Evaluation of fatigue properties of EN31 steel heat treated using biodegradable gingili oil

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Abstract. Rotating bending fatigue is the most commonly encountered loading in most machines and machine tools. At the same time, modern literature in this area is very little. EN31 steel is a steel which is commonly used in load bearing applications which encounters fatigue loading. Further, studies on heat treated EN31 steel to improve fatigue strength is hardly reported. This paper takes this rare issue further ahead by using bio-degradable gingili oil to heat treat EN31 steel for fatigue applications. This paper reports the results of rotating bending fatigue study of EN31 steel. Fatigue tests were conducted for three conditions a) Untreated, b) Heat treated with water, and c) Heat treated with gingili oil, with cantilever loads ranging from 30% to 90% using double sided rotating bending fatigue testing machine. It is seen that EN31 steel heat treated using gingili oil has far superior fatigue properties than water treated and untreated ones, with gingili oil quenched specimen have ~10 times more fatigue life than water quenched specimen and ~100 times more than unquenched specimens when lower bending stresses are involved.

1. Introduction

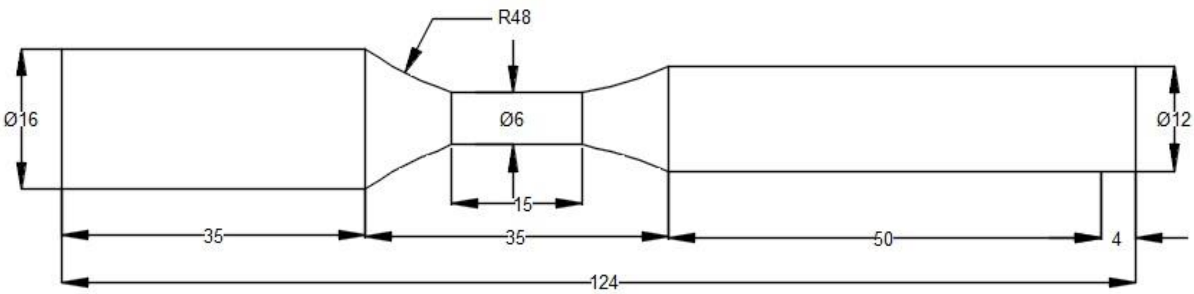
Fatigue fracture is one of the major failure mode for structures and machine parts under cyclic loading [1]. The variable load in the machine parts and the structural elements influence their fatigue strength [2, 3]. It is also based on the type of the heat treatment, work hardening processes, load, material characteristics and operating temperatures, the elastic response during the cyclic loading which has its effect on crack initiation and propagation of the fatigue failure, one of the major modes of material failure which it is dependent upon [4].

From the literature it is understood that, surface induced fracture occur at high stress levels in fatigue fracture [5,6,] and the direct work hardening process helps in surface hardening. In the process of work hardening, water is regarded as the quenchant which is most often utilized, but petroleum based quenchants are utilized where more uniform cooling and a better control over distortion and crack prevention is preferred. Also it is evident from literature that the improved properties of EN 31 steel can be achieved if the material is quenched in biodegradable oil such as Gingili oil, soybean oil substituting the petroleum based oil [7].

EN31 steel which is a type of high carbon steel has high dimensional stability with added wear resistance mainly used in ball and roller bearings, spinning tool, beading rolls, punches and dies, shafts, bolts, studs, gear components or propeller etc., [8]. Hence an attempt is made to work harden the material by using different quenchants and conduct a fatigue test to find the fatigue life of EN31 steel which is being not heat treated condition and heat treated and quenched in biodegradable gingili oil and water quenched condition.

2. Materials and methods

Determination of fatigue characteristics is mainly through the stress vs. no. of cycles to failure curve, which is very commonly known as S-N curve. The fatigue test was conducted as per IS 5075: 1975 (Reaffirmed 2006) standards. The specimens for the test were machined on a lathe from EN31 rods to the shape as shown in Figure 1.



All dimensions in mm.

Figure 1. Fatigue test specimen.

The composition of EN31 specimens was confirmed using Baird's Optical Emission Spectroscopy method. Table 1 shows the composition of the raw material.

Table 1. Composition of EN31 used in the test.

