213 Reliability Evaluation of Statistical Fatigue Property of SUJ2 Steel in Very High Cycle Regime

Ritsumeikan University: ○Wei Li, Tatsuo Sakai and Ryohei Takizawa,
Toyota College of Tech.: Masaki Nakajima, University of Toyama: Kazuaki Shiozawa, Noriyasu Oguma

1 Introduction

In recent years, many unexpected failures in the very high cycle regime beyond 10^7 cycles have been reported for the machinery parts made of ferrous metals which are assumed to have a distinct fatigue limit. The study on very high cycle fatigue properties of structural materials has already become an important and active subject to ensure the long-term safety of actual mechanical structures, moreover, which is also an effective way to conserve the natural resource and alleviate the environmental pressure to the globe [1]. Up to now, fatigue tests in rotating bending have been widely carried out to study the very high cycle fatigue properties of metallic materials. However, the actual load imposed to the components of mechanical structures is not only restricted to the rotating bending. Thus, from the standpoint of fatigue reliability design, statistical evaluation on the very high cycle fatigue properties of metallic materials under various types of loading are very necessary to investigate, such as in axial loading [2].

2 Experimental Procedures

2.1 Material and Specimen

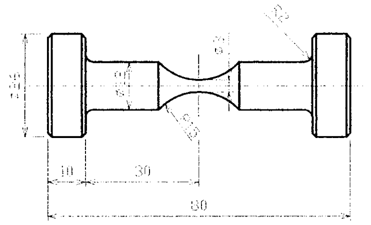

Fig.1 Shape and Dimensions of specimen

Material used in this study is SUJ2 bearing steel, whose chemical composition (mass percentage) is: 1.01 C, 0.23 Si, 0.36 Mn, 0.012 P, 0.007 S, 1.45 Cr, 0.06 Cu, etc. Firstly, some specimens were machined into the shape of hourglass with a certain amount of finishing margin from the anneal material. Then, they were quenched at 835℃×40min+oil cooling, and tempered at 180℃×120min+air cooling. After the heat treatments, the surface of all specimens was polished by a grinder of #100 to the final shape in Fig. 1. The hardness distribution over the cross section of the specimen was almost uniform and the average value was given as HV=737. The tensile strength of the specimen was about 2316MPa. Diameter of the tested portion was 3.0mm and the stress concentration factor was given as α=1.04.

2.2 Fatigue Testing

A multi-type fatigue testing machine in axial loading was adopted to carry out the very high cycle fatigue test of SUJ2 bearing steel, whose test frequency is 80Hz. Fatigue tests were performed in an open environment at room temperature, and the stress ratio was given as $R=-1$. Fracture surfaces of all the failed specimens were carefully observed by means of a scanning electronic microscope (SEM), paying an attention to the crack initiation sites and crack initiation and propagation mechanisms particularly.

3 Experimental Results and Discussions

3.1 *S-N* Characteristics

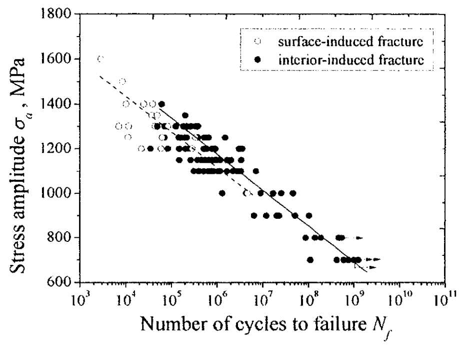

Fig.2 *S-N* diagram of SUJ2 in axial loading

Fig. 2 shows the *S-N* diagram of SUJ2 bearing steel in axial loading. Based on the SEM observation of all fracture surfaces, fracture mode of specimen can be clearly classified into two different fracture modes including surface-induced fracture and interior-induced fracture. Furthermore, the *S-N* curves obtained for surface-induced fracture and interior-induced fracture are shown by a dashed line and a solid line in Fig. 2, respectively, which approximately represent the so-called duplex *S-N* curves characteristic. However, compared with the experimental result in rotating bending, the dividing line of two *S-N* curves for respective fracture modes is not so clear due to the effect of stress gradient.

3.2 Statistical Evaluation on Fatigue Test Data

According to analysis of test data in Fig. 2, it can be found that the high stress region corresponding to $\sigma_a > 1300$MPa is mainly composed of test data in surface-induced fracture and the low stress region corresponding to $\sigma_a < 1200$MPa is basically composed of test data in interior-induced fracture. These test data in the two regions can all be evaluated by means of the single Weibull distribution. However, fatigue test data in the middle stress region exhibits mixed distribution trend, so a mixed Weibull cumulative distribution function is proposed to evaluate these test data and can be given as follows

$$F(N_f)=\sum_{i=1}^{2}P_iF_i(N_f) \qquad P_1+P_2=1$$
$$F_i(N_f)=1-\exp\left\{-\left(\frac{N_f-C_i}{B_i}\right)^{A_i}\right\} \quad (i=1,2) \tag{1}$$

where i denote fracture mode, A, B and C are shape parameter, scale parameter and location parameter of Weibull distribution, respectively. The probability P_i denotes the proportion of fatigue test data in single fracture mode in the total test data, which can be obtained by the following equation

$$P_i=\frac{N_i-0.3}{N+0.4} \tag{2}$$

where N denotes the number of total test data, N_i denotes the number of test data in single fracture mode. Statistical distribution result under $\sigma_a=1100\sim1300$MPa is shown in Fig. 3. However, it can be found that the result is not so ideal, especially for test data in mixed distribution mode, whose probability regression lines take place the phenomenon of mutual intersecting. Thus, a new general statistical method is proposed to evaluate on the basis of the parameter optimization of the Weibull distribution function.

