and cooling of the casting.

Figure 2 shows cumulative results of temperature measurements. The curves in Figure 3 refer specifically to the thermocouples TC1, TC2, TC9, and TC10. An almost total overlapping of the cooling curves noticeable for the thermocouples TC3, TC4, TC6, and TC7 was expected, because they were immersed in the melt. More prominent differences can be observed between the

Table 2. **Thermocouples used in measurements**

No.	Data Logger Channel	Thermocouple type	Location	ANSI designation
TC1	*Ch02*	Fe-Constantan	Chill	J
TC2	*Ch03*	Ni-CrNi	Chill	K
TC3	*Ch04*	PtRh	Chill/Melt	R
TC4	*Ch05*	PtRh	Feeder/Melt	R
TC5	*Ch06*	Ni-CrNi	Central core	K
TC6	*Ch07*	PtRh	Feeder/Melt	R
TC7	*Ch08*	PtRh	Chromite /Melt	R
TC8	*Ch09*	Ni-CrNi	Chromite /Chill	K
TC9	*Ch10*	Fe-Constantan	Chill	J
TC10	*Ch11*	Fe-Constantan	Chill	J

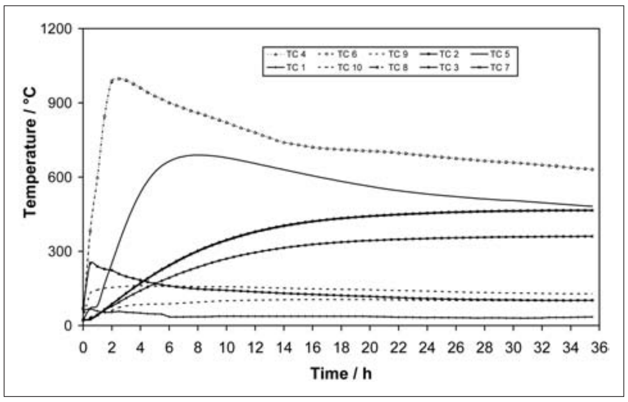

Figure 2. Measured temperature curves

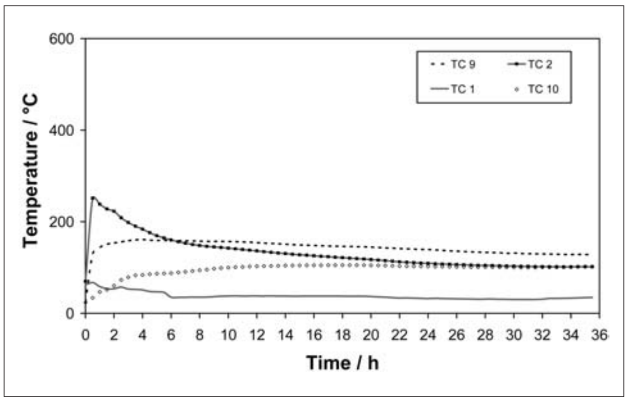

Figure 3. Measured temperature curves for thermocouples 1, 2, 9, and 10

cooling curves for the thermocouples at positions 2 and 9 in Figure 3. A steeper rise of the TC2 curve in the first half hour of measurement as compared to the TC9 curve can be explained by a more intense heat transfer through the grey iron chill. After six hours of cooling the heat flow at that position equals the heat flow through the chromite core and the grey iron chill, and then it begins to decrease. The TC9 curve, on the other hand, reflects a uniform and steady heat flow with a slight decrease with time.

Figure 3 also shows the cooling curves for positions 1 and 10, i.e. for the thermocouples TC1 and TC10, which were located on the outer part of the grey iron chill. The curves can be taken to best reflect the differences in conduction heat transfer between the right side of the mould with the chromite core on it and the opposite side without the chromite core.

The TC1 curve demonstrates a fast increase in temperature over the melt casting/mould filling period followed by a continuous descent. The TC10 curve, on the other hand, reflects a somewhat slower increase in temperature in the mould filling period but a much slower temperature decrease with time than the TC1. This is due to the effect produced by the chromite core on conduction heat transfer.

The temperature data collected during the casting and solidification of the melt allow to conclude that the presence of the chromite core on one half of the grey iron chill ensured control over the intensity of heat conduction as one of the prerequisites for achieving a desired sizing roll microstructure.

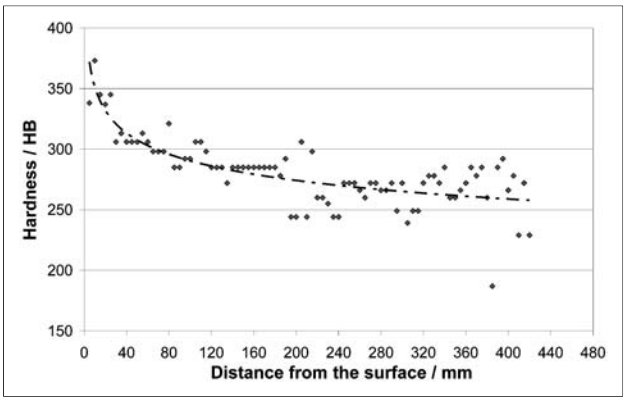

Figure 4. Hardness test results

Hardness measurements were conducted using a Wolpert-Werk type DTA 2R hardness tester on the samples cut from the sizing roll at different locations i.e. depths. From the diagram in Figure 4 it is evident that there is a non-linear decrease in hardness with the distance from the sizing roll working surface. Higher hardness values for the sizing roll surface can be accounted for by iron carbide formation as a result of the high cooling rate.