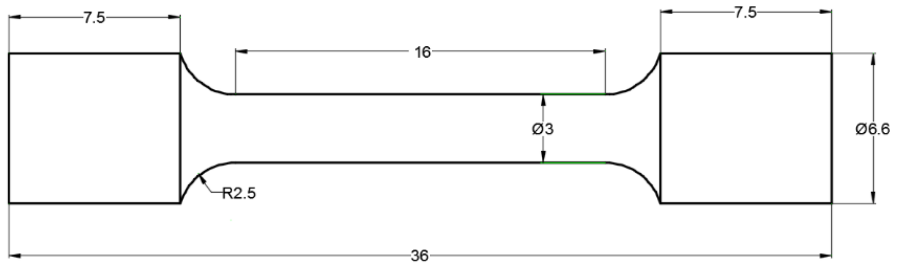
Element →	C	Si	Mn	P	S	Cr	Mo	Ni	Fe
% composition	1.055	0.216	0.325	0.013	0.022	1.415	-	-	Remaining
Specification requirement[9]	0.90-1.20	0.10-0.35	0.30-0.75	<0.04	<0.04	1.00-1.60	-	-	Remaining

2.1. Heat treatment:

Here the direct hardening process, one of the most known heat treatment processes for carbon steels is utilized. The specimens were heated to austenization temperature i.e. 860 ^{O}C in an electric furnace. The specimens were soaked for a period of 1 hour at 860^{O}C. The specimens were then removed from the furnace and dropped into gingili oil bath/water bath. It took less than 15 seconds for the specimens to be removed from the furnace and dropping them into the bath. The specimens were allowed to be naturally cooled down in the oil to room temperature. Later, the specimens were tempered at 450^{O}C. For this, the specimens were heated to 450^{O}C in the furnace, soaked at that temperature for one hour, and the allowed to air cool. Then the specimen were cleaned to remove rust and oxide formed on the surface. Figure 2 shows the specimens heat treated in gingili oil.

2.2. Tension test:

The application of load for fatigue test experiments requires the loads to be calculated based on Ultimate Tensile strength (UTS) of the material. Determination of UTS requires conduction of the tension test. Hence, initially tension test was conducted by preparing the specimen as per ASTM E8 standards. Accordingly, tension test specimens were prepared as shown in figure2.



All dimensions in mm.

Figure 2. Tension test specimen.

2.3. Fatigue testing machine:

The fatigue test was carried on a two sided rotating bending fatigue testing machine. Figure 3 shows the rotating bending fatigue testing machine. This machine has an induction motor which has a shaft extending either sides. Facility for mounting the specimens on both sides of the shaft is provided, and the specimens are mounted using collets. The loading is of cantilever type. The free end of the specimen can be loaded. The specimens can be mounted on both sides and tests can be done simultaneously. Two digital indicators are provided which count the number of turns of the specimen. The advancing of the value of the indicator stops the moment the corresponding specimen fails. Even when one specimen fails the other specimen keeps rotating till the other specimen too fails. Once the other specimen fails, the indicator stops advancing, and the reading of the indicator can be noted down.

Figure 3. Fatigue testing machine.

2.4. Fatigue testing:

One end (holding end) of the specimen were mounted on both the ends of the motorized shaft using collets. The free end of the specimen was loaded with loads calculated based on 30%, 40%...... of the UTS. The loads that were required as per the calculations were rounded off to nearest 0.5kg, keeping in mind the availability of the loads. Based on these rounded off values of the loads the %UTS was back calculated and tabulated. Once both the specimens were mounted and loads applied, the motor was switched on which run at 1,650 rpm and allowed to rotate till the specimens broke. Once the specimens broke, the readings of the number of turns in the indicator corresponding to the specimen was tabulated.

3. Results and discussion:

3.1. Tension test

At first, there is a drastic increase in the UTS of heat treated specimens as compared to the untreated ones. This increase is ~2.2 times in water quenched ones and ~2.5 times in gingili oil quenched ones Thus there is ~120% increase in the UTS life of the water quenched specimens and ~150% increase in case of gingili oil quenched specimen. Figure 4, indicates the UTS of untreated, water treated and gingili oil treated specimens.

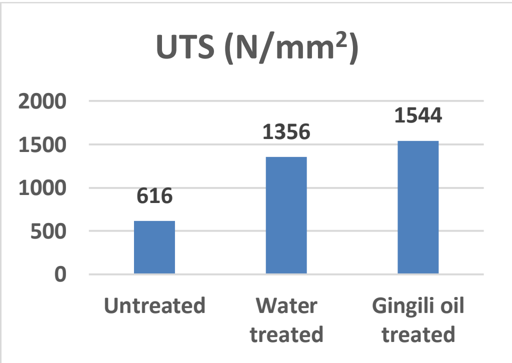


Figure 4. UTS of untreated, water treated and gingili oil treated specimens.

