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Some Factors Affecting on the Structure-formation and Mechanical Properties of As-Cast High Toughness Nodular Cast Iron*

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ABSTRACT: Using sand moulds for step-shape casting tests and different silicon percentage of nodular cast iron it was possible to separate structural variations produced during freezing from those occurring at Ac_1 transformation temperature. The results show that an increase in silicon content leading to different variation in the matrix structure, leads to a changing mechanical properties of nodular cast irons. Tensile strength and elongation of obtained as-cast nodular cast iron with the composition of 3.9%C, 3.2%Si, 0.5%Mn are maximum of about 524.5N/mm^2 and 19.8% accordingly. In the same nodular cast iron, but only with 0.1%Mn the silicon addition first increases after decreases elongation, impact toughness and hardness. But tensile strength changes to the opposite side.

KEY WORDS: cast iron, ferritic structure, thin-wall casting

By varying the composition within the deformation limits, the wide variation in the microstructure and in mechanical properties of nodular cast irons can be obtained. Further structural changes for a fixed iron composition can be readily brought about by heat treatment. But this technology becomes more expensive. Relating the composition of these alloys to their mechanical properties is therefore arbitrarily selected melt and solidification treatment, as well as for the cooling conditions during freezing[1]. But there is the problem about selecting the chemical composition of as-cast nodular cast iron for production of thin-walled castings with ferritic structure and high elongation[2].

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It was our task to select suitable composition of as-cast nodular cast iron for production thin-walled castings of ferritic structure (more than 80% ferrite) with high mechanical properties, especially high elongation.

1 Experimental Methods

The alloy compositions were selected to examine the effects of silicon on the structure formation and mechanical properties of as-cast nodular cast iron with ordinary manganese content (0.5%). Master alloys were melted in acid lined induction furnace of the capacity 20kg. Silicon and magnesium alloy were added in a ladle, stirred, and the alloy poured in sand moulds for making of wedge-shape and step-shape castings with different thicknesses of 7,12, 30, 45, 60mm. All alloys were hypereutectic. The alloy compositions are given in Table 1.

Table 1 Chemical Composition of As-cast nodular cast iron

No.	Chemical composition, %						
	C	Si	Mn	S	P	Mg	C.E
1	3.9	2.8	0.5	0.010	0.058	0.062	4.83
2	3.9	3.2	0.5	0.010	0.058	0.056	4.97
3	3.9	3.4	0.5	0.011	0.045	0.051	5.03
4	3.9	2.8	0.1	0.011	0.045	0.054	4.83
5	3.9	3.0	0.1	0.012	0.045	0.056	4.90
6	3.9	3.2	0.1	0.010	0.045	0.053	4.97

2 Experimental Results and Discussion

2.1 Structure

Photographs of the microstructures of step-shape castings sections of 12mm and 7 mm with different composition of silicon and manganese are shown in Fig. 1. The graphite structure of the nodular cast iron in all cases was entirely spherulitic.

Castings section of 12mm with the ordinary composition of manganese (0.5%) and silicon of about 2.8% solidifies as ferrite-pearlitic structure (60% ferrite, Fig. 1, a). In spite of high cooling rate, due to low percentage of manganese (0.1%) the graphitization rate of similar to cast iron for castings section of 7mm is almost the same (65% ferrite). In both case, with the increasing of silicon content the process of ferritic structure formation is highly developed.

Castings sections of 12mm and 7 mm with the composition of 3.2% Si, 0.5% Mn and 3.0% Si, 0.1% Mn accordingly represent the ferritic structure of about 80% or more (Fig. 1, b). The results obtained in further investigation show that mechanical properties (especially elongation) of these compositions of as-cast nodular cast irons are maximums.

The amount of ferritic structure according to the wall-thicknesses in different sections of castings is tabulated in Table 2. The effect of cooling rate on the formation of ferritic structure is illustrated in Fig. 2.

