Fatigue of Nodular Cast Iron Connecting Rods

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ABSTRACT

Axial fatigue behavior of as-cast and austempered pearlitic nodular cast iron connecting rods were obtained at room temperature using a load ratio, R, equal to 0.01. The fatigue resistance of the austempered connecting rods was greater than that of the as-cast rods. A fatigue limit increase of about 25 percent existed in the austempered condition.

KEYWORDS

Fatigue, connecting rods, nodular cast iron, austempered, fractography

INTRODUCTION

The objective of this research was to acquire constant amplitude fatigue behavior of pearlitic nodular cast iron connecting rods designed for use in small (1.9 liter) automobile engines. Both as-cast and austempered conditions with hardness levels of about 230 BHN were evaluated and compared. Fatigue life data between 10^4 and 5×10^6 cycles were of major interest. An analysis of fracture surfaces, both macroscopic and microscopic, was conducted to better understand fatigue crack initiation and fatigue crack growth mechanisms.

MATERIALS AND TEST PROCEDURES

The specific cast iron used was SAE J434b grade D7003. Two different batches of the as-cast connecting rods and one batch of austempered connecting rods were tested. The connecting rods were cast in batches of 12 to 16. Austempering was done by normalizing the cast iron connecting rods at 900°C for 1.5 hours, quenching to 370°C and tempering for 1 hour, then slowly cooling to room temperature. The chemistry and microstructure of the two as-cast batches were very similar and the two batches were thus considered as one. The average chemical composition of the two as-cast batches and the chemical composition of the austempered batch is given in Table 1. Typical microstructures for the as-cast and austempered conditions etched with 2% nital are shown in Fig. 1. Percent pearlite for the two as-cast batches were 60 to 65 and 70 to 75 respectively. Average monotonic tensile properties for the as-cast and austempered connecting rod materials are given in Table 2. The ultimate tensile strength and the yield strength of the austempered nodular cast iron was approximately 9 and 17 percent higher respectively, than for the as-cast nodular iron. Greater percent elongation at fracture was also attained for the austempered condition.

Connecting rods usually have two high strength knurled bolts to fasten the crank end to the crankshaft. Due to preliminary problems with bolt failures, the test connecting rods were cast integrally to omit the bolts. In addition, preliminary failures occurred in the eye of the piston-connecting pin due to excess pin clearance. This was overcome by reducing the pin clearance during testing. The resulting I cross-section connecting rod test specimen and dimensions are given in Fig. 2.

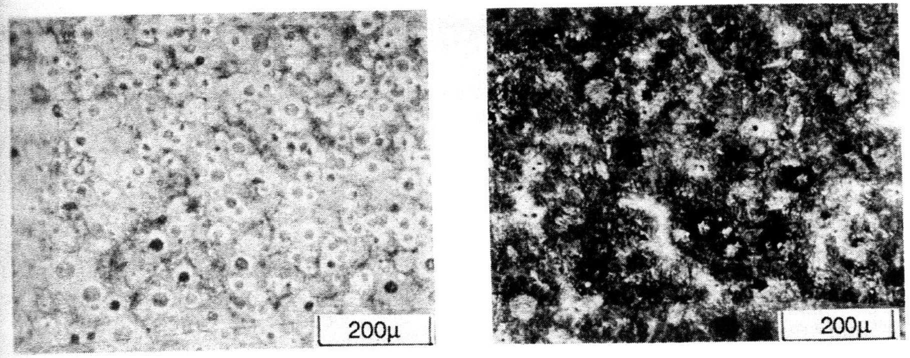
Fatigue tests were conducted at room temperature using an 89 kN closed-loop electrohydraulic test system. The fatigue tests were axial and were done in load control with the load ratio $R = P_{min}/P_{max}$ equal to 0.01. Frequencies ranged from 11 to 20 Hz depending on the load magnitude. The criterion for failure was complete fracture. Connecting rods that had not failed by 5×10^6 cycles were considered as run-outs. Since short life was not of interest in this research, minimum test life was established at about 10^4 cycles. Under actual engine conditions, the compressive

Table 1. Chemical composition - % weight

material	C	Si	Ni	Cu	Mg	Al	P	Mo	Cr	Mn	V
As-Cast	3.7	2.7	.01	.55	.055	.031	.015	.007	.032	.34	.05
Austempered	3.7	2.7	.03	.44	.045	.025	.024	.006	.034	.23	.05

Table 2. Average Monotonic Tensile Properties

	As-Cast	Austempered
Tensile Strength-MPa	790	860
.2% Yield Strength-MPa	500	585
Percent Elongation in 50 mm	3	10
Young's Modulus-GPa	152	166



