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Thermal shock resistance test for cast iron used in casting environments

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The thermal shock resistance test was conducted for grey cast iron and a compacted cast iron for use in casting environment. The test consisted of a specimen partially immersed in a molten salt bath of 55% Na_2CO_3 and 45% $CaCO_3$ at 1000° C for 4.5 min, followed by plunging into water. The test results from laboratory and field indicated that the grey cast iron is superior to the compacted cast iron. In the laboratory test, the thermal shock resistance of the cast iron can be judged from the summation of crack length and crack patterns in the specimen after a certain number of thermal shock cycles. The inferior thermal shock resistance of the compacted cast iron is mainly attributed to the more extensive martensite formation after the thermal shock cycling compared with the grey cast iron.

1. Introduction

The ingot mould used in a pig-iron casting machine suffers extremely severe thermal shock. When molten iron is poured into the ingot mould, the temperature of the hot face of the mould reaches 850 to 1000° C instantaneously [1]. Moreover, the ingot mould is subsequently cooled by a water spray to accelerate the solidification and removal of a pig-iron cast in minutes.

In Decrop *et al.*'s investigation [2], a cast-iron bushing was heated from the inner surface to 850° C by a high-frequency induction and subsequently cooled to ≈400° C in air by radiation; the test results from laboratory and field indicated that the cast iron of a structure similar to the compacted cast iron was more thermally shock resistant than the grey cast iron for use in steel ingot moulds. The present observation showed that the compacted iron was inferior to the grey cast iron for use in pig-iron casting machine moulds.

The working environment in a pig-iron casting machine is much severer than that in steel ingot moulds, however, a life of 200 casts for a steel ingot mould is pretty good and a life of 800 casts for a pig-iron casting machine mould is not satisfactory. The determination of service life of mould materials for pig-iron production is very time consuming and a well-established experimental method to evaluate the thermal shock resistance of mould materials in an extremely severe environment has been scarcely reported. The purpose of the present investigation was to develop an experimental method to evaluate mould materials for use in a pig-iron casting machine.

2. Experimental details

2.1. Materials

Two cast irons were inductively melted, inoculated and cast into ingot moulds and test blocks, 55 mm by 150 mm by 300 mm. The chemical composition of the cast irons is given in Table I. Fig. 1 shows the microstructures of the grey cast iron as well as the compacted cast iron. The difference in graphite morphology arose from a small amount of magnesium inoculation for the compacted cast iron.

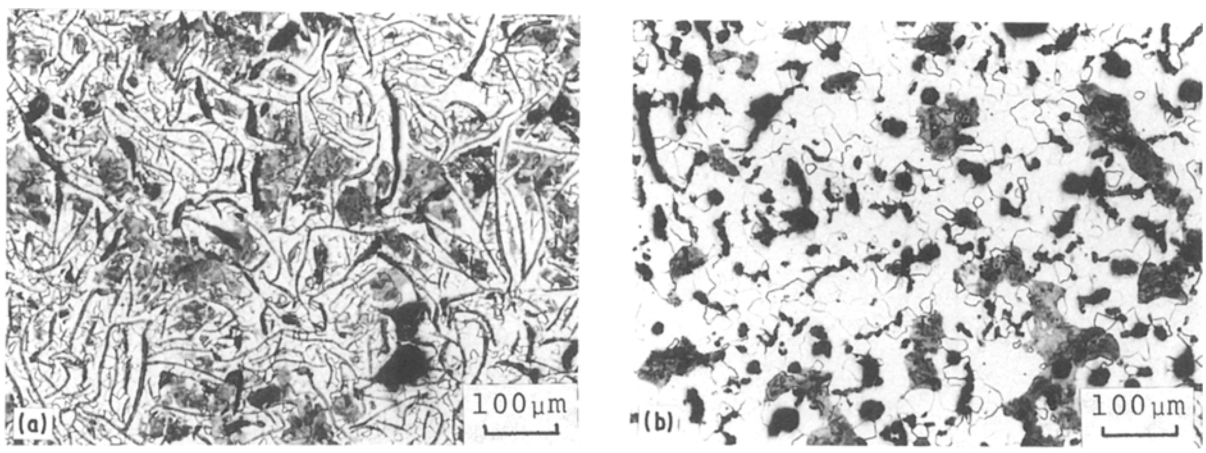

Figure 1 Optical micrographs of the cast irons before thermal shock cyclings: (a) grey cast iron, (b) compacted cast iron, 3% nital etched.

