Fatigue strength scatter characteristics of JIS SUS630 Stainless Steel with duplex S-N curve

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Abstract

The scatter behavior of fatigue strength for 17-4 PH stainless steel (JIS SUS630, equivalent to ASTM-A563 Grade 630), which exhibited a duplex S-N curve, was investigated. It was found that the fatigue strength scatter of the SUS630 at 10^6 and 10^7 cycles, which were corresponding to the fatigue strengths for the surface-induced and the subsurface-inclusion-induced crack nucleation modes, respectively, were significantly small and comparable to each other. The scatter of inclusion size in the present material was small and resulted in the small scatter of fatigue strength comparable to that for the surface-induced crack nucleation mode. The variation in size of non-metallic inclusions is known as one of the main factors for the fatigue strength scatter [1]. It was also found that the scatter of fatigue strength was in the same order of tensile strength.

Keywords: scatter, fatigue strength, tensile strength, duplex S-N curve, 17-4 PH stainless steel

1. Introduction

Precipitation-hardened (PH