(a) As-Cast

(b) Austempered

Fig. 1 Microstructure

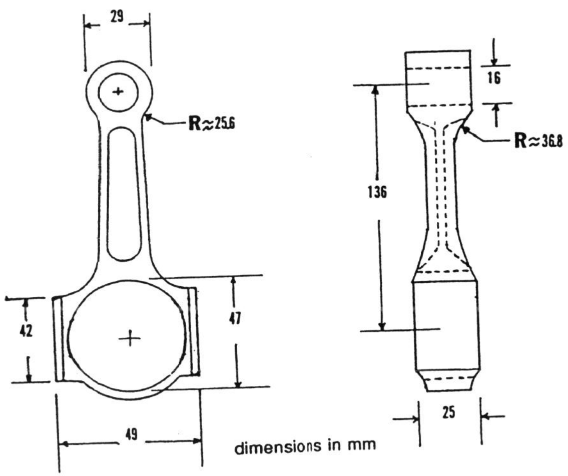


Fig. 2 Connecting rod test specimen

gas pressure loads on connecting rods dominate under high torque and low engine speed. McRobert and Watson (1983), however showed that under high engine speed conditions the tensile loads became the dominating force. The type of connecting rods used in this study are for engines that normally run at high engine speeds and thus only axial cyclic tensile loads were employed.

TEST RESULTS AND DISCUSSION

The maximum cyclic load versus cycles to failure for the as-cast connecting rods are shown in Fig. 3. The median data line along with 95% confidence limits are shown. Appreciable scatter exists and this is due principally to the many different fatigue crack initiation sites rather than batch to batch differences. Sixty percent of the fatigue failures initiated at various locations of lettering on the shank web section and at near surface slag. Theoretical stress concentration factors, K_t, at the different discontinuity location sites were estimated from Peterson (1974) to range from 1.15 to 1.5. The fatigue limit was estimated from runnouts at 5×10^6 cycles using the maximum liklihood analysis. The fatigue limit maximum load was 30.1 kN which converts to a maximum nominal stress of 276 MPa based upon the minimum shank cross-sectional area and $K_t = 1$.

The maximum cyclic load versus cycles to failure for the austempered connecting rods are shown in Fig. 4. The median data line along with the 95% confidence limits are shown. Due to the limited number of different test loads and run-outs, only a fatigue limit range was possible to calculate. These ranges were found to be between 37.3 kN and 38.5 kN, and 335 MPa and 346 MPa. Of the austempered rods that failed, 91% were the result of a crack that initiated at a small stress raiser

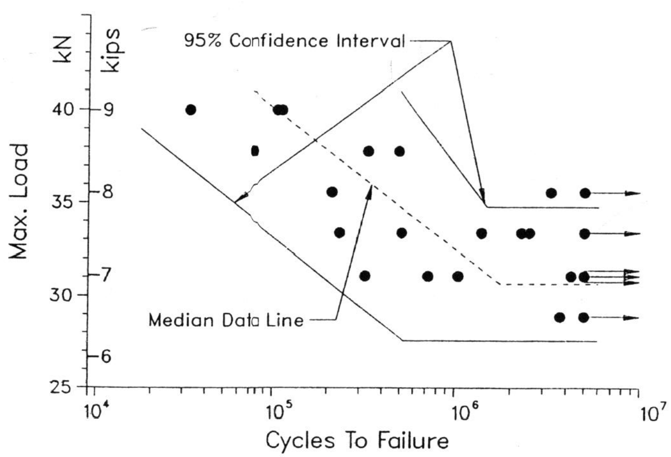


Fig. 3 Load versus cycles, as-cast

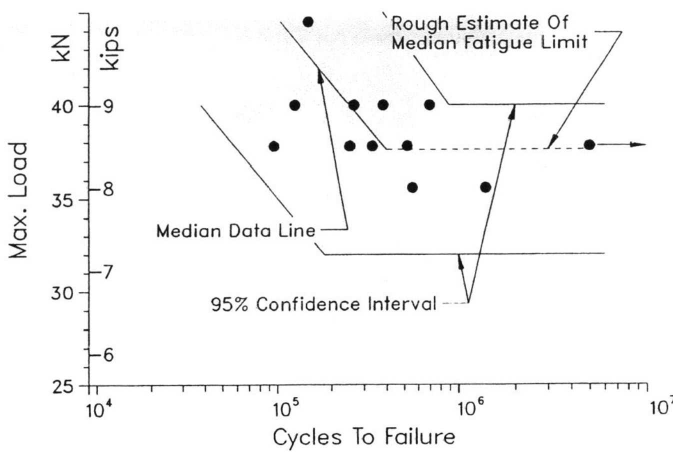
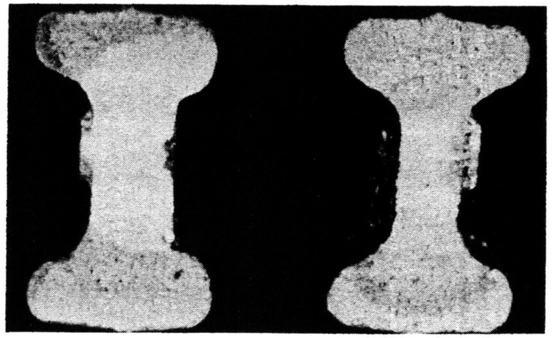