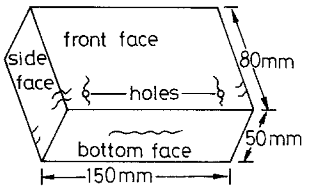

Figure 2 The dimension of specimen and conceptual aspects of the cracks originating from the mark holes and the sharp edges and on the bottom face.

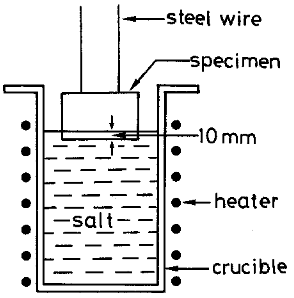

Figure 3 The salt-bath test.

2.2. Thermal shock resistance test

Test specimens were cut from the portion of the cast block which was far away from the shrinkage voids. These specimens were machined to dimensions of 50 mm by 80 mm by 150 mm as shown in Fig. 2. Two 3 mm diameter holes were drilled on the front face, 10 mm from the bottom face, as a sign to prevent excessive immersion during the thermal shock test.

A depth of 10 mm below the two mark holes in the specimen was immersed in the molten salt bath of 55% Na_2CO_3 and 45% $CaCO_3$ at 1000° C. The configuration of the salt bath test is shown in Fig. 3. After having been partially immersed for 4.5 min in the salt bath, the whole specimen was plunged into water. The heating–cooling procedure was repeated. After a certain number of cycles the specimen was ground with SiC papers up to no. 800, to reveal crack patterns.

The field test was also conducted to test these cast-iron moulds in a pig-iron casting machine. The ingot mould was subjected to a cyclic heating and cooling by molten iron and water spray. It took around 8 min to complete one cycle.

3. Results and discussion

3.1. The salt bath test

Fig. 2 shows the conceptual aspect of cracks which appeared during the thermal shock test. It was observed that the first to appear were the cracks originating

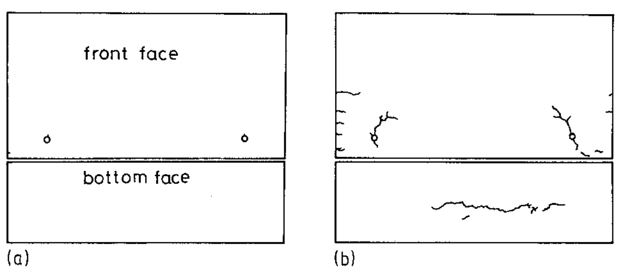

Figure 4 The crack patterns in grey cast iron after (a) 20 cycles, (b) 38 cycles.

TABLE I Chemical composition of cast irons

Composition (wt %)	Grey cast iron	Compacted cast iron
C	3.93	3.40
Si	2.29	2.95
Mn	0.56	0.57
P	0.085	0.031
S	0.011	0.016
Mg	–	0.023

from the mark holes, then the cracks on the bottom face and finally the cracks at edges.

Figs 4 and 5 show the crack patterns on the test blocks. After 20 heating–cooling cycles, no obvious cracks can be seen on the surface of the grey cast-iron specimen while several cracks appeared on the compacted cast iron. Cracks in the compacted iron grew much faster than those in the grey cast iron with increasing thermal shock as revealed by the crack patterns after 38 cycles.

