Research Article

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Effect of grain size on fatigue strength of 304 stainless steel

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Abstract: In this study, three types of 304 stainless steel samples with different strengths were prepared by refining the grain size through rolling. The microstructure of the samples was observed by electron microscopy. The influence of grain size on the static tensile properties and fatigue strength of the material is mainly attributed to changes in the plastic deformation fracture mechanism and micro-deformation mechanism. In addition, a new fatigue strength prediction model is proposed based on the influence of tensile strength and work-hardening capacity. Compared with the staircase method and Basquin formula models, the proposed model maintains the accuracy of fatigue strength prediction while reducing the cost of fatigue experiments. This provides a new approach for predicting the fatigue strength of specific materials and improving anti-fatigue design capabilities.

Keywords: grain size, microscopic deformation mechanism, tensile strength, work hardening ability, fatigue strength prediction

1 Introduction

Fatigue failure has been widely recognized as one of the primary failure modes for engineering materials under long-term cyclic loading. Statistics show that 90% of failures in metallic materials are caused by fatigue damage. Typically, fatigue performance optimization is achieved through anti-fatigue design [1]. However, the time-consuming and effort-consuming of fatigue experiments make the development and selection of materials lag seriously. To solve this problem, a simple and effective fatigue strength prediction model is very necessary.

The prediction of fatigue strength has been one of the hot topics in materials science in recent years. In 1870, Wohler proposed a linear relationship between fatigue strength and tensile strength/yield strength. Based on this correlation, Wohler’s criterion suggested that improving the tensile strength of metal materials may improve their fatigue performance. This criterion is still in use today [1,2]. Basquin discovered an obvious linear relationship between the logarithms of S–N curves, which led to the empirical relationship of S–N curves [3–5]. In addition, fatigue strength has a certain relationship with other mechanical properties and the microstructure of the material. With the development of material-strengthening mechanisms, such as solid solution strengthening, grain refinement, precipitation strengthening, the strength of materials has been significantly improved [6–8]. Murakami proposed a fatigue strength prediction model based on the relationship between material hardness and defect size [9]. Thus began the quantitative study of fatigue strength. Beretta improved Murakami’s model and proposed a method for predicting fatigue strength based on maximum material defects [10]. Pang believed that there was a linear relationship between material hardness and tensile strength. Based on this insight, he improved Murakami’s model and concluded that there is a parabolic relationship between fatigue strength and tensile strength [11]. Liu and Zhang proposed a theoretical model that simultaneously considered fatigue damage and internal resistance. The ratio of fatigue strength to yield strength is used as an indicator of the degree of fatigue damage localization, while the ratio of yield strength to fatigue strength is used as an indicator of the material’s resistance to internal fatigue damage [12]. There is a linear relationship between the two ratios. With the continuous improvement of the experimental level, researchers found that the engineering stress–strain curve ignored the influence of the Poisson effect of materials, so they took into account the non-uniformity of stress distribution and put forward the real stress–strain curve, which can more accurately study the mechanical properties of materials. Mengxiao Zhang and Jian Chao Pang combined the fatigue strength with the real stress–strain curve and took the
difference between the highest point and the elastic limit in the real stress–strain curve as the characteristic quantity of the plastic limit [13]. Stinville and Charpaigne conducted a quantitative analysis of the relationship between microstructure and single slip positioning events. They utilized multimodal data to examine the effects of slip action on the deformation of metal alloys and proposed that the fatigue strength of these alloys could be predicted by considering the amplitude of slip positioning during the initial loading cycle [14]. The common feature of these studies is to predict fatigue strength based on the tensile properties of materials.

In this article, we investigated the influence of grain size on static tensile properties and fatigue strength. A series of 304 austenitic stainless steel (SS) specimens with different grain sizes through rolling treatment were obtained. The effects of different rolling deformation on mechanical and fatigue properties were examined, and the relationship between tensile strength and fatigue strength was explored. In addition, a new fatigue strength prediction model was proposed based on the influence of tensile strength and work-hardening ability. The fatigue strength was calculated using this model and compared with the fatigue strength calculated using the Basquin method and staircase method. The advantages and disadvantages of these three methods in calculating fatigue strength were compared.

2 Experimental materials and methods

In this experiment, 304 austenitic SS was used as the experimental object, and its chemical composition is listed in Table 1.