In nodular cast iron with 0.5% Mn (Fig.2), by the increase of silicon content and thicknesses of castings the amount of ferritic structure is increased also. But for the cast iron with 3.4% Si a slight decreasing ferritic structure within 30-60 mm of casting thicknesses is observed. When silicon contents are 2.8% and 3.2% and thicknesses of castings section is more than 30mm such a reduction of the amount of ferritic structure is observed also for nodular cast iron with low manganese content (Fig.3). This phenomenon is probably connected with reverse segregation of chemical elements present in nodular cast iron.

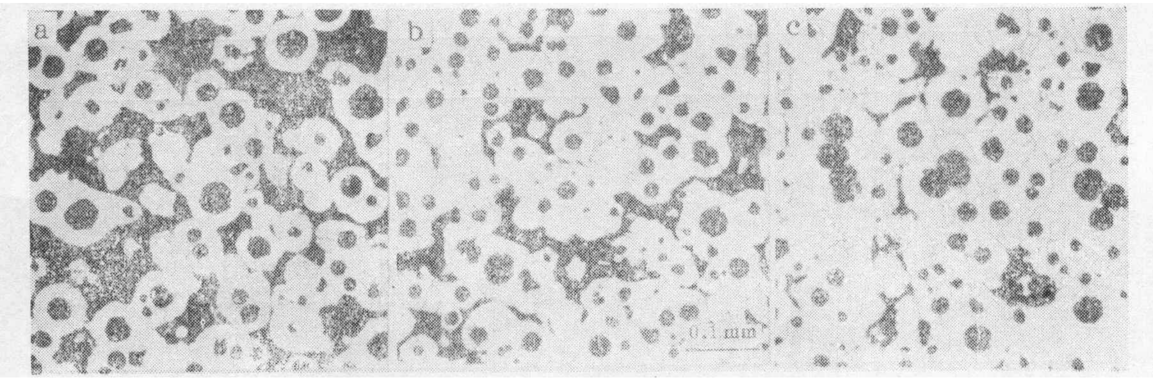

Fig.1 Microstructure of step-shape castings section of 12mm

a. 2.8% Si; b. 3.2% Si; c. 3.4% Si (Mn = 0.5%)

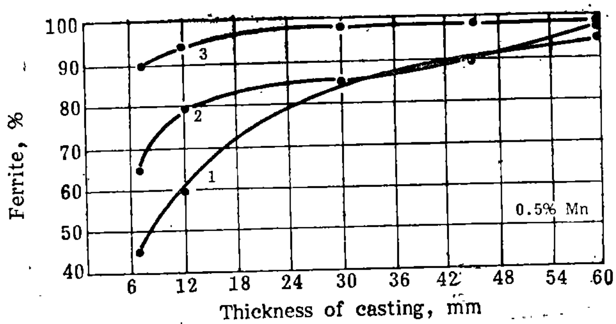

Fig.2 Effect of cooling rate on formation of ferritic structure (0.5% Mn)

(1) 2.8% Si, (2) 3.2% Si, (3) 3.4% Si

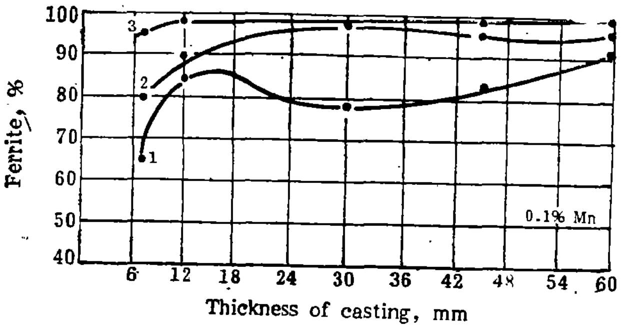

Fig.3 Effect of cooling rate on formation of ferritic structure (0.1% Mn)