Fig. 6 is a plot of the summation of the crack length against the number of the thermal shocks. The slope of the curve is equivalent to the crack growth rate. As can be seen, the crack initiation of the compacted cast iron occurred much earlier than that of the grey cast iron; moreover, the crack propagation rate of the former was much faster than that of the latter in an increasing rate as the thermal shock test continued. These suggest that the grey cast iron has better ther-

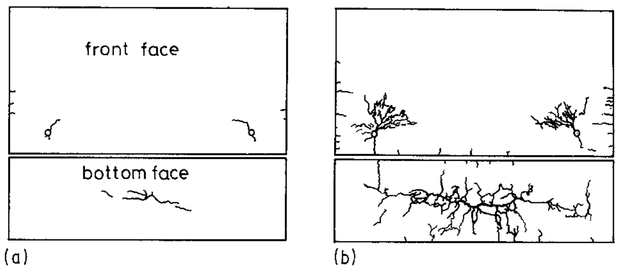

Figure 5 The crack patterns in compacted cast iron after (a) 20 cycles, (b) 38 cycles.

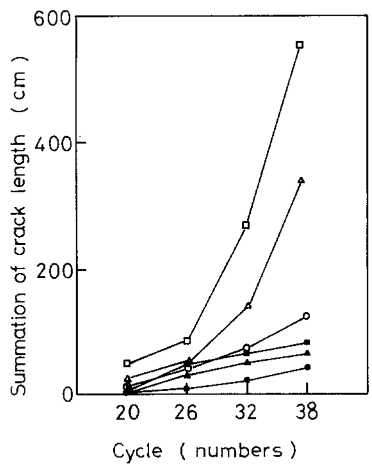

Figure 6 The crack growth during thermal shock cyclings: (■, □) cracks on bottom face, (▲, △) cracks from holes, (●, ○) cracks from sharp edges, for (■, ▲, ●) grey iron, (□, △, ○) compacted iron.

Figure 7 The ingot mould used for field tests.

mal shock resistance than the compacted cast iron in the extremely severe environment.

3.2. The field test

Fig. 7 shows the ingot mould for use in a pig-iron casting machine. Fig. 8 demonstrates the hot-face conditions of the ingot moulds after 70 cycles in service. As can be seen from Fig. 8a, there are no cracks showing up in the grey cast-iron ingot mould while there is one clearly visible crack in the compacted cast iron (Fig. 8b). Moreover, the compacted cast-iron mould failed after a service of 223 cycles and the grey cast-iron mould was still in service as usual after 500 cycles.

3.3. The microstructural changes and the thermal shock resistance

Fig. 9 shows the microstructural changes in a salt-bath test specimen after the thermal shock test. As can be seen, an extensive graphite growth appeared in the grey cast iron while part of the graphite disappeared in the compacted cast iron as compared with Fig. 1; there is much more martensite phase in the compacted cast iron than in the grey cast iron. Fig. 10 shows micrographs of these two cast irons at higher magnification.

These microstructural changes are reflected in the hardness distribution in the hot face of the salt-bath test specimen (Fig. 11). The increase in hardness is related to martensite formation in the hot face through a rapid cooling and the decrease in hardness is related to graphite growth. The transition from austenite to martensite is reversible and is accompanied by an increase in volume [3]. Just as in ZrO_2 [4], because this transformation takes place very rapidly and is accompanied by compression during heating and expansion during cooling, it causes cracking of articles made of the cast iron. The compacted cast iron contained much more martensite phase than the grey cast iron as shown in Fig. 9. Consequently, the compacted cast iron is less thermally shock resistant than grey cast iron.

4. Conclusion

The thermal shock resistance test was conducted for grey cast iron and compacted cast iron. The test

