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Experimental investigation of some parameters on isothermal cyclic fatigue creep behavior of AISI 3137 steel at low homologous regimes

M. MAKARACI
Mechanical Engineering Department, Kocaeli University, Veziroglu Campus, 41040 Izmit, Turkey; Division of Mechanical Engineering, Technical Sciences Department, Turkish Military Academy, 06100 Ankara, Turkey
E-mail: murat@alum.rpi.edu

It has been estimated that between 50 and 90% failures observed in energy generation, aerospace applications and propulsion systems are due to fatigue alone or interactions of fatigue with time and temperature dependent creep deformation [1, 2]. In engineering sciences fatigue has been defined as "the progressive localized permanent structural change that occurs in a material subjected to repeated or fluctuating strains at stresses having a maximum value less than the tensile strength of the material" [3]. While ferrous metals have fatigue endurance limits, other materials such as aluminum alloys do not have this distinctive property [4].

The fatigue life of a structural member is affected by many factors [5, 6]. Broadly speaking these factors are type of load; nature of load-displacement curve; frequency of load repetitions; loading history [7, 8]; size of member; material flaws; manufacturing method; operating temperature at homologous regime; and environmental conditions such as corrosion [9].

The present study is related to the investigation of some parameters on isothermal cyclic fatigue creep behavior of Type AISI 3137 steel, which is widely used in several industrial/military applications. Both short and long term tests were conducted to explore influences of thermal hardening, of surface coating thickness, and particularly of hold time effects to simulate imposed creep conditions at predetermined lives.

The rotary bending fatigue machine used in the experiments is shown in Fig. 1 and the composition of the steel is given in Table I. Test specimens were manufactured according to the machine specifications [10]. The available maximum bending moment and the interchangeable rotational speed was 10 kg-m and 1200/3000 rpm, respectively.

The experiments were carried out in four main areas at room temperature (low homologous regime). These were experiments on (1) reference specimens at 36 HRC hardness, (2) thermally hardened specimens at 53 HRC, (3) surface copper coating with 20 μ and 40 μ thicknesses, and (4) short and long period hold times for fatigue-creep effects.

The experiments on the specimens having 36 HRC hardness value is in agreement with a usual curve of a ferrous alloy (Fig. 2). To explore the impact of hardening, another set of virgin specimens were heat treated at 900 °C and quenched for 20 min. The subsequent hardness tests have shown an increase to 53 HRC value. Fatigue tests conducted on these specimens revealed a significant boost of 6 to 9 times greater lives with respect to the reference states as shown in Fig. 3.

The third section of the experiments investigated effect of surface coating and thickness variations. Since the coating material (i.e., copper) inhibits ductile nature and has better surface finish than lathe manufactured specimens, some improvement was expected in the fatigue life. In fact, as shown in Fig. 4, for the low cycle fatigue (LCF) region (where failure cycles are less than 1000), the coating approximately doubled the fatigue lives of the uncoated material. The LCF is very important subject and traditional methods of Coffin-Manson [11, 12] and its derivatives are frequently employed and recent studies suggest coupling of fatigue failures with damage criterion in a continuum mechanics aspects [13]. It has also been inferred from Fig. 4 that although 20 and 40 μ coating depths showed indifference under the same load (of 94 kg), the fatigue lives of double layer coated specimens were actually increased with decreasing the loads (bending stresses) with respect to the single layer coated ones. The life enhancement has been up to 50%. When high cycle fatigue is to be considered in a design where corrosive effects have to be eliminated, the negative effect of surface coating should be taken into consideration. However, Treglio [14] reports that ion implantation on gears made from structural steel increases fatigue endurance. As set forth in a specialist meeting [15], carburization, nitridation and radiation rates affect fatigue life conversely for low cycle and high cycle, where the former will increase and the latter will decrease.