Fig. 4 Load versus cycles, austempered

such as the lettering on the web, a surface pore, a small scratch, or a piece of slag. This compares with 60% of the as-cast specimens that failed at similar locations. This indicates that the austempered nodular iron is more notch sensitive than the as-cast iron or that manufacturing flaws were more numerous for the austempered rods or both. This problem also made it very difficult for the austempered specimens to survive to the run-out stage. Since this had not been encountered in the as-cast tests, many of the austempered load levels were repeated in order to accumulate satisfactory data. This procedure had the disadvantage of exhausting the supply of connecting rods before the desired number of different load levels could be run.

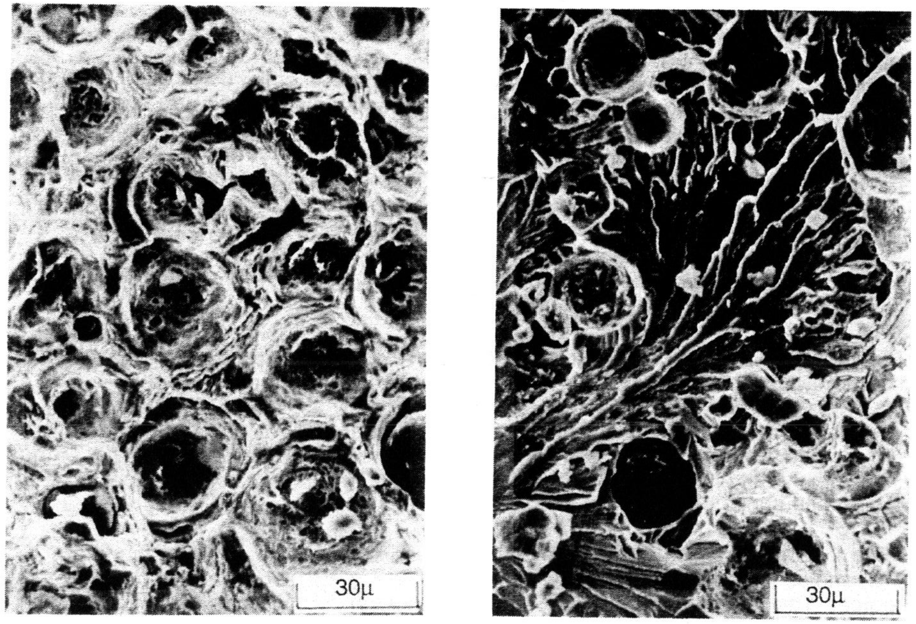
Figure 5 shows typical macroscopic aspects of the fracture surfaces for both the as-cast and austempered conditions. The fatigue crack initiation and growth region was always very evident. Cracks grew predominately as a circular or semi-circular shape with a characteristically smooth texture. Final fracture regions were also quite evident due to their contrasting rough surface and darker appearance. Small shear lips were present in the final fracture region for approximately 80 percent of the specimens.

Figure 6 shows typical scanning electron fractographs for the as-cast condition. Fig. 6(a) shows the fatigue crack growth region while Fig. 6(b) shows the final fracture region. The fatigue crack growth region is characterized by slow crack growth with fracture in the pearlite by the breaking up of lamallae. The crack front goes around the graphite nodules, leaving them intact. Shown here are either nodules or the cavities corresponding to them. The final fracture region shows quasi-cleavage features in the pearlite matrix which surround ductile fracture areas in the ferrite immediately surrounding the nodules. These fractographs are very representative of the fracture surface and are comparable to fractographs of other as-cast nodular irons.



