Effect of austempering temperature on the mechanical properties, wear resistance and low cycle fatigue behavior of austempered ductile iron

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Abstract
The effect of austempering temperature on the mechanical properties, low cycle fatigue resistance and wear resistance of commercial EN-GJS-700-2 grade ductile cast iron were experimentally studied in detail. Standard keel blocks were produced with traditional sand-casting technique. Austempering treatments were performed at 340 °C, 310 °C and 240 °C for 90, min in a salt bath.

Keywords: EN-GJS-700-2, austempered ductile iron (ADI), microstructure, mechanical properties, low cycle fatigue, wear.

Introduction

Although numerous studies have investigated ADI, comprehensive research focusing on the combined influence of austempering temperature on mechanical properties, fatigue behavior, and wear resistance of commercial EN-GJS-700-2 grade ductile cast iron remains limited. Therefore, the present study aims to systematically evaluate the effect of austempering temperature on the mechanical properties, fatigue resistance, and wear performance of EN-GJS-700-2 ductile cast iron, providing insight into the underlying mechanisms governing performance improvements.

Experimental procedure

EN-GJS-700-2 (GGG-70) grade ductile iron in the form of keel blocks was produced at Mesa Machinery. The keel blocks were subjected to heat treatment according to the following procedure: (i) austenization at 880 °C for 2 h, (ii) quenching to salt bath at 340 °C, 310 °C and 240 °C, and (iii) austempering at 340 °C, 310 °C and 240 °C for 90 min.
Microstructural examinations were performed using a Nikon Eclipse MA100 optical microscope. Tensile tests were conducted using an ALSA KTM 600 model universal testing machine at a deformation rate of 8 mm/min. Brinell hardness tests were conducted utilizing a Bulut Makine Digirock RBOV model hardness tester under a load of 187.5 kgf. Wear experiments were performed using a UTS Tribolog tribometer operating in a reciprocating ball-on-disc configuration. The displacement-controlled fatigue tests were carried out using a 100 kN capacity Shimadzu Servopulser E model servo-hydraulic testing machine. The fatigue tests were conducted under a sinusoidal waveform with a strain ratio (R) of −1 at a frequency of 5 Hz.

Result and discussion

The measured chemical composition of the investigated EN-GJS-700-2 DI is given in Table 1. The calculated CE value of 4.274% is very close to the eutectic composition value of 4.3%, which helps reduce casting defects and promotes the formation of the targeted microstructural features and mechanical properties [1].

Table 1. Composition of EN-GJS-700-2 DI

C	Si	Mn	Cu	Ni	Mo	Mg	Cr
3.356	2.736	0.244	0.939	0.874	0.224	0.048	0,098

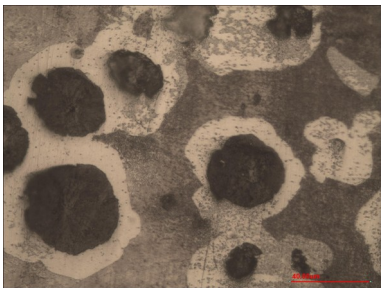

Figure1. Optical micrograph of EN-GJS-700-2 DI

EN-GJS-700-2 DI has a typical bull eye microstructure (Figure 2) with mainly pearlitic matrix

phase. Optical micrographs of ADI specimens are shown in Figure 3. The characteristic bull's eye microstructure is fully transformed into the typical ausferritic microstructure of ADI. The microstructures of all examined ADI specimens consist of graphite nodules embedded in an ausferritic matrix, comprising ausferrite (bainitic ferrite, acicular ferrite (dark regions)) and high-carbon retained austenite (yhc, light regions). Optical micrographs reveal that no carbide precipitation or martensite formation is detected.