The final part studied hold time effects, which leads to creep conditions under stationary loads. Thus, the fatigue tests were interrupted at the half of the total lives of the specimens that were predetermined from the reference states. These included short time periods of 5 min and 1 h, and longer periods of 9 and 15 h on the reference (36 HRC), the hardened (53 HRC), and the surface coated specimens. Fig. 5 shows hold time effect on the reference hardness specimens under 94 kg load. Interestingly, it was found that 5 min hold time at 50% of remaining life is significantly greater than both the reference test and 1 h hold time case. The latter two yielded almost the same results.

Fig. 6 also shows the positive effect of 5 min hold time on the surface coated parts. Here, for the constant load of 72 kg, 20 μ coating increased the fatigue life

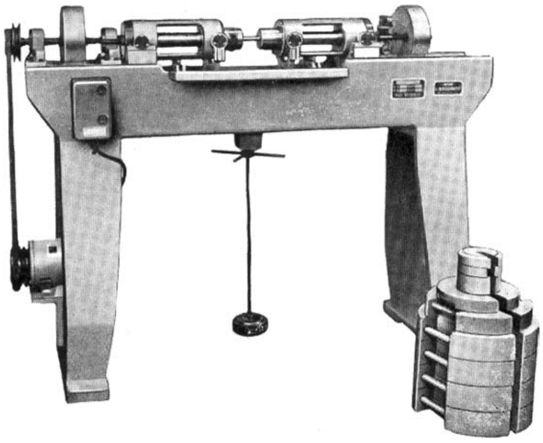

Figure 1 The rotary bending fatigue test [10].

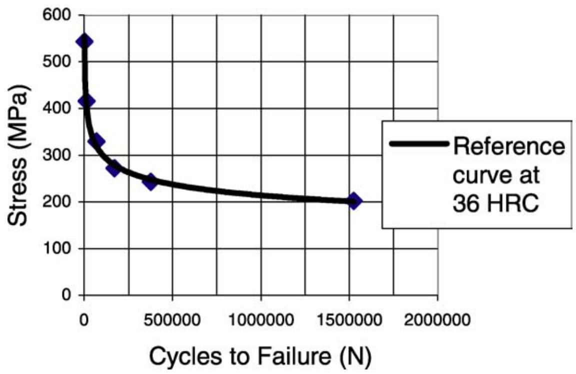

Figure 2 Reference fatigue curve at 36 HRC hardness value.

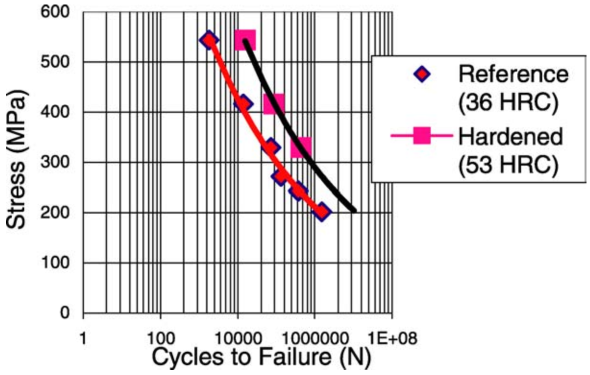

Figure 3 Comparison of fatigue curves for 36 HRC and 53 HRC to illustrate heat treatment effect.

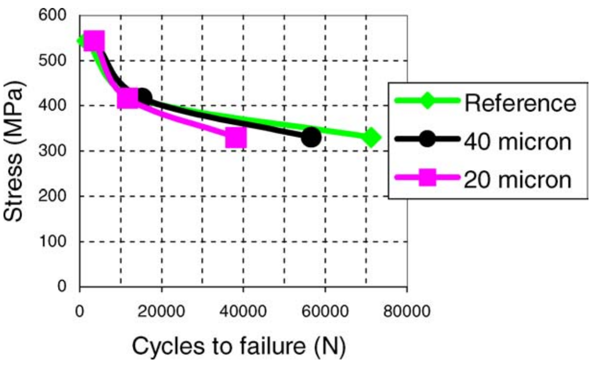

Figure 4 The effect of surface coating and various thicknesses on the fatigue properties.

