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C, Si and Ni as alloying elements to vary carbon equivalent of austenitic ductile cast iron: Microstructure and mechanical properties

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ABSTRACT

Successful casting of three groups of austenitic ductile irons was achieved covering a carbon equivalent (CE) range from 3.51% to 5.04%. The three groups implied the change of C, Si or Ni contents to control the CE%. In case of using Ni element to vary CE%, austenitic ductile iron could be obtained starting from 13.5% up to 34.7% Ni. Generally, the microstructure consisted of graphite nodules embedded in austenitic matrix. Nodule characteristics were affected by the variation of CE%. Nodularity was almost 100% for all tested specimens. Slight decrease in hardness and tensile strength (σ_u) was observed with increasing the CE%. 0.2% proof stress ($\sigma_{0.2}$) showed almost a constant value with increasing CE%. Tensile elongation was mainly increased with increasing CE% with different degrees owing to the alloying element (C, Si or Ni).

1. Introduction

Austenitic ductile cast irons are series of cast irons that contain nickel from 18 up to 36 mass%, having been treated with magnesium to bring about the formation of nodular graphite [1]. It contains sufficient nickel to produce an austenitic matrix structure similar to that of austenitic stainless steel. These irons have tensile strength ranging from 3870 to 5620 MPa, elongation from 4% up to 40% and Brinell hardness ranging from 1110 to 1710 MPa [1–6]. These high nickel alloyed ductile cast irons are made in a number of different compositions to produce the desired properties [1–3,7–13]. While conventional foundry practices are used for the production of Ni-resist ductile iron castings, special precautions, not normally used, must be taken into consideration. Treating and gating practices, and pouring temperature must be modified considerably from those used in conventional ductile iron production. For this reason, design engineers and Ni-resist ductile cast iron producers should review proposed casting designs if minimum cost and maximum product reliability are to be obtained [1]. Numerous data have been published about the production, microstructure and mechanical properties of austempered ductile cast iron (ADI) [1–7,14–19] and conventional ductile iron [1–7,20–31]. Few information [1–3,7–13] do exist for the production and properties of austenitic ductile iron in a narrow range of CE%. To fill this gap, the present investigation focused on studying the effect of CE% in a wide range, for austenitic ductile cast iron, on microstructure and mechanical properties. C, Si and Ni were, each solely, used as alloying elements to vary the CE% in the range 3.51–5.04.

2. Experimental procedure

Three heats (A, B and C) were prepared in a 90 kg high frequency (1000 Hz) induction furnace. Charges were low sulphur, low manganese, and low phosphor pig iron (Sorel metal) and steel scrap (cf. Table 1). Necessary amounts of Si, C and Ni were added to yield a Si-content 1.63–5.31 mass%, C-content 2.1–3.5 mass%, and Ni-content 4.99–34.70 mass%. Melts were superheated to 1773–1823 K. Magnesium treatment and inoculation were performed using the "Sandwich Technique" [1] for producing ductile cast iron. The ferrosilicon alloy containing 10% Mg was used in the spheroidising treatment. The heats were inoculated with 0.5 mass% of the charge with FeSi alloy (65% Si). The grain size of inoculants ranged from 1.5 to 3 mm. Pure Ni was melted with raw materials to get austenitic ductile iron in the as cast condition. Table 2 lists the actual chemical composition of all heats involved in this study. The melt was poured at a temperature ranging from 1620 to 1640 K into two different moulds to produce specimens for both chemical analysis and tests. A half-inch Y-block sand mould was used (cf. Fig. 1). Carbon

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Table 1
Chemical composition of the raw materials used to produce austenitic ductile cast iron in the present study.

Raw materials	Composition%						
	C	Si	Mn	S	P	Ni	Fe
Sorel metal	4.0	0.1	0.1	0.02	0.03	0.0	Balance
Steel scrap	0.16	0.15	0.6	0.02	0.03	0.0	Balance
Ferrosilicon	0.0	65.0	0.0	0.0	0.0	0.0	Balance
Carboriser	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Nickel	0.0	0.0	0.0	0.0	0.0	99	Balance

Table 2
Chemical composition of all heats of austenitic ductile cast iron produced in the present study.

