Journal of Materials Processing Technology 217 (2015) 262–271

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Thermal distortion of disc-shaped ductile iron castings in vertically parted moulds

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ARTICLE INFO

Article history:
Received 26 March 2014
Received in revised form 15 October 2014
Accepted 11 November 2014
Available online 20 November 2014

Keywords:
Dimensional accuracy
SG iron
Feeder and riser
Machining allowance
Si content
Thermal gradient

ABSTRACT

A disc-shaped casting with an inner boss and an outer rim, separated by a thin walled section, was examined. This measurable deformation varied with the feeding modulus. The influence of alloy composition, particularly Si content, was examined with a pearlitic ductile iron (EN-GJS-500-7) and a fully ferritic ductile iron (EN-GJS-450-10).

The experiment showed that both the alloy composition and choice of feeder influenced the degree of deformation measured in the finished casting. It was found that the deformation of the pearlitic alloy was influenced controllably by changing the feeder modulus, whereas the deformation of the fully ferritic alloy was less affected by a change in thermal gradient. Both alloys underwent comparable deformations with respect to size, shape, and location.

1. Introduction

Working with grey cast iron and steel, Jackson (1963) showed why casting precision was more than just a distance between a finite number of working faces, but more importantly also a concern with regards to eliminating excess machining and grinding. Jackson's paper also discussed the influence of alloy composition, casting geometry, and thermal gradients on the dimensional variation of the castings. Demonstrating that free linear contraction was inversely related to the section modulus, Mkumbo et al. (2002) also reported a correlation between the modulus and shape of the casting and modelled how flanges affected this. Likewise, Motoyama et al. (2013) examined the effect of flanges and showed how residual stress and distortion develop during solidification and cooling of the casting, and that these were affected by the casting geometry and the strength of the sand mould.

The idea of counteracting distortion by modifying the pattern geometry was suggested by Kang et al. (2011) who also proposed machining allowance as a parameter for distortion reduction. This requires precise measurements and an understanding of the casting's dimensional change and surface finish. As part of their development of an improved model for a sand surface element, Chang and Dantzig (2004) described how the green sand mould itself was deformed by the contraction of the casting, and how that left the casting unconstrained by the mould. Subsequently, Nwaogu et al. (2013) described how to characterise the surface of ductile iron castings, and provide some guidance as to which types and sizes of surface roughness can be expected with and without coating.

Mkumbo et al. (2002) showed that ductile iron, even with a higher CEV, displayed greater contraction than grey iron, and variations in dimensional change between pearlitic and ferritic alloys were demonstrated by Sosa et al. (2004). They worked with ADI to show that a ferritic microstructure displayed greater dimensional stability than a pearlitic microstructure, and that a ferritic-pearlitic structure was even more prone to dimensional change.

Distortion of castings made under production conditions were investigated to quantify the reproducibility of large scale manufacturing facilities.

This paper presents a detailed analysis of the changes in thermal distortion of a disc-shaped casting, examined with respect to a number of different spot feeder and top feeder combinations, tested for both a ferritic-pearlitic and a fully ferritic alloy, and correlated to the cooling curves and austenite to ferrite phase transformation at various measurement positions (MP) in the casting.

Abbreviations: ADI, austempered ductile iron; CEV, carbon equivalent value; CMM, coordinate measuring machine; M_g, geometric modulus; LGI, Lamellar graphite iron; MP, measurement position; MEF, modulus extension factor; PPI, pores per inch; SGI, spheroidal graphite iron; TC, thermo couple; M_t, thermal modulus.

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http://dx.doi.org/10.1016/j.jmatprotec.2014.11.025
0924-0136/

Table 1
Casting geometry in mm and moduli in mm.

Section	T.Rim	U.Sec	Boss	L.Sec	B.Rim
Height	27.5	55	55	55	27.5
Thickness	20	10	30	10	20
Modulus	6	5	9	5	6
Feed modulus	7	6	11	6	7

Table 2
Material and modulus for the feeders used as top and centre feeder respectively.

Feeder	Top		Centre					
	1	2	1	2	3	1s	2s	3s
Material	Ins	E/I	Ins	E/I	Exo	Ins	E/I	Exo
Modulus [mm]	9	10	11	11	12	9	10	11

2. Methods

2.1. Casting geometry

The casting design was circular with a diameter of 220 mm, with an outer rim and an inner boss. See Figs. 1 and 2. The circular design provided a casting that was mirrored thermally about a vertical plane through its centre, so that any distortions that were not symmetrical must originate from the thermal imbalance in the casting caused by the feeders and the filling. See Table 1 for the dimensions and moduli of the different casting sections.