(a) As-Cast (b) Austempered

Fig. 5 Typical macro fracture surfaces

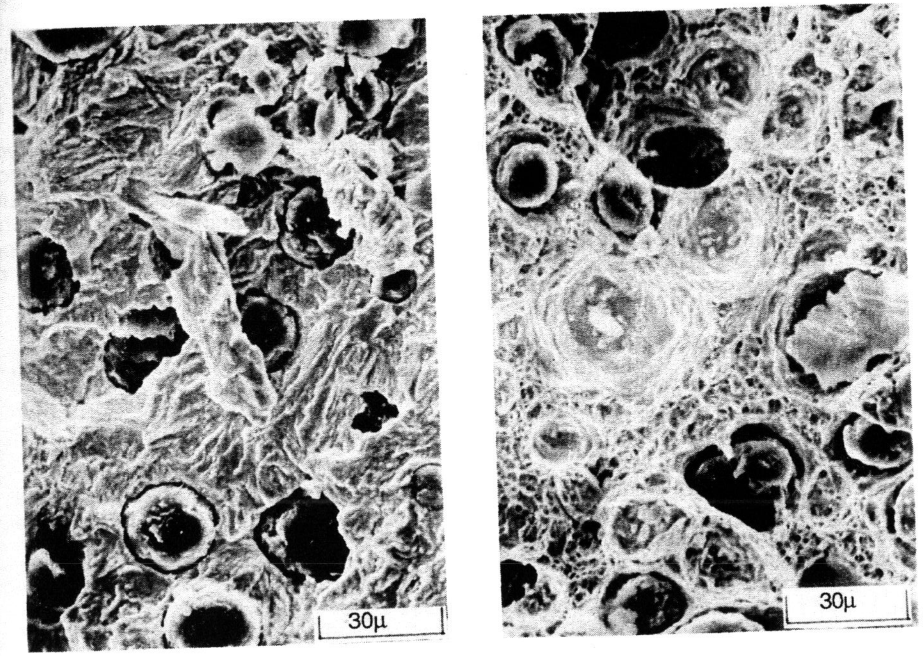


(a) Fatigue Crack Region (b) Final Fracture Region

Fig. 6 Typical Fracture surfaces, as-cast

Figure 7 shows typical scanning electron fractographs for the austempered condition for both the fatigue crack growth region and the final fracture region. Again, as with the as-cast material, the crack front goes around the nodules in the fatigue crack growth region. In the final fracture region, ductile fracture in the ferrite structure around the nodules and through the austenite is evident. The rest of the fracture surface shows ductile dimples formed by microvoid coalescence. Some flat quasi-cleavage also existed in the final fracture region.

A superposition of the fatigue data for both the as-cast and austempered condition from Figs. 3 and 4 is given in Fig. 8. The 95% confidence limits have been left off for better clarity and comparison. It is evident that the austempered finite life and runnout data are more desirable than that of the as-cast material. The increase in the austempered fatigue limit was about twenty five percent which is significant for design.



(a) Fatigue Crack Region (b) Final Fracture Region

Fig. 7 Typical Fracture surfaces, austempered

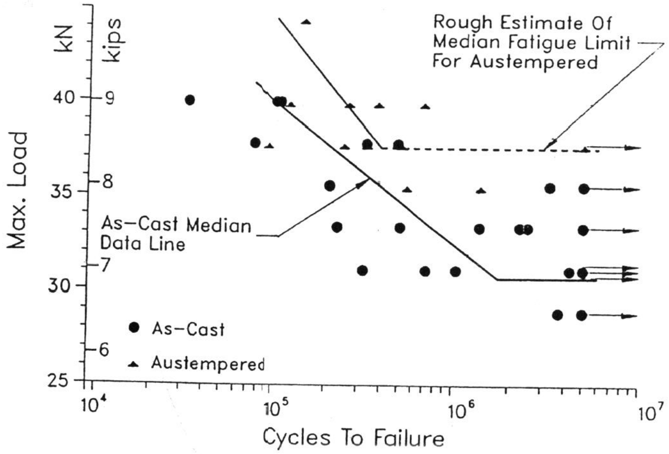


Fig. 8 Superposition of load versus cycles, as-cast and austempered

CONCLUSIONS

1. The fatigue resistance of the austempered nodular cast iron connecting rods was greater than that for the as-cast nodular cast iron rods. The median fatigue limit based upon nominal maximum stress was between 335 and 345 MPa for the austempered condition and 276 MPa for the as-cast conditions. This is approximately a twenty five percent increase in fatigue limit.

2. The predominate locations for fatigue crack initiation were from lettering on the shank, machine marks and near surface slag. A larger number of these failure sites existed with the austempered condition implying that the austempered material is more notch sensitive than the as-cast material.

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