(1) 2.8%Si, (2) 3.0%Si, (3) 3.2%Si

Table 2 Microstructural results

Nodular cast iron with manganese content of 0.5%				Nodular cast iron with manganese content of 0.1%			
Specimen	Silicon conten %	Thickness of casting mm	Ferrite, %	Specimen	Silicon conten %	Thickness of casting mm	Ferrite %
1	2.8	7	45	16	2.8	7	65
2	2.8	12	60	17	2.8	12	85
3	2.8	30	85	18	2.8	30	78
4	2.8	45	90	19	2.8	45	82
5	2.8	60	95	20	2.8	60	95
6	3.2	7	65	21	3.0	7	80
7	3.2	12	85	22	3.0	12	90
8	3.2	30	85	23	3.0	30	98
9	3.2	45	90	24	3.0	45	95
10	3.2	60	97	25	3.0	60	95
11	3.4	7	90	26	3.2	7	95
12	3.4	12	95	27	3.2	12	98
13	3.4	30	99	28	3.2	30	98
14	3.4	45	98	29	3.2	45	99
15	3.4	60	98	30	3.2	60	100

Comment: metallographic examinations carried out according to Chinese JB 1802—76.

Fig.4 and Fig.5 show how the ferritic structure is changed in difference thicknesses of step-shape castings with the increasing of silicon content in nodular cast irons. Changing silicon content in the range of from 2.8% up to 3.4%, the effectivenes of precipitation ferrite phases in small thicknesses of castings section (Fig.4, section 7mm and 12mm) is more higher than that in the larges ones (30, 45, 60mm). Intensification of ferritic structure formation for section 30, 45, 60 mm of cast iron with 0.5% Mn is almost the same within 2.8~3.2%Si (Fig.4).

This phenomenon may be explained by the weak action of low manganese content on the graphitization processes.

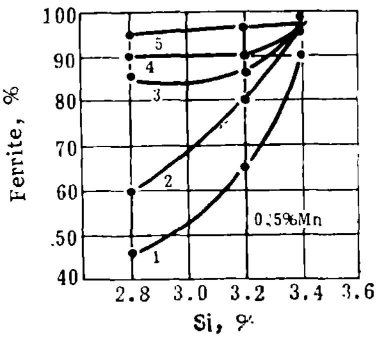

Fig.4 Effect of silicon on formation of ferritic structure; (0.5% Mn)

(1) 7mm, (2) 12mm, (3) 30mm, (4) 45mm, (5) 60mm

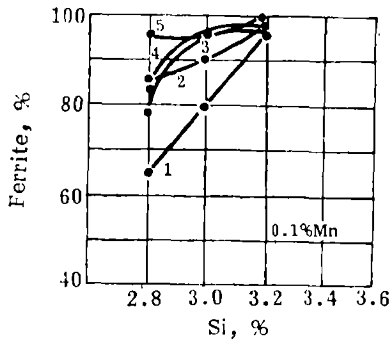

Fig.5 Effect of silicon on formation of ferritic structure; (0.1% Mn)

(1) 7mm, (2) 12mm, (3) 30mm, (4) 45mm, (5) 60mm,

2.2 Mechanical Properties

In each case of producing step-shape casting tests of different compositions for determination of structural changes, test bars of 25 mm wall-thicknesses were made simultaneously. These wedge-shape were intended for a further machining standard specimens for definition of mechanical properties.

The effect of silicon content on mechanical properties of nodular cast irons with 0.5% Mn and 0.1% Mn is illustrated in Fig. 6 and Fig. 7 respectively.

The results obtained show that an increase in silicon content which giving rise to different variation in the matrix structure leads to a change of mechanical properties of nodular cast irons. Increasing ratio ferrite to pearlite in nodular cast irons with 0.5% Mn by addition of silicon from 2.8% up to 3.4% leads first to an increase, followed by a decrease in elongation, tensile strength and impact toughness, while the hardness changes in the opposite direction (Fig.6). Tensile strength and elongation of this series nodular cast iron with 3.2%Si are maximum of about 524.6N/mm^2 and 19.8% respectively. In the second series nodular cast irons with 0.1% Mn, the silicon addition first increases after the decreases in elongation, impact strength and hardness, while tensile strength changes to the opposite side. Elongation and tensile strength of nodular cast iron containing 3.0% Si are about 23.6% and 485 N/mm^2 accordingly (Fig.7).