TABLE I The composition of the test material

C	Mn	Si	P	S
0.32	1.35	0.30	0.040	0.080

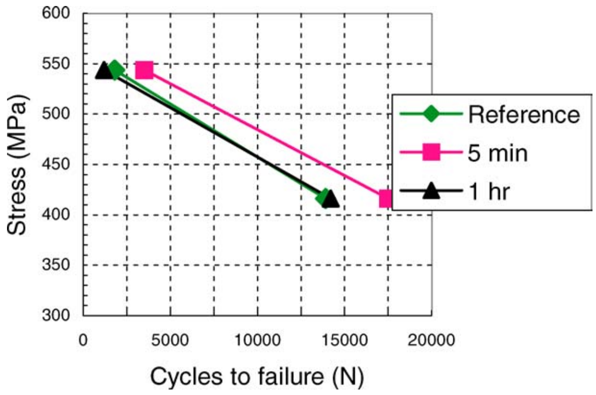

Figure 5 The hold time effect of 5 min and 1 h on the reference specimens.

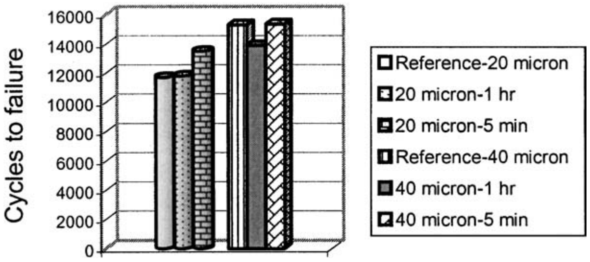

Figure 6 The hold time effect of 5 min and 1 h on the coated specimens.

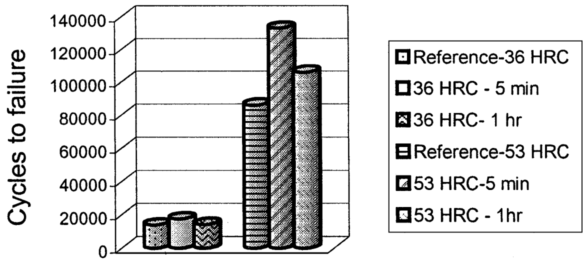

Figure 7 The hold time effect of 5 min and 1 h on the hardened specimens.

by 30%, and for 40 μ coating it was improved by 15% with respect to 1 h period.

The same trend of hold time effect was also observed for the hardened specimens. The apparent impact of 5 min hold time over both the reference and 1 h period has been shown in Fig. 7. Here, the fatigue life improvement was 50 and 30%, respectively. Fig. 7 illustrates how simultaneous hardening and short period hold time can increase the cyclic life.

Fig. 8 depicts very long hold time effects under relatively lower load of 42 kg. In this case, while 15 h wait period at the half life of the virgin material increased the reference life by a factor of 1.5, 9 h hold time at the same remaining life of the hardened specimen (53 HRC) improved the reference life by a factor of 5.

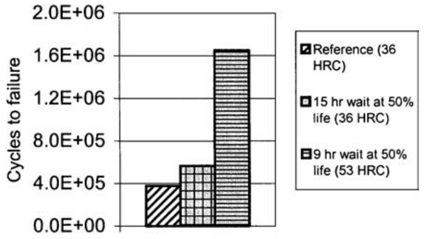

Figure 8 The very long hold time effect under 42 kg load on the reference and the hardened specimens.

The present study concludes that thermal hardening and hold time tests have major impact on the fatigue properties of the aforementioned steel. The heat treatment actually escalated the endurance life by 6 to 9 times. Similarly, hold time periods applied at half-life increased the life up to 50%. An interesting result has been brought to light that short time hold period of 5 min is more efficient than 1 h period in improving the fatigue lives. This finding is linked with internal static and dynamic recovery mechanisms [13]. It has also been revealed that copper coating doubled the fatigue life in the low cycle fatigue regime for higher loads while number of cycles to failure were decreased depending on decreasing stress with respect to the reference experiments. One of the outcomes of the study is that increasing coating thickness will have nonlinear positive improvement on the fatigue life.

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