Table 1: Chemical composition of 304 SS

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>0.054</td>
<td>0.79</td>
<td>0.002</td>
<td>0.034</td>
<td>0.42</td>
<td>17.27</td>
<td>8.14</td>
<td>73.29</td>
</tr>
</tbody>
</table>

To obtain 304 SS with different grain sizes, the samples were prepared by the following methods. The 304 SS was heated at 600°C, held for 30 min, and taken out as the original sample (sample A). Then, 30 and 70% deformation treatments were carried out on the rolling mill, respectively, and two 5 mm-thick SS plates were obtained. The original and rolled samples were regarded as three samples with different grain sizes, denoted as A, B, and C, respectively. They are processed into standard tensile and fatigue specimens by a wire-cutting machine. To eliminate the surface differences between the samples, 400# 800# 2000# sandpaper was used for polishing. In this experiment, the original state, 30% deformation, and 70% deformation samples were, respectively, tested with a uniaxial tensile test and a high cycle fatigue test. The sample sizes of the tensile test and fatigue test were the same, as shown in Figure 1.

Tensile tests were conducted at a strain rate of $10^{-3}$ s$^{-1}$ on the electronic universal test machine INSTIRN 5982, which was controlled by displacement. Three sample tests were carried out on different rolled samples to measure the engineering stress–strain curve of each specimen. The full load of the testing machine was ±100 kN.

Stress-controlled symmetric push–pull fatigue tests were carried out on a servo hydraulic fatigue testing machine INSTORN 8850. Fatigue tests were carried out under uniaxial and sinusoidal loading at a frequency of 30 Hz up to $5 \times 10^6$ cycles. The fatigue strength at $5 \times 10^6$ cycles was determined by the staircase method.

The average size of the three grains was measured by the intercept method. First, we drew a horizontal or vertical straight line on the electron back scatter diffraction (EBSD) diagram and calculated the number of intersections between the grain boundary and the straight line. Then, the grain size was calculated according to the following formula:

$$d = \frac{L}{P_i},$$

where $d$ is the grain size, $L$ is the length of the straight line, and $P_i$ is the number of intersections between the grain boundary and the line. To reduce the error, each specimen was calculated five times. We measured rolling direction...
(RD) and transverse direction (TD) on the EBSD diagram and finally took the average value as the final value. The grain sizes of A, B, and C samples were 22.3, 3.5, and 2.0 μm, respectively.

3 Results

The staircase method is one of the most commonly used methods for determining the fatigue strength of materials. It is a widely accepted method in the field and has established credibility in evaluating the fatigue properties of materials. Therefore, this experiment adopted the staircase method to measure sample’s fatigue strength.

The staircase method is a method to determine the fatigue limit under a specified cycle base or to determine the fatigue strength under a fixed cycle. The test starts at a stress level higher than fatigue strength and then gradually decreases. If fatigue strength is unknown, yield power or 0.3–0.45σb may be selected as the initial stress. The first test shall be conducted at the specified stress level. If the failure occurs before the specified life of N = 10^7 times, the following sample shall be carried out at a lower stress level. Otherwise, it shall be carried out at a higher stress level until all pieces are completed. The difference in stress levels is called the “stress increment,” which should remain constant throughout the test. In this case, we took the stress increment of 4%. After the experiment, 5–6 groups of experimental data of 304 austenitic SS with failure and non-failure were selected, and the weighted average method was used to calculate the fatigue strength of the test samples:

\[
\sigma_w = \frac{1}{m} \sum_{i=1}^{n} V_i \sigma_i, \tag{2}
\]

where m is the number of data obtained in the experiment. In this experiment, m = 6; n is the stress level of the test; \(\sigma_i\) is the ith stress level; \(V_i\) is the number of tests under i stress level, and the stress values of the three specimens are, respectively, 4, 3, and 3. According to Formula (1), the experimental data shown in Figure 2 are calculated, and the fatigue strength of the three samples is 215, 443, and 480 MPa.

4 Influencing factors of fatigue strength

In theory [13], a linear relationship exists between tensile strength and fatigue strength. After searching the data [11,13–16], with further increasing the tensile strength, the linear equation cannot adequately be applied to estimate the fatigue strength of those high-strength materials such as steels, Cu and Al alloys. After consideration and analysis of the microchanges in the processing technology and tensile process [17,18], it is considered that the factors affecting the separation of the linear relationship between fatigue strength and tensile strength are as follows.