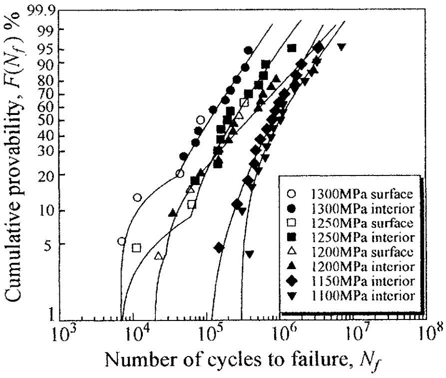

Fig.3 Weibull plots of fatigue test data

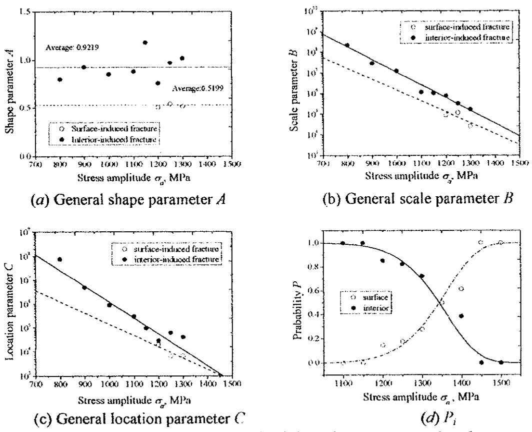

Fig.4 Parameter definition in new method

Figs. 4 show the relationship between parameter A or B or C or P_i and stress amplitude, respectively. Firstly, it can be found that the values of A in respective fracture mode almost keep constant regardless of stress amplitude. So the average value of A in respective fracture mode is approximatively regarded as the value of the general shape parameter in respective fracture mode. Furthermore, based on the equations of regression line between parameter B or C and stress amplitude in respective fracture mode, the random values of B and C in respective fracture mode corresponding to different stress amplitude can be obtained conveniently. For the P_i, its value in respective fracture mode can better follow the single Weibull distribution, so the random value of P_i in respective fracture mode corresponding to different stress amplitude can also be obtained by means of the Weibull curve equation. Thus, the new mixed Weibull distribution curves can be replotted by means of the new general statistical method and is shown in the Fig. 5.

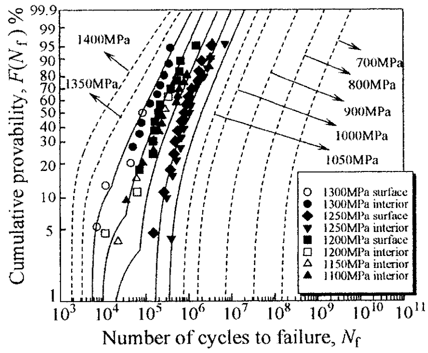

Fig.5 Weibull replot based on the new general method

3.3 *P-S-N* Characteristics

Based on statistical evaluation result in Fig. 5, the fatigue life corresponding to any level of the fatigue destroy probability can be easily obtained. Thus, the *P-S-N* diagrams obtained for SUJ2 steel in axial loading are shown in Fig.6, where *S-N* curves giving the failure probabilities of $F(N)$=1, 10, 50, 90, 99(%) are plotted as *P-S-N* curves.

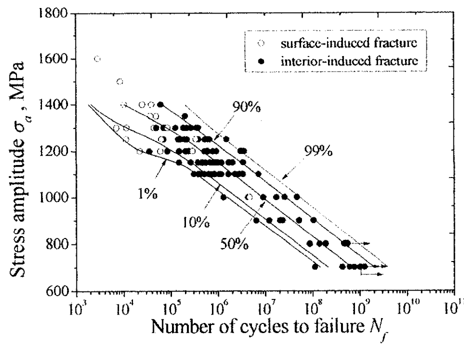

Fig.6 *P-S-N* diagram of SUJ2 in axial loading

4 Conclusions

1) *S-N* curves of SUJ2 bearing steel in axial loading represent the so-called duplex *S-N* curves characteristic.

2) A new general statistical method can better evaluate the very high cycle fatigue property of SUJ2 bearing steel in axial loading.

Reference

1) Sakai T, Takeda M, Tanaka N, Kanemitsu M, Oguma N, Shiozawa K. Trans JSME, 67A, 663 (2001).
2) Sakai T, Sato Y, Nagano Y, Takeda M, Oguma N. Int J Fatigue, 28, 11 (2006)