EFFECT OF SURFACE TREATMENT ON THE FATIGUE PERFORMANCE
OF AISI4340 STEEL

Ahmed M. Mosa

Abstract:

The effect of surface treatment on fatigue life of AISI4340 steel was studied. The specimens were heat treated by oil quenching, then they were low tempered at 200°C, medium tempered at 320°C and high tempered at 650°C. The specimens were then tested. Best fatigue performance was obtained from high tempered specimens. The surface of 650°C tempered specimens was then ground, polished, and chromium plated. It was found that best fatigue performance was obtained from specimens that were oil quenched and tempered at 650°C, then polished.

Introduction:

Fatigue is the progressive, localized and permanent structural change, that occurs in a material subjected to repeated or fluctuating strains, at engineering stresses that have values well below tensile strength of that material [1].

Fatigue may cause fracture after a sufficient number of fluctuations. The process of fatigue consists of crack initiations, crack propagation to a critical size, then sudden fracture of the remaining cross-section [2].

The fatigue damage is caused by the simultaneous action of cyclic stress, tensile stress and plastic deformation. The plastic deformation caused by repeated stress initiates the crack, and the tensile stress leads to crack growth. So, the variations in mechanical properties, chemical composition, microstructure and macro-structure, have reasonable effect on fatigue resistance of the material [3].

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Mosa studied the effect of surface finish of AISI 1005 steel specimens. It was concluded that an improvement of 50% in fatigue life was obtained for ground specimens as compared to turned specimens [4]. Ball states that high work-hardening capacity materials lead to great improvement in wear and fatigue resistance [5]. Shephard et al, states that better surface finish and deeper thermally stable compressive residual stresses, lead to superior fatigue resistance [6]. Spice et al, studied the effect of vacuum carburizing, reheating to refine grain size and gas-carburizing specimen. It was concluded that reheating gives the best results [7].

Altenberger et al, found that deep rolling was quite effective in retarding the initiation of fatigue crack for Ti-6Al-4V specimen [8]. Gean indicates that neither nugget porosity nor weld size has any significant effects on fatigue properties of the weld [9].

Experimental Techniques

Ultra – high strength AISI4340, was studied for its wide use in aircraft and automotive industries, such as: gears, shafts, connecting roads, crankpin…etc. Chemical composition and mechanical properties are shown in Table 1, for annealed, 200mm diameter bar as received from Al-Kindi company.

<table>
<thead>
<tr>
<th>Element (wt%)</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Mn</td>
</tr>
<tr>
<td>0.39</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Fatigue and tensile specimens were turned on copy machine lathe TOS-SN50B. Impact specimens were machined on universal milling machine, Iwashita NK65.

Heat treatment procedure for the specimens, in volves electrical furnace Heraeus-KR170: heating to 870C, holding time 20 minutes, and quenching in mineral oil. Tempering procedure was: low tempering at 200C for 80 minutes, medium tempering at 320C for 80 minutes, and high tempering at 650C for 80 minutes. Normalizing was chosen as a substitution for quenching and high tempering. Charpy impact tests were carried out on impact testing machine Amster PW 30/15 K. Tensile tests were carried out on Tokyokoki universal testing machine –RUF50. Rockwell hardness tests were carried out on universal hardness machine Wolpert-Diastar 2RC. Fatigue tests were carried out on Rotary-Bending
machine Schenck-WP 120. All tests were conducted in Mechanical Testing Laboratory, Mosul Institute of Technology and in Mechanical Engineering Department, Mosul University.

High tempered specimens at 650C, gave the best results for fatigue performance as shown in Table (2). Then the surface of high tempered specimens at 650C was treated as follows: Group (1), grinding with silicon carbide emery paper grade 320 for 5 minutes. Group (2), grinding, polishing by magnesia grade 4 micron for 5 minutes. Group (3) grinding then Chromium electroplating. Then fatigue tests were conducted on these specimens. Best results for fatigue performance were for polished specimens.
Table (2): Mechanical Properties of UHS 4340 Steel after Heat – Treatment