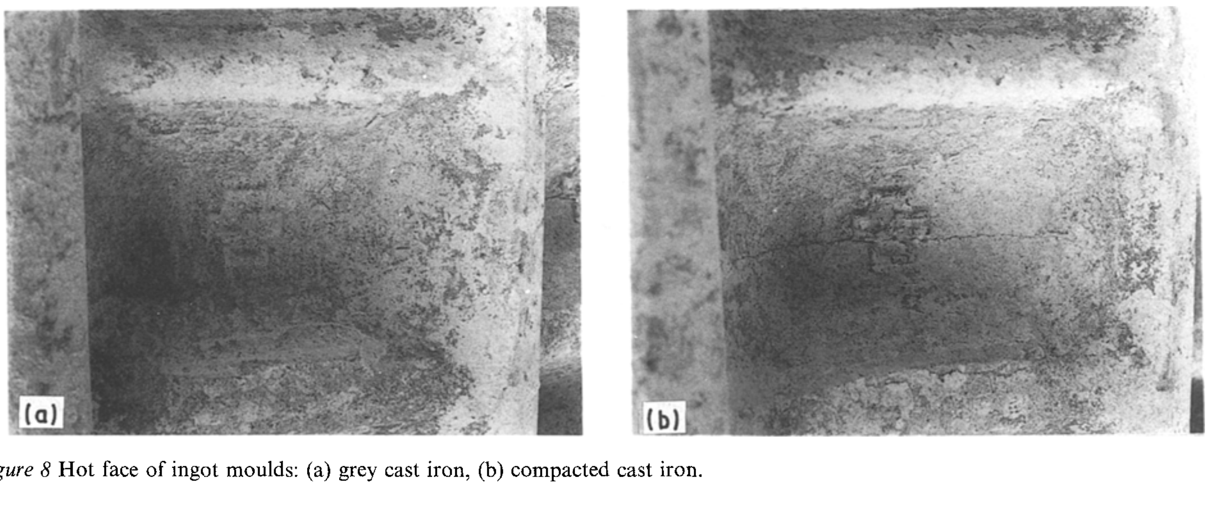

Figure 8 Hot face of ingot moulds: (a) grey cast iron, (b) compacted cast iron.

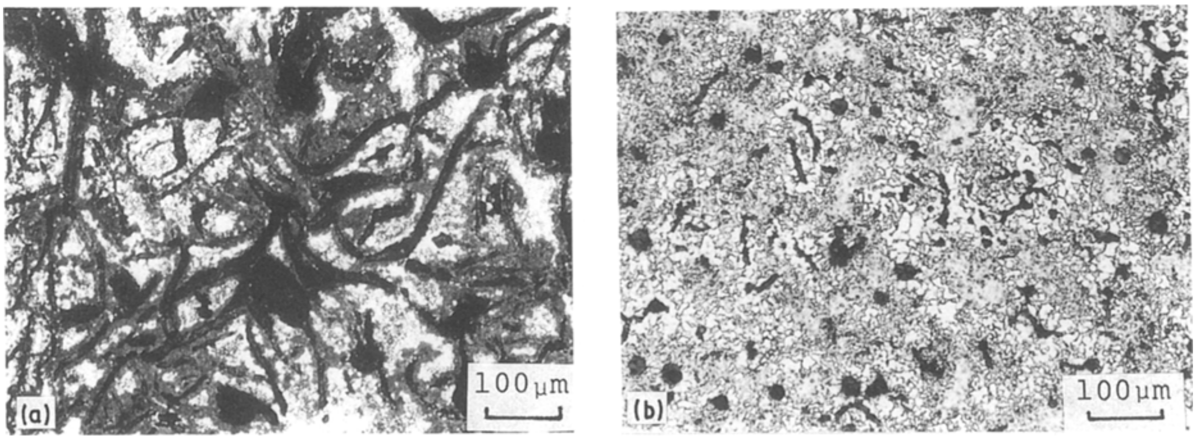

Figure 9 Optical micrographs of cast irons after thermal shock cyclings: (a) grey cast iron, (b) compacted cast iron, 3% nital etched.