2.2. Feeder placement and modulus

One feeder was mounted at the mould parting line, at the top of the casting. See Fig. 1. The second feeder was mounted onto the centre boss, and placed slightly above the centre to provide better ferro-static pressure for feeding. Ram-up sleeve feeders were used for the centre feeder.

In the experiment, different sleeve materials were used for the feeders—insulating (1), exothermic-insulating (2), or purely exothermic (3). Using sleeves made from different materials (1,2,3) it was possible to change the modulus of the feeder while maintaining a constant geometric size and ferro-static pressure. It was also possible to remove the feeder altogether, but this change also entailed a change in ferro-static pressure. An overview of the feeder moduli is given in Table 2.

Distinction was made between the geometric modulus (M_g) of the feeder and the thermal (or true) modulus (M_t) of the feeder. This distinction was required because the sleeves covering the melt in the feeders changed the basic modulus relation $M_g = V/A$, with the addition of the Modulus Extension Factor (MEF). As described by Brown (2000), the modulus equation for the feeders could thus be stated as $M_t = \text{MEF} \times M_g$, allowing changes to the thermal modulus while keeping the geometric modulus and the ferro-static pressure constant.

2.3. Alloys and feeder combinations

The 16 different combinations were distinguished by four parameters; (1) alloy, (2) top feeder (or parting line feeder), (3) centre feeder (or boss feeder), and (4) size variations for the centre feeder. This gave 36 possible combinations, of which 16 were cast as part of the experiment. See the combinations in Table 4. Each of the combinations were cast in triplicate for statistical analysis. Additionally two castings were fitted with 11 thermo couples (TC) to measure the temperature of the different areas of the casting during solidification (TC-castings). The four parameters are elaborated below:

Table 3
Alloy compositions for α (EN-GJS-500-7), β (EN-GJS-450-10), and τ (Temperature Measurements) [wt%].

Alloy	C	Si	Mn	P	S	Mg	Cu
α	3.67	2.73	0.50	0.015	0.005	0.049	0.025
β	3.35	3.48	0.34	0.017	0.003	0.046	0.010
τ	3.20	3.71	0.27	0.044	0.028	0.048	0.081

Table 4
The 16 combinations sorted by alloy, top feeder, centre feeder. (x) indicate M_t in mm.

Alloy	Top Feeder		Centre Feeder			Size
α	0	(0)	0	(0)		
α	0	(0)	2	(11)		
α	1	(9)	1	(11)		
α	1	(9)	2	(11)		
α	1	(9)	3	(12)		
α	2	(10)	0	(0)		
α	2	(10)	1	(11)		
α	2	(10)	2	(11)		
α	2	(10)	3	(12)		
β	1	(9)	1	(11)		
β	1	(9)	2	(10)	s	(Small)
β	2	(10)	0	(0)		
β	2	(10)	1	(9)	s	(Small)
β	2	(10)	3	(12)		
β	2	(10)	3	(11)	s	(Small)
τ	2	(10)	3	(12)		

(1) The castings were made using three different alloys—one pearlitic EN-GJS-500-7 (labelled α in Table 4) and one purely ferritic EN-GJS-450-10 (labelled β in Table 4), both as defined by EN 1563:2012-3 (2012). The alloy used for the TC-castings was made to be a fully ferritic alloy (labelled τ). See alloy composition in Table 3.
(2) The top feeders were all identical in size and were only varied by using either insulating (labelled 1 in Table 4) or exothermic-insulating material (labelled 2 in Table 4) for the sleeve. In one experiment this feeder was removed altogether, indicated as 0 in Table 4.
(3) The centre feeders had the same basic options as the top feeder (0,1,2), but could also be purely exothermic (3). The geometric moduli of the top and centre feeders are different, thus the number-designation indicates sleeve material and not moduli as is shown in Table 2.
(4) Additional information regarding the centre feeder configuration. When appended with an *s* for small, it indicates that the feeders' geometric modulus was reduced to the same size as that of the top feeder, which in turn also reduced the thermal modulus compared to the other centre feeders using the same sleeve material.

2.4. Production

The castings were produced on a vertically parted moulding machine—Disamatic 230A—as part of a production run in an operating foundry.

The poured weight was approximately 8 kg and the castings themselves weighed 4 kg. The pouring time was approximately 3.5 s and the three series were poured at; (1) 1401 ± 5 °C, (2) at 1408 ± 5 °C, and (3) at 1392 ± 5 °C.

The castings solidified and cooled in the mould for approximately 1 h and were then separated from the other goods at the