<table>
<thead>
<tr>
<th>Heat-treatment</th>
<th>Yield strength (Y.S) Mpa</th>
<th>UTS Mpa</th>
<th>Elong %</th>
<th>RA %</th>
<th>Hardness</th>
<th>Y.S. UTS</th>
<th>Impact strength $A_k$ J/cm$^2$</th>
<th>Endurance limit Mpa</th>
<th>Endurance limit UTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized From 870C</td>
<td>861</td>
<td>1279</td>
<td>12</td>
<td>36</td>
<td>HRC36 (HB363)</td>
<td>0.67</td>
<td>62</td>
<td>345</td>
<td>0.27</td>
</tr>
<tr>
<td>Oil Q. 850C &amp; Tempered at 200C</td>
<td>1680</td>
<td>1980</td>
<td>11</td>
<td>39</td>
<td>HRC53 (HB520)</td>
<td>0.85</td>
<td>25</td>
<td>550</td>
<td>0.28</td>
</tr>
<tr>
<td>Oil Q. 850C &amp; Tempered at 320C</td>
<td>1620</td>
<td>1760</td>
<td>12</td>
<td>44</td>
<td>HRC49 (HB490)</td>
<td>0.92</td>
<td>17.5</td>
<td>500</td>
<td>0.284</td>
</tr>
<tr>
<td>Oil Q. 850C &amp; Tempered at 650C</td>
<td>860</td>
<td>1020</td>
<td>20</td>
<td>60</td>
<td>HRC31 (HB290)</td>
<td>0.84</td>
<td>125</td>
<td>465</td>
<td>0.447</td>
</tr>
</tbody>
</table>
Discussion:

1. Effect of Heat Treatment on Mechanical Properties of AISI4340 Steel.

Visualizing mechanical test results from heat-treated 4340 steel specimens, tabulated in Table (2), it can be noticed that specimens tempered at 650°C have better ductility, impact strength, and endurance limit to tensile strength ratio. Also, when comparing normalized and 650°C tempered specimens (Fig 1 and Table 2), although normalized specimens have better hardness and tensile strength, endurance limit and impact strength are low. The cause can be expressed as follows: 650°C tempered specimens, since they have higher ductility, then they have greater ability for continuous permanent shape variation at surface irregularities, leading to redistribution of surface stresses, so decreasing strain-hardening would issue at the surface as a consequence of shape variation, and this would delay cracks propagation, and hence higher endurance limit.

2. Effect of Surface Hardness on Endurance Limit.

From Fig 2, it can be observed that higher hardness values increase endurance limit for tempered AISI4340 steel specimens for high-cycle regime (>10⁴). But endurance limit was impaired for low-cycle regime (<10⁴), and high repeated stresses, because ductility is the more important factor. This can be explained as lower ductility and toughness, with higher hardness values, will lead to smaller strain-hardening values and redistribution of surface stresses, but higher local stresses will encourage crack propagation at low cycle regime [8].


Fig. 3, shows that endurance limit for AISI4340 steel specimen, is directly proportional to hardness, and tensile strength, but inversely proportional to impact strength for tempered specimens.

Stresses are concentrated at internal and external discontinuities. The values of these stresses are high, and are hard to be estimated. If the value of these stresses is higher than cohesive resistance of the steel particles, then microscopic crack may be initiated, and spread at a specific speed depending on repeated stress value and number of cycles [10]. Also, thermal stresses may be induced in steel due to mechanical machining and heat treatment. The stress values depend on: drastic quenching, tempering temperature, and type of machining. Fatigue failure is caused by combination of internal stresses effect with stresses caused by external loads [5]. The effect of surface roughness and internal stresses is readily seen from Fig.(4).

Polished AISI4340 steel specimens have greater endurance limit, because rough surfaces are stress concentration areas, thus leading to decreasing endurance limit. The ground, chromium plated specimens have lower endurance limits due to higher tensile internal stresses caused by electroplating [6].

Conclusions:

1. Endurance limit is directly proportional to hardness and tensile strength, but inversely proportional to impact strength.

2. 650C tempered AISI4340 steel specimens have optimized results of ductility, toughness, impact strength, and endurance limit to tensile strength ratio.
3. Polished AISI4340 steel specimens have greater endurance limit compared to ground and chromium plated specimens.

Fig (1): S-N Curve for AISI 4340 Steel at Various Heat Treatment

Fig (2): S-N Curve for AISI 4340 Steel at Various Brinell Hardness
Fig(3): Endurance Limit Relationships for AISI4340 steel

Fig(4): Effect of Surface Roughness on Endurance Limit on
Reference