4.1 Change of fatigue damage location

After searching the data [19], fatigue damage localization is one of the reasons for the fatigue strength decline. Fatigue

![Figure 2: (a)–(c) represent small sample lifting test results of A, B, and C specimens.](image-url)
damage localization intensifies the sensitivity of material defects and reduces microstructure stability. Since the samples obtained in this experiment are all from the same material in the same batch and their surfaces have been polished, the influence of surface defects on fatigue strength can be approximately regarded as constant. The fatigue strength can be regarded as the threshold of a non-propagating crack, and the stress amplitude below the entry will not cause irreparable damage to the material [11]. Therefore, crack initiation dominates the fatigue life of materials. By scanning electron microscopy, we found that the macrofracture morphology on the surface can be divided into three parts: I fatigue crack origin zone, II fatigue crack growth zone, and III instantaneous fracture zone, as is shown in Figure 3(a)–(c). To identify the initial location of the crack, the origin region of the fatigue crack was enlarged and observed, as shown in Figure 3(d)–(f). Due to the constant change of load, the cracks of the material keep opening and closing to form bright arcs. The origin of these arcs is the origin of fatigue cracks. It can be seen that the fatigue cracks of samples A, B, and C almost all start from the corner of the specimen and propagate along the diagonal. Most of the cracks in specimens A, B, and C started from the corner and propagate along the diagonal direction in the experiment because of the stress concentration caused by the sharp shape of the corner of the rectangular specimen, which indicates that the stress concentration is the dominant influence on fatigue crack generation compared with the defect size. The specimens used in this experiment are samples of regular fatigue test model from the same batch, and their surfaces have been polished. Therefore, the influence of stress concentration caused by shape on fatigue strength can also be regarded as a constant.

4.2 Change of microscopic fracture mechanism

The fracture mechanism changes from ductile fracture to dissociative fracture when there is a significant difference in grain size [20]. As shown in Figure 4, the original 304 SS sample A has low strength and strong toughness due to its large grain size. Under external force, the local defect is generated by microholes. Then, adjacent microholes are connected to form dimples with larger defect sizes. The continuous connection of dimples makes the defect size grow again. Finally, it leads to the formation and propagation of cracks until they fracture.

Dimple size is related to material plasticity for the same material. The larger the dimple size, the better the plasticity of the material [21,22]. We used the average of the maximum transverse and longitudinal sizes as the size concentration.

Figure 3: Macroscopic fracture morphologies and initial crack locations of three samples: (a) and (d) are the macroscopic fracture morphologies and initial crack locations of sample A, (b) and (e) are the macroscopic fracture morphologies and initial crack locations of sample B, and (c) and (f) are the macroscopic fracture morphologies and initial crack locations of sample C.
of the dimples in the red circle in Figure 4, and the dimple sizes of specimens A, B, and C are 1.8, 0.6, and 0.2 μm, respectively.

As shown in Figure 4, dimple sizes of specimens A, B, and C gradually decreased with grain refinement, which indicated that the tensile fracture mode of the material changed from ductile fracture of specimen A to semi-quasi state not complete brittle state of specimen C. As shown in Figure 4(a), the dimples of sample A are large, deep, and uneven; the dimple of sample B became shallower and the size decreased significantly, as shown in Figure 4(b). The fracture color of the semi-quasi-state of specimen C is dark, and the dimples are small and shallow (red circle in Figure 4(c)). The same trend also exists in the data of 201LN austenitic SS [21]: The average grain size of 201LN austenitic SS is refined from 18 μm in coarse-grained samples to 0.9 μm in ultrafine-grained samples, and the average dimple size decreased from 1.5 to 0.9 μm, while the yield strength increased from 389 to 704 MPa.

### 4.3 Change of microscopic deformation mechanism

In this experiment, the grain sizes of the RDs of specimens 304 SS specimens obtained by different degrees of plastic deformation are 22.3, 3.5, and 2.0 μm, respectively. The cross-section and RD of specimens A, B, and C were, respectively, observed by an EBSD microscope, as shown in Figure 5. It can be observed from Figure 5(a) and (d) that the original specimen A can be approximately regarded as an equiaxed crystal, with little difference in size between the transverse section and the RD. With an increase in the degree of plastic deformation, the grain size slightly decreased in the TD and significantly decreased in the RD. The grain shape gradually changed from the original equiaxed crystal to an elongated crystal, and the grain boundaries increased and became more tortuous. With the decrease of grain size, the mean free path of dislocation inside the material decreased and the dislocation produced plugging in the grain boundary. As a result, the microstructure deformation mechanism inside the material gradually changed from dislocation slip to dislocation plugging, and the tensile strength and fatigue strength of the material are enhanced. Similarly, the scope of application of the Hall–Petch relation based on dislocation slip theory proves this: The Hall–Petch relation is only applicable to materials with grain size ≥20–30 nm [22].