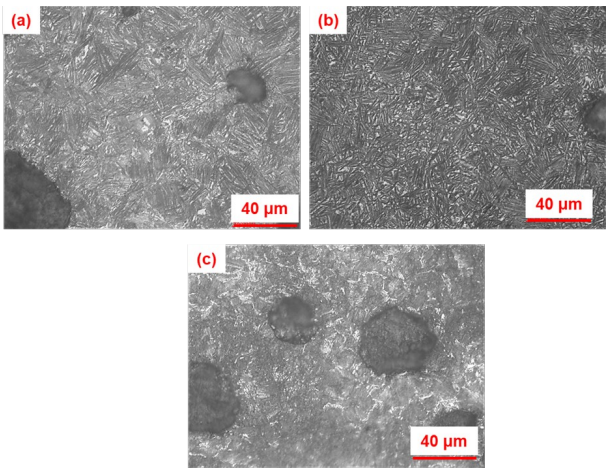

Figure 3. Optical micrographs of the austempered ductile irons (a) 90 min, (b) 120 min, (c) 150 min, and (d) 180min.

The mechanical properties of as-cast EN-GJS-700-2 DI and ADI specimens are given in Table 2. The measured mechanical properties from test specimens are 1.3-2.4 times higher than those for presented in EN 1563 standard.

Table 2. Mechanical properties of the investigated ductile cast iron alloys.

Condition	Yield Strength (MPa)	Tensile Strength (MPa)	Elong. (%)	Brinell Hardness (HB)	Impact Energy (J)
GGG70	610.8	879.5	4.7	237.5	35.1
340°C	873.7	1194.5	8.7	279.1	89.9
310°C	1104.0	1372.3	6.2	326.1	76.7
240°C	1245.9	1410.6	3.5	374.2	44.0

The mechanical properties of EN-GJS-700-2 DI are importantly improved after austempering heat-treatment due to their ausferritic microstructure. For all austempering temperatures, ADI specimens exhibit higher yield strength, ultimate tensile strength, hardness and impact energy rather than as-cast specimen. On the other hand, the specimens that austempered at 340 °C and 310 °C have considerably higher elongation than that of as-cast DI. For ADI specimens, the yield strength, the ultimate strength and hardness continuously increase, whereas elongation and impact energy continuously decrease with increasing austempering temperature.

Table 3. The width of the wear scans of the investigated ductile cast iron alloys.

Condition	Width of wear scan (µm)		
	10 N	20 N	30 N
GGG70	216 ± 5	265 ± 6	270 ± 7
340°C	185 ± 6	225 ± 2	232 ± 4
310°C	168 ± 4	185 ± 3	188 ± 3
240°C	138 ± 2	161 ± 2	228 ± 3

The width of the wear scans of the investigated ductile cast irons with respect to applied force is given in Table 3. Austempered specimens show higher wear resistance than EN-GJS-700-2 DI with narrower wear scan widths for all applied forces. In addition, the wear resistance (wear scan width) of all studied specimens decreases with increasing applied force.

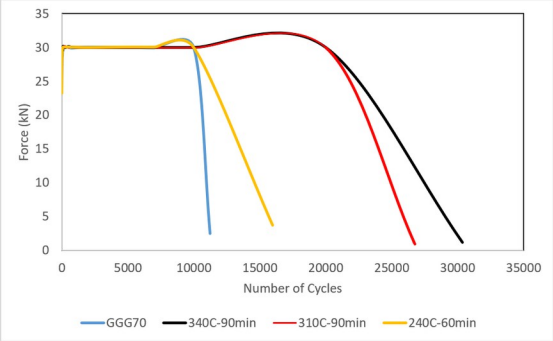

Figure 4. Force amplitude variations with respect to number of cycles.

The variation of force amplitude with respect to number of cycles is shown in Figure 4. Under the same displacement amplitude conditions, the average life of the ADI specimens is considerably higher than that of EN-GJS-700-2 DI. In addition, the specimen austempered at 340 °C shows the longest fatigue life.

Conclusion

All ADI specimens exhibit better mechanical, wear and fatigue properties. The specimen austempered at 240 °C shows the highest yield strength, tensile strength, hardness and wear resistance, whereas the specimen austempered at 340 °C shows the best fatigue live with highest toughness.

References

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