The samples prepared metallographically were examined by means of a Reichert MeF2 optical microscope at 200 × magnification. Figures 5a, 5b, and 5c show the microstructure of the nital etched samples at different depths.

Careful examination of the figures shows the carbon fractions that precipitated partly as carbides and partly as lamellar graphite to depend on the cooling rate during eutectic solidification. The shape and the portion of the precipitated graphite vary with the distance from the sizing roll surface. The working surface of the sizing roll has a mottled microstructure. The fraction of cementite gradually decreases with the distance from the surface, while the graphite fraction increases accordingly. The matrix structure is fully pearlitic and its constituents testify to a directional, partly metastable solidification of alloyed cast iron.

From the hardness test results and the data concerning the sizing roll microstructure it can be concluded that a good conformity between the chemical composition and the moulding technology has been achieved.

CONCLUSIONS

From the temperature records it is evident that the use of the chromite core on one half of the chill ensured control over the conduction heat flow rate as a prerequisite for obtaining a right microstructure and proper mechanical properties of the casting. The grey iron chill proved to be advantageous over a steel one owing to better heat conduction, higher resistance to thermal

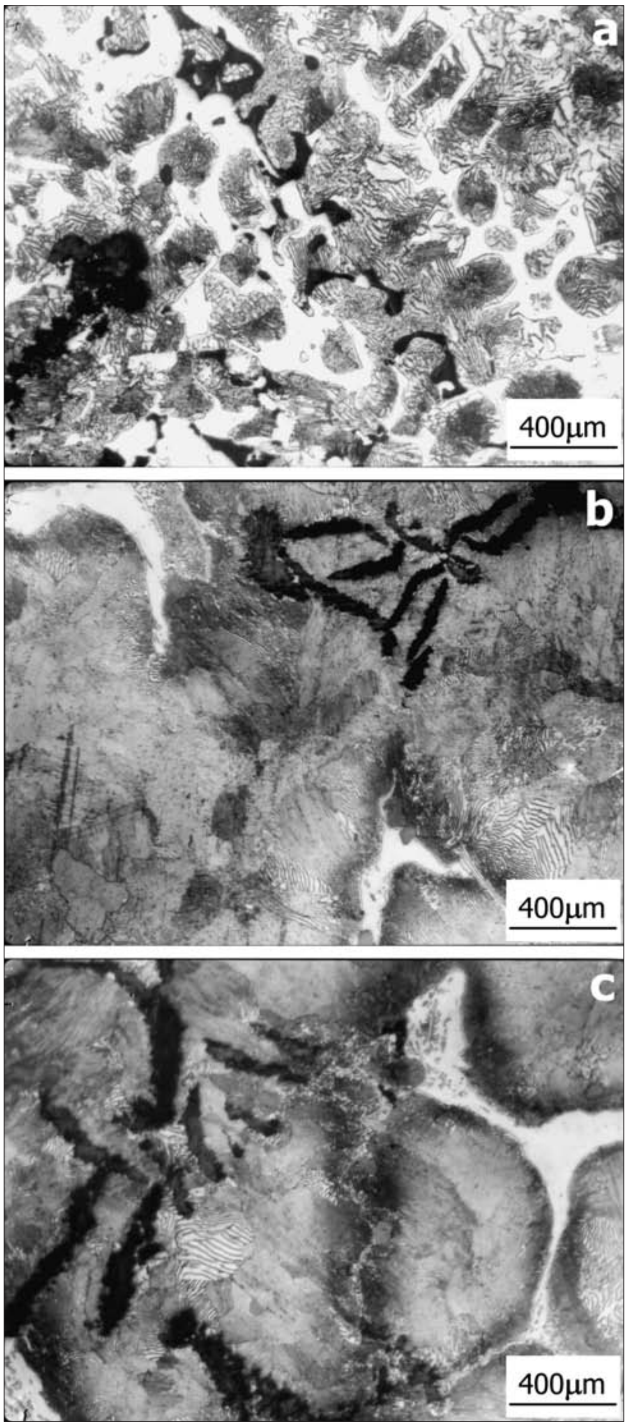

Figure 5. Microstructure of etched sizing rollsamples:
a) at the surface,
b) at the depth of 200 mm,
c) at the depth of 400 mm.

shocks, and higher dimensional stability at temperature changes.

Hardness and metallographic tests eventually confirmed predictions and showed soundness of the modifications made in the casting technology and in the chemical composition of the melt. A high cooling rate induced carbide formation in the surface and near-surface areas of the sizing roll. The graphite content increased and the carbide content decreased with the distance from the surface, because of a lower cooling rate, i.e. a slower heat transfer.

The resultant matrix structure was a pearlitic one. The quantity of eutectic carbides gradually decreased with the distance from the sizing roll surface to the interior, while the proportion of flake graphite increased with the distance from the surface. The volume fractions of microstructural constituents and their distribution ensured proper hardness value distribution throughout the sizing roll.

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Acknowledgements – The authors wish to thank *Felis d.o.o. for production castings*, Sisak, Croatia, for providing help during the research.

Note: The language lecturer for Englich language is prof. Neda Banić