In summary, the influence of grain size on tensile strength can be summarized as follows: as the grain size decreased, the surface area per unit volume increased, and there was more dislocation accumulation at grain boundaries. Excessive dislocation packing increased the tensile strength of materials. On the other hand, the effect of grain size on fatigue strength is as follows: a smaller grain size reduces the defect size, making it more difficult for stress to concentrate at sizes exceeding the material’s critical stress. As a result, this inhibits the early nucleation and propagation of cracks, ultimately enhancing fatigue strength.

### 5 A new fatigue strength prediction model

From the aforementioned content, fatigue strength is influenced not only by tensile strength but also by other factors. In general [12–16], it is believed that tensile strength is the
resistance to the dislocation motion. The larger the tensile strength, the higher the resistance to the dislocation motion. Therefore, it can be inferred that an increase in tensile strength is beneficial to fatigue strength. The decrease of plastic deformation capacity during material strengthening could be a general answer to the fatigue strength decline, which is expressed in terms of work hardening capacity. The tensile strength and work-hardening ability influence the fatigue strength of the material synergistically. These two variables are selected as dependent variables to build the fatigue strength prediction model based on the relationship between strength and plasticity, and the decline of plastic ability often accompanies the increase of strength, as shown in Figure 6.

Because the fatigue strength of high cycle or very high cycle is regarded as the threshold stress of fatigue crack propagation, rather than the critical stress caused by crack, yield strength \( \sigma_y \) demarcates the start of macroscopic plastic deformation, which more coincides with the meaning of fatigue strength. Therefore, compared to the elastic limit, yield strength is more suitable for representing the resistance to plastic non-uniform deformation related to fatigue strength in static tensile performance. \( \Delta \sigma_t \) is used to represent the work-hardening capacity in this article. Since the deformation of the material is taken into account, the true stress–strain curve is regarded as the real tensile strength \( S_b \). In the same way, the definition of the yield strength of the engineering stress–strain curve is analogically extrapolated to the real stress–strain curve (the stress value that produces 0.2% residual deformation) as the true yield strength \( \sigma_{T,Y} \), as is shown in Figure 7:

\[
\Delta \sigma_t = S_b - \sigma_{T,Y},
\]  

where \( S_b \) is the real tensile strength and \( \sigma_{T,Y} \) is the true yield strength.

Figure 5: EBSD microstructure of specimens with different grain sizes: (a)–(c) are the TDs of specimens A, B, and C, respectively, and (d)–(f) are the RDs of specimens A, B, and C, respectively.

Figure 6: Influencing factors of fatigue strength.
The fatigue strength of materials can be expressed by the following formula:

\[ \sigma_f = g(\sigma_b) + f(\Delta \sigma_T) \]  

\[ s = \sigma(1 + \varepsilon), \]  

\[ e = \ln(1 + \varepsilon). \]

The resulting true stress–strain curve is shown in Figure 9.

In order to compare with 316L, we chose 304-3, 304-5, and 304-8 as the representative of sample A (primitive state), sample B (HR30%), and sample C (HR70%), respectively. The grain sizes of 304-3, 304-5, and 304-8 are 22.3, 3.5, and 2.0 μm, respectively. It can be seen from Figure 9 that grain refinement improved the tensile strength and decreased work-hardening capability of 304 SS samples. The tensile strengths in the true stress–strain curves of the three 304 samples are 1,303, 1,340, and 1,380 MPa, respectively. And \( \Delta \sigma_T \) of the three 304 samples are 928, 534, and 429 MPa, respectively. From a macro-point of view, work-hardening ability indicates the degree of resistance of a material to local deformation. The higher \( \Delta \sigma_T \) means better ability to keep dislocation slipping and tangling, which means better deformation homogeneity when the heterogeneous deformation occurs. 316L SS and 304 SS have the same changing trend.