3.2. Fatigue test

The results of the EN31 steel specimen tested for fatigue under the three conditions, a) without heat treatment, b) heat treated and quenched in water, and c) heat treated and quenched in gingili oil. Six set of experiments were conducted for each condition and the results are discussed below with the help of SN curves.

3.2.1. SN Curves

SN curve is drawn with logarithm of no. of cycles for failure along x axis and bending stress along y axis. The bending stress was calculated using the equation (1).

$$\sigma = \frac{L \times P \times 32}{\pi \times d^3} \quad (1)$$

Where,
L = Distance from fixed end of the specimen to specimen's contact point with loading arrangement (mm)
d = Diameter at the neck of the specimen (mm)
P = Load applied (N)

The values of bending stresses (in this case alternating fully reverse alternating bending stresses are involved. Hence bending stresses are indicated on y-axis unlike stress in axial loaded fatigue testing) and the corresponding fatigue life N (log10) i.e. on a logarithmic scale for which the graph is plotted and is as shown in figure 5.

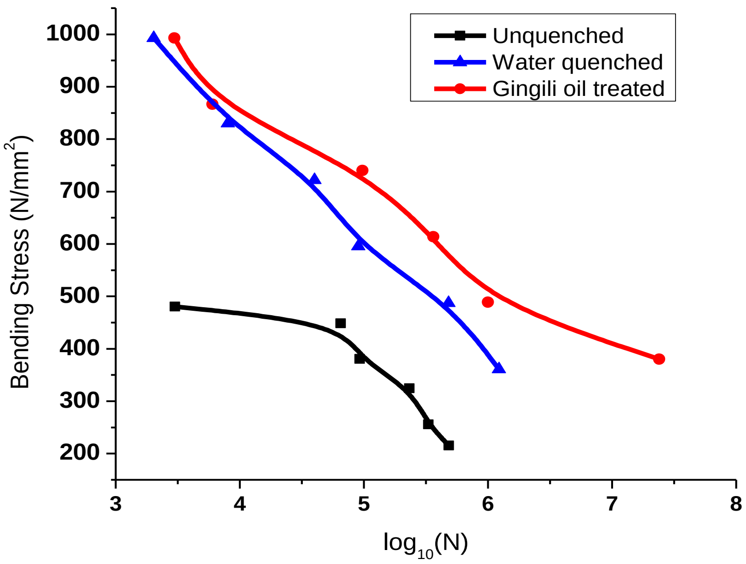


Figure 5. SN curves of untreated, water treated and gingili oil treated specimens.

Figure 5, shows the SN curves of the three condition. One obvious phenomenon that can be observed through all the curves is that, as the stress increases, the number of cycles for fracture reduces. However it can be noticed that for the stress values the water quenched specimens withstand ~10 times higher the number of cycles before failure, and the gingili oil quenched samples withstand ~150 times the number of cycles before failure when compared to the unquenched ones. Even if we consider a design for a fixed number of cycles, say 10^5 cycles, while unquenched samples can withstand a stress of ~210 N/mm^2, the water quenched samples can withstand 480 N/mm^2, and the gingili oil quenched samples can withstand a stress of ~600 N/mm^2. Although at higher levels of stresses, both water quenched and gingili oil quenched withstand only ~2 times the number of cycles of operation, as the stress levels reduce, it can be noticed that it goes up to 10 times, with gingili oil quenched samples being on the higher side. Thus gingili oil quenching can be a good candidature for improving the fatigue life of EN31 steel as it exhibits a higher fatigue life when compared to the other two cases.

4. Conclusions

1) Both water quenched and gingili oil quenched specimens have significantly higher UTS than that of the unquenched specimens of EN31 steel, however gingili oil quenched specimens have much higher UTS than even the water quenched specimen.
2) Although both water quenched specimens withstand higher fatigue cycles before failure when compared to unquenched EN31 steel, the gingili oil quenched specimen have ~10 times more fatigue life than water quenched specimen and ~100 times more than unquenched specimens when lower bending stresses are involved.
3) At higher levels of stresses gingili oil quenched specimens have ~2 times the life of water quenched specimens.

4) As gingili oil quenched EN31 steels exhibits a higher fatigue life compared to others, it has a better scope for applications involving fatigue loading.

5. References:

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