EFFECT OF PRE-STRAIN ON FATIGUE PROPERTIES 
IN LOW AND HIGH CARBON STEELS 

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ABSTRACT

In this work, Fatigue tests have been performed to investigate the fatigue damage process for two kinds of plain carbon steels, (low and high carbon steels). The effect of pre-strain process on fatigue crack initiation and fatigue strength has been examined. The main results obtained are summarized as follows: (1) In the case of low carbon steel (0.15%C), the fatigue limit of $\varepsilon_p=0\%$ (non-pre-strained specimen) is higher than or equal to those of $\varepsilon_p=2\%$ and $\varepsilon_p=5\%$ pre-strained specimens and lower than that of $\varepsilon_p=8\%$ pre-strained specimens. (2) In the case of high carbon steel (0.46%C), the fatigue limit of $\varepsilon_p=0\%$ (non-pre-strained specimen) is higher than those of $\varepsilon_p=2\%$, $5\%$ and $8\%$ pre-strained specimens. (3) Though the fatigue limits of pre-strained specimens are lower than those of non-pre-strained specimen, the fatigue limits increase according to the increasing of pre-strain percentage for both of tested material.

1. INTRODUCTION

Most of plain carbon steels are practically used after plastic deformation caused by tensile or bending process. It will be consider that it is very important to investigate the effect of pre-
from the crack of pearlite block and the plastic slip between ferrite grain and pearlite block which appeared after pre-straining process.

Finally, it seems to be clear that the fatigue crack initiation is highly affected by the weak field of plastic slip which appeared in pearlite block after pre-straining.

4. CONCLUSIONS

From this study, the following conclusions may be drawn:

1. In the case of tensile test, the plastic slip is generated in the boundary area between ferrite grain and pearlite block by total strain of 5% for material A (low carbon steel), and the cracks are observed in pearlite block by the total strain of 4.8% for material B (high carbon steel).

2. In the case of material A, the fatigue limit of pre-strained $\varepsilon_p=2\%$ is lower than that of $\varepsilon_p=0\%$. On the other hand, the fatigue limit of pre-strained $\varepsilon_p=5\%$ is equal to that of $\varepsilon_p=0\%$, and the fatigue limit of pre-strained $\varepsilon_p=8\%$ is higher than that of $\varepsilon_p=0\%$.

3. In the case of material B, the fatigue limit of non-pre-strained $\varepsilon_p=0\%$ is higher than those of pre-strained $\varepsilon_p=2.5\%$ and 8%, respectively.

4. The fatigue limit of pre-strained specimen is lower than the non-pre-strained ones, and the fatigue limit increases due to the increasing of pre-strain for both of tested materials.

REFERENCES


strain process to fatigue properties. Until now, researches about static tensile and fatigue test for non-pre-strained specimen have been reported, but the research for pre-strained specimen is limited [1-6]. Low and high carbon steels (0.15% C and 0.46%C) have been used in this work. In the case of low carbon steel, after tensile test, it has been observed that the plastic sliding is generated in the boundary area between ferrite grain and pearlite block by total strain of $\varepsilon_p=5\%$ without crack initiation. On contrary, for high carbon steel, after tensile test, cracks are initiated in pearlite block by total strain of $\varepsilon_p=4.8\%$ [7].

Therefore, it is interesting to investigate the influence of pre-strain on fatigue properties such as fatigue crack initiation, and to study the behaviour of plastic slip and micro-cracks which initiated by tensile test.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The chemical composition and mechanical properties of tested material are shown in tables (1) and (2), respectively. Furthermore, material grain size was unified by annealing at 900°C for 2 hrs (for 0.15%C carbon steel), and 990°C for 2 hrs (2 times) (for 0.46%C carbon steel) the mechanical properties were evaluated in the rolling direction.

The specimens from the material were cut out and were machined in the rolling direction concerning with the partial notch at the rolling surface as shown in Fig.(1).