Figure 10 shows the relationships between mechanical properties and fatigue strength. It can be seen from Figure 10(a) that the relationship between tensile strength and fatigue strength of 304 SS and 316L SS can be approximately regarded as linear in the early stage. With the increase of the tensile strength, their fatigue strength appeared to increase linearly. With the further increase of experimental data of samples 3, 5, 8 and 316L [12] collected were processed by formulas (5) and (6):

\[ s = \sigma(1 + \varepsilon), \]  

\[ e = \ln(1 + \varepsilon). \]
the tensile strength, the relationship between tensile strength and fatigue strength is gradually losing linearity. Figure 10(b) shows the relationship between fatigue strength and work-hardening capacity. It is clear that the relationship between fatigue strength and work-hardening capacity is non-linear. So we use the following formula (7) and formula (8) to represent them:

\[
g(\sigma_b) = AS_b + B, \quad (7)
\]

\[
f(\Delta\sigma_T) = C\Delta\sigma_T^2 + D\sigma_T + E, \quad (8)
\]

where \(A, C, \) and \(D\) are the material parameters, and \(B\) and \(E\) are the constants.

By ignoring the influence of constant terms and combining similar terms, a new fatigue strength prediction model is proposed:

\[
\sigma_w = a(\sigma_b - \sigma_{T,Y})^2 + b\sigma_b + c\sigma_{T,Y}, \quad (9)
\]

where \(a, b, \) and \(c\) are the material constants, \(\sigma_b\) is the real tensile strength, and \(\sigma_{T,Y}\) is the true yield strength.

The parameters required by the model are shown in Table 2, and the fitting effect is shown in Figure 11. It is found that the prediction error is within \(\pm 7\%\), which proves that the model is also suitable for these five materials.

ECAP is the equal diameter angular extrusion; HR is the hot rolling; CR is the cold rolling; SP is the standardized
treatment; RH is the repeated heating; CG is the coarse crystal; FG is the fine crystal; UFG is a superfine crystal; NG for nanocrystals. Error = \(\frac{\sigma_{w,cal} - \sigma_{w,exp}}{\sigma_{w,exp}}\)

Basquin formula is a traditional S–N curve fitting method, and its expression is

\[
\sigma_a = \sigma_f \left(\frac{2N_f}{2N_c}\right)^b,
\]

where \(\sigma_a\) is the stress amplitude, \(\sigma_f\) is the fatigue strength coefficient, \(N_f\) is the number of fatigue failure cycles, and \(b\) is the fatigue strength index.

Basquin formula was used to fit the S–N curves of material 304 and 316L SS, and its parameters and prediction errors are shown in Figure 12. Figure 12(a)–(c) shows the fatigue test data of samples 304 A, B, and C and the fitting curves of the Basquin formula. Figure 12(d)–(f) shows the fatigue test data of samples A, B, and C of 316L and the fitting curve of the Basquin formula. It can be seen from Figure 12(a) and (f) that the original fatigue data of sample 304, 316L have higher dispersion, and the fitting data are more accurate after the strengthening process, such as rolling deformation. This is because the differences between the treated samples are reduced.

By comparing the staircase method, the Basquin formula, and the fatigue model proposed in this study, the results indicated that the staircase method is the most precise approach for measuring fatigue strength among them. However, it is worth noting that this method also incurs the highest cost. The Basquin formula has dramatically reduced the required fatigue test samples, but it still needs to carry out some fatigue tests. Each fitting value only applies to the same batch of samples prepared by the same process. The advantage is that it can accurately predict the fatigue strength under different cycles in more experimental samples and has higher convincing power, but it consumes time and energy. This study proposes a novel fatigue strength prediction model, which utilizes the static tensile properties obtained from natural stress–strain curves to predict fatigue strength. This model applies to the same material manufactured through different processes, and it can effectively reduce the cost of fatigue experiments without compromising the accuracy of fatigue strength prediction, which offers a fresh perspective and introduces a new approach to fatigue strength prediction.