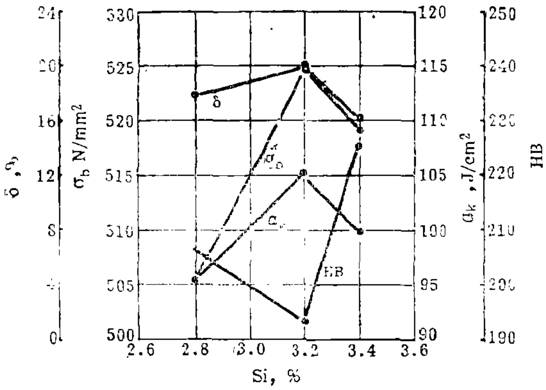

Fig.6 The effect of silicon content on mechanical properties of nodular cast irons with 0.5% Mn

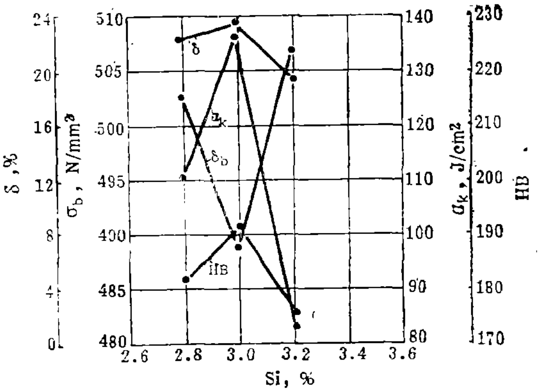

Fig.7 The effect of silicon content on mechanical properties of nodular cast irons with 0.1% Mn

The fact that mechanical properties of nodular cast irons are strongly influenced by the chemical composition, and consequently, the matrix structure has been well established. The results show that two compositions of ferritic structure as-cast nodular cast irons with very high mechanical properties were produced. Both of the alloys are convenient for producing thin-walled castings with ferritic structure (about 80% and more ferrite). For obtaining castings with wall-thicknesses of 12 mm or more it is better to use nodular cast iron containing 3.9% C, 3.2% Si, 0.5% Mn, (Fig.6) as well as castings of wall thicknesses of 7-12mm produced from cast iron of 3.9% C, 3.0% Si, 0.1% Mn (Fig.7). The ratio of ferrite to pearlite in the iron matrixs of these alloys are shown in Fig.8. In both case the amount of ferrite is about 80-85%.

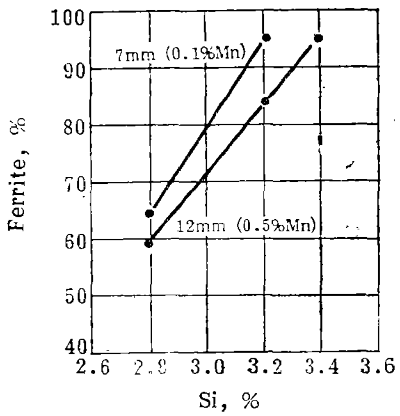

Fig.8 The effect of silicon content on formation of ferritic structure in castings with 7mm and 12 mm wall-thicknesses

3 Conclusions

For producing of thin-walled castings two compositions of ferritic structure of nodular cast iron are obtained.Castings with wall-thicknesses 7-12 mm may be produced from alloys containing 3.9% C, 3.0% Si, 0.1% Mn, as well as castings of wall-thicknesses 12 mm and more from nodular cast iron containing 3.9% C, 3.2% Si, 0.5% Mn. The first As-cast nodular cast iron possesses elongation of about 23.6% and tensile strength of about 489 N/mm^2, the second one-20% and 525 N/mm^2 accordingly. Both of these compositions of as-cast nodular cast iron may be successfully used in practice.

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