The specimens were soaked at 600°C for 1hr, next cooling to room temperature for stress relief annealing, then the specimens were polished by mechanical polishing, finally were etched.

The pre-strain was given to specimen using a universal testing machine. The fatigue tested specimens were machined from the pre-strained specimens to the shape and dimensions as shown in Fig.(1). On contrary, fatigue test was carried out at room temperature using rotating bending fatigue testing machine at speed of 2880 R.P.M. Fatigue micro-cracks were observed by successive taken replica method on the circumferencial direction of the specimen surface. The taken replicas of the specimens were examined using
metallurgical microscope and scanning electron microscope, SEM (Jeol Ts-20 Japan).

Table (1) : Chemical composition

<table>
<thead>
<tr>
<th>Material</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.15</td>
<td>0.22</td>
<td>0.55</td>
<td>0.034</td>
<td>0.025</td>
<td>----</td>
</tr>
<tr>
<td>B</td>
<td>0.46</td>
<td>0.20</td>
<td>0.73</td>
<td>0.029</td>
<td>0.017</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Table (2) : Mechanical properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Mechanical properties</th>
<th>Heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\sigma_u$ MPa</td>
<td>$\sigma_y$ MPa</td>
</tr>
<tr>
<td>A</td>
<td>440</td>
<td>283</td>
</tr>
<tr>
<td>B</td>
<td>632</td>
<td>360</td>
</tr>
</tbody>
</table>

$\sigma_u$: Tensile strength, $\sigma_y$: Yield strength, $\psi$: Reduction of area, A.C.: Air cooling, F.C.: Furnace cooling

3. RESULTS AND DISCUSSION

The stress-strain curves of both tested materials are shown in Fig.(2). The changes of surface state during static tensile test process for both materials 0.15%C (material A) and 0.46%C (material B) are shown in Fig. (3). The plastic slip is generated in the boundary area between ferrite grain and pearlite block by total strain of 5% for material A, while the cracks generating are observed in the pearlite block by total strain of 4.8% for material B.

The changes of surface state of the pre-strained specimen are significant at about $\varepsilon_p=5\%$. It is reasonable to choose this level pre-strain to investigate the effect of pre-strain process to the fatigue properties. In addition, pre-strained $\varepsilon_p=2\%$ and $\varepsilon_p=8\%$ specimens are also employed in order to represent the lower and higher pre-strain cases.

The S-N curves of both materials A and B are shown in Figs. (4) and (5). From the curves, it is concluded that, the fatigue limits of material A (0.15%C) reached by $1 \times 10^7$ cycles at pre-strain $\varepsilon_p=0, 2, 5$ and 8% are 205, 200, 205 and 220 MPa, while the fatigue limits of
material B (0.46%C) reached by $1 \times 10^7$ cycles at $\varepsilon_p=0, 2, 5$ and 8% are 250, 215, 235 and 245 MPa, respectively.

The comparison of the fatigue limits of pre-strained specimens to the non-pre-strained one is shown in Fig. (6). It is remarked that, (1) for material A, the fatigue limit of $\varepsilon_p=2\%$ pre-strained specimen is lower than that of the non-prestrained specimen ($\varepsilon_p=0\%$) by 2.4%, while the fatigue limit of $\varepsilon_p=5\%$ is equal to the fatigue limit of $\varepsilon_p=0$ (non-prestrained specimen), and on contrary, the fatigue limit of $\varepsilon_p=8\%$ is higher than that of the $[\varepsilon_p=0\%]$ by 7.3%, (2) for material B (0.46%C), the fatigue limit of the non-pre-strained specimen is higher than that of the pre-strained specimens, especially for material B, the fatigue limit of $\varepsilon_p=2\%$ is lower than that of $\varepsilon_p=0\%$ by 35 MPa. Though the fatigue limit of pre-strained specimens are lower than that of the non-pre-strained one, the fatigue limit of pre-strained specimens increases due to the increasing of pre-strain for both kinds of material.