### Table 2: Tensile properties, fatigue strength, and fitting values of different materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Technology</th>
<th>Microstructure</th>
<th>(\sigma_b)</th>
<th>(\sigma_{t,y})</th>
<th>(\sigma_{w,exp})</th>
<th>Model parameter</th>
<th>(\sigma_{w,cal}) Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>304</td>
<td>Primitive state</td>
<td>CG</td>
<td>1,303</td>
<td>380</td>
<td>215</td>
<td>(a = -0.00027, b = 0.32, c = 0.14)</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>HR30%</td>
<td>FG</td>
<td>1,340</td>
<td>806</td>
<td>443</td>
<td></td>
<td>456</td>
</tr>
<tr>
<td></td>
<td>HR70%</td>
<td>FG</td>
<td>1,380</td>
<td>951</td>
<td>480</td>
<td></td>
<td>515</td>
</tr>
<tr>
<td>316L [13]</td>
<td>HR90%</td>
<td>FG</td>
<td>1,300</td>
<td>1,160</td>
<td>618</td>
<td>(a = -0.00026, b = 0.3, c = 0.19)</td>
<td>605</td>
</tr>
<tr>
<td></td>
<td>HR40%</td>
<td>FG</td>
<td>1,225</td>
<td>925</td>
<td>483</td>
<td></td>
<td>519</td>
</tr>
<tr>
<td></td>
<td>Primitive state</td>
<td>CG</td>
<td>1,155</td>
<td>337</td>
<td>237</td>
<td></td>
<td>232</td>
</tr>
<tr>
<td>Cu11%at Al [23]</td>
<td>CR10%</td>
<td>FG</td>
<td>606</td>
<td>226</td>
<td>190</td>
<td>(a = -0.00031, b = 0.29, c = 0.17)</td>
<td>176</td>
</tr>
<tr>
<td></td>
<td>CR50%</td>
<td>UFG</td>
<td>631</td>
<td>302</td>
<td>210</td>
<td></td>
<td>209</td>
</tr>
<tr>
<td></td>
<td>ECAP</td>
<td>NG</td>
<td>488</td>
<td>90</td>
<td>110</td>
<td></td>
<td>117.7</td>
</tr>
<tr>
<td>35Crmo steel [12]</td>
<td>Primitive state</td>
<td>FG</td>
<td>2,098</td>
<td>1,840</td>
<td>627</td>
<td>(a = -0.00032, b = 0.17, c = 0.17)</td>
<td>648</td>
</tr>
<tr>
<td></td>
<td>Tempered at 400°C for 90 min</td>
<td>FG</td>
<td>1,617</td>
<td>1,510</td>
<td>548</td>
<td>(a = -0.00032, b = 0.17, c = 0.17)</td>
<td>528</td>
</tr>
<tr>
<td></td>
<td>Tempered at 500°C for 90 min</td>
<td>FG</td>
<td>1,346</td>
<td>1,210</td>
<td>418</td>
<td>(a = -0.00032, b = 0.17, c = 0.17)</td>
<td>428</td>
</tr>
<tr>
<td>Cu11% at Al [23]</td>
<td>CR10%</td>
<td>CG</td>
<td>1,004</td>
<td>545</td>
<td>420</td>
<td>(a = -0.00052, b = 0.32, c = 0.14)</td>
<td>409</td>
</tr>
<tr>
<td></td>
<td>CR30%</td>
<td>CG</td>
<td>1,129</td>
<td>736</td>
<td>570</td>
<td>(a = -0.00052, b = 0.32, c = 0.14)</td>
<td>544</td>
</tr>
<tr>
<td>Fe–18Mn TWIP steel [24]</td>
<td>CR10%</td>
<td>CG</td>
<td>1,357</td>
<td>1,152</td>
<td>845</td>
<td>(a = -0.00052, b = 0.32, c = 0.14)</td>
<td>846</td>
</tr>
<tr>
<td></td>
<td>CR30%</td>
<td>FG</td>
<td>1,357</td>
<td>1,152</td>
<td>845</td>
<td>(a = -0.00052, b = 0.32, c = 0.14)</td>
<td>846</td>
</tr>
</tbody>
</table>

**Figure 11:** Comparison of fatigue strength predicted by four material models and experimental fatigue strength.
6 Conclusion

1. From the microscopic point of view, the reduction of grain size changed the plastic deformation fracture mechanism and the microscopic deformation mechanism of the material: the plastic deformation fracture mechanism changed from ductile fracture to dissociation fracture, and the microscopic deformation mechanism gradually changed from dislocation slip to dislocation plugging, thus enhancing the static tensile property and fatigue strength of the material.

2. For high-strength materials, due to the influence of stress concentration caused by the shape of standard fatigue samples, the fatigue cracks are often generated from the corner and spread along the diagonal. Compared with surface defects and inclusions, the stress concentration caused by the shape of the sample used in this experiment has a more significant influence on fatigue cracks. Since the fatigue cracks of the experimental samples are all generated from the corners and spread along the diagonal, this effect can be regarded as a constant in this study.

3. Based on the influence of tensile strength and work-hardening capacity on fatigue strength, a new fatigue strength prediction model is proposed, which can accurately predict the fatigue strength of materials by using the tensile strength and yield strength of materials and greatly reduce the cost of fatigue experiments.

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Conflict of interest: The authors state no conflict of interest.

References