Group symbol	Heat no.	Composition				
		C	Si	Ni	Mn	Mg
A	A1	2.11	2.12	19.77	1.40	0.043
	A2	2.31	2.07	19.44	1.40	0.041
	A3	2.53	2.11	19.41	1.40	0.045
	A4	2.71	2.08	19.70	1.40	0.050
	A5	2.95	2.12	19.54	1.40	0.045
	A6	3.16	2.14	19.41	1.40	0.053
	A7	3.29	2.08	19.52	1.40	0.048
	A8	3.42	2.16	20.02	1.40	0.059
B	B1	2.50	1.63	21.54	1.34	0.047
	B2	2.53	2.17	21.59	1.33	0.040
	B3	2.52	2.76	21.90	1.32	0.042
	B4	2.56	3.32	21.67	1.33	0.049
	B5	2.54	3.89	21.86	1.34	0.051
	B6	2.51	4.41	21.87	1.34	0.049
	B7	2.53	4.92	21.65	1.33	0.038
	B8	2.50	5.31	21.58	1.33	0.036
C	C1	2.90	1.86	4.99	1.77	0.045
	C2	2.85	1.82	9.09	1.72	0.069
	C3	2.79	1.84	13.50	1.48	0.061
	C4	2.80	1.85	16.10	1.56	0.065
	C5	2.83	1.75	19.80	1.71	0.051
	C6	2.78	1.79	23.90	1.60	0.063
	C7	2.77	1.85	30.40	1.59	0.067
	C8	2.91	1.83	34.70	1.39	0.062

Table 3
Effect of CE% on nodule-characteristics of all groups of austenitic ductile cast iron produced in the present study.

Group symbol	Heat no.	CE%	Nodule count nodule (mm^2)	Nodule size (μm)	Nodularity (%)
A	A1	3.51	80	15	80
	A2	3.69	125	28	100
	A3	3.91	125	25	100
	A4	4.1	125	25	100
	A5	4.34	70	20	100
	A6	4.55	220	25	100
	A7	4.67	220	25	100
	A8	5.04	220	25	100
B	B1	3.86	130	28	100
	B2	4	160	25	100
	B3	4.16	200	25	100
	B4	4.28	200	25	100
	B5	4.38	225	22	100
	B6	4.46	225	22	100
	B7	4.59	225	22	100
	B8	4.64	250	20	100
C	C1	3.7	125	28	100
	C2	3.79	200	10	100
	C3	3.9	250	15	100
	C4	4	180	15	100
	C5	4.15	200	15	100
	C6	4.26	250	15	100
	C7	4.49	250	15	100
	C8	4.8	250	15	100

equivalent was calculated according to the following formula [1]:

$$\text{C.E.} = \text{C\%} + 0.33\text{Si\%} + 0.047\text{Ni\%} - (0.0055\text{Ni\%} \times \text{Si\%})$$

Standard microstructure examination procedures for cast irons were used [3]. Vicker's hardness test was performed at room temperature of 298 K using Otto Wolpert Werk tester. Squared based diamond indenter (Angle 136°), with 125 kg load and 15 s duration was applied. Tensile tests were carried out according to ASTM (A370-2002). Specimens were machined to 5 mm gauge diameter and 30 mm gauge length. Tests were conducted in Instron universal testing machine connected to computer to draw the stress–strain curves and recording the tensile strength (σ_u), 0.2 proof stress

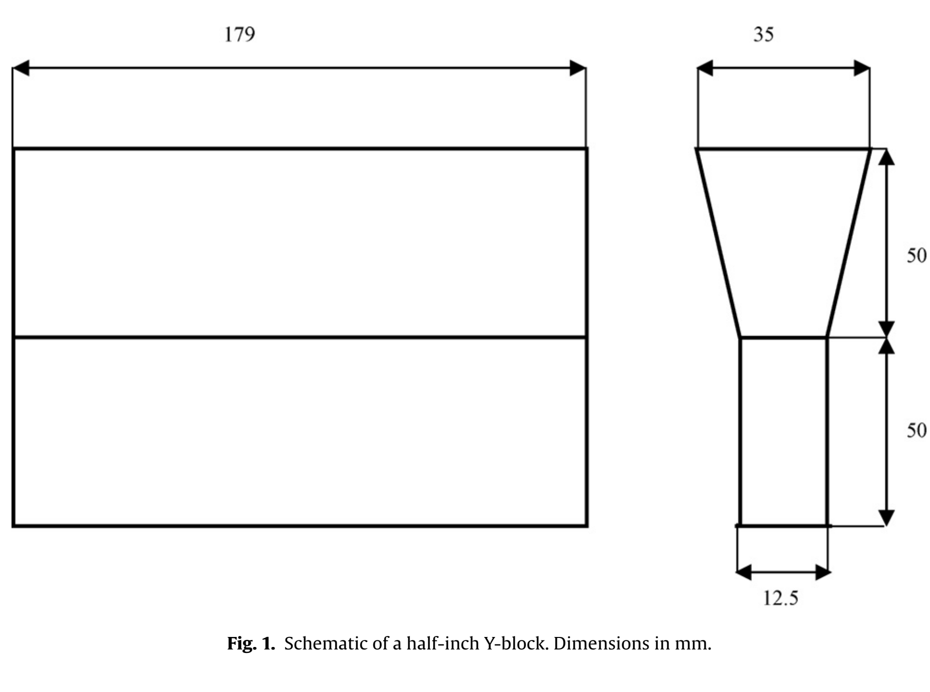

Fig. 1. Schematic of a half-inch Y-block. Dimensions in mm.