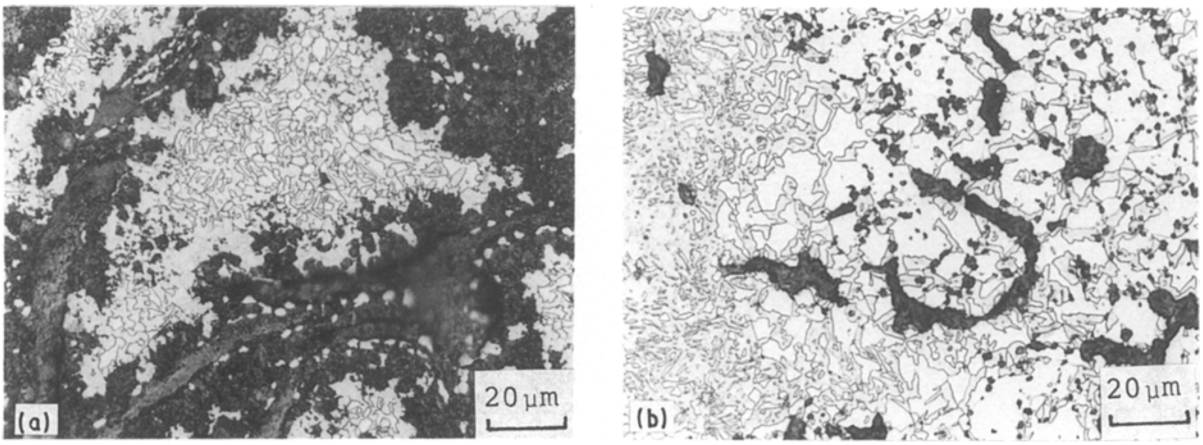

Figure 10 Optical micrographs showing the martensite matrix of cast irons after thermal shock cyclings, (a) grey cast iron, (b) compacted cast iron, 3% nital etched.

consisted of a specimen partially immersed in a molten salt bath of 55% Na_2CO_3 and 45% $CaCo_3$ at 1000° C for 4.5 min followed by plunging into water. The test results from laboratory and field indicated that the grey cast iron is superior to the compacted cast iron for use in casting environment. In the laboratory test, the thermal shock resistance of cast irons can be judged from the summation of crack length and crack patterns in the test specimens after a certain number of thermal shock cycles. In the field test, the compacted cast-iron mould failed after a service of 223 cycles in a pig-iron casting machine while the grey cast iron mould was still in service as usual after 500 cycles.

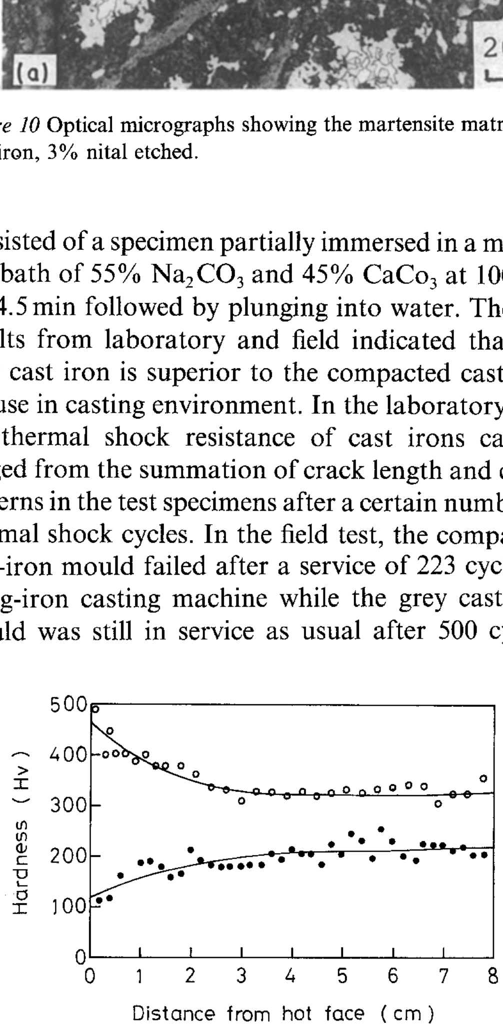

Figure 11 Hardness variation from the hot face toward the interior of the specimen after thermal shock cyclings: (●) grey cast iron, (○) compacted cast iron.

Microscopic observation revealed that in the hot-face region the compacted cast iron contained much more martensite than the grey cast iron. The inferior thermal shock resistance of the compacted cast iron compared to the grey cast iron is mainly attributed to the more extensive martensite formation after the thermal shock cycling.

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