The improvement of fatigue limit have been reported in a previous researches [1-4]. But in this study, the fatigue limit of pre-strained specimen for high carbon steel, such as material B (0.46%C) become worse than that of non-pre-strained. This can be attributed to the crack initiation and plastic slip which appeared after static tension (pre-strain).

Fatigue micro-cracks have been observed by successive application of taken replica technique on the circumferential direction of the specimens for material A and material B, as shown in Figs. (7), and (8). Further details of the fatigue cracks initiation in Fig. (8) are shown in Figs. (9) and (10) by SEM observation.

For material A (0.15%C) Fig (7), the cracks in $\varepsilon_p=2\%$ specimen initiate from the plastic slip of ferrite transcrystalline and intercrystalline which appeared after pre-straining process. The cracks in $\varepsilon_p=5$ and 8% specimens initiate from the plastic slip between ferrite grain and pearlite block which appeared after pre-straining process. For material B (0.46%C) [Figs. (8), (9) and (10)], the cracks in $\varepsilon_p=2\%$ specimen initiate from the plastic slip between ferrite grain and pearlite block which appeared after pre-straining process. Further the cracks of $\varepsilon_p=5\%$ and 8% specimens initiate
7. Abo El-Ainene, A. M., “Crack Initiation in Plain Carbon Steels During Static Tension and Fatigue”, to be Published.
Fig. 1 Shape and dimensions of specimen. mm.

Fig. 2 Stress-strain curves.
Fig. 3 Changes of surface state during pre-strain process.

Fig. 4 S-N curves of material A (0.15%C).
Fig. 5 S-N curves of material B(0.46%C).

Fig. 6 Relation between $\sigma_w/\sigma_{wo}$ and $\varepsilon_p\%$. 
Fig. 7 Successive observation of fatigue crack initiation of pre-strained specimen (material A:0.15% C).
Fig. 8 Successive observation of fatigue crack initiation of pre-strained specimen (material B: 0.46% C).
Before pre-strain ($\varepsilon_p = 0$)  
$\varepsilon_p = 2\%$, $\sigma_a = 280$ MPa, $N_f = 19.8 \times 10^4$ cycles

After pre-strain ($\varepsilon_p = 2\%$)

$\varepsilon_p = 2\%$, $\sigma_a = 280$ MPa, $N_f = 19.8 \times 10^4$ cycles

Axial direction

Fig. 9 Successive observation of fatigue crack initiation of pre-strained specimen using SEM (material B:0.46\% C).

Before pre-strain ($\varepsilon_p = 0$)  
$\varepsilon_p = 5\%$, $\sigma_a = 250$ MPa, $N_f = 78.5 \times 10^4$ cycles

After pre-strain ($\varepsilon_p = 5\%$)

$\varepsilon_p = 5\%$, $\sigma_a = 250$ MPa, $N_f = 78.5 \times 10^4$ cycles

Axial direction

Fig. 10 Successive observation of fatigue crack initiation of pre-strained specimen using SEM (material B:0.46\% C).
تأثير الانفعال المسبق على خصائص الكلال
لكل من الصلب المنخفض والعالي الكربون

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ملخص البحث:

يهدف هذا البحث إلى دراسة تأثير انفعال الشد المسبق على خصائص الكلال لكل من الصلب المنخفض والعالي الكربون. وتم في البحث إعداد عينات اختبار الكلال بعد تعرضها لانفعال شد مسبق. كذلك اشتمل البحث على إجراء اختبارات الكلال الانحنائية الدوارية. وشمل البحث على استخدام الـ Replication tecnique للاحظة منشأ شرح الكلال باستخدام كل من الميكروسكوب الضوئي والميكروسكوب SEM. 

ولقد خلص البحث إلى أن قيمة حد الكلال التي تم تعريضها لانفعال شد مسبق تكون أقل من قيمةها عما في حالة عدم تعرضها، وعلى أن حد الكلال يتزايد بتزايد الانفعال المسبق لكلا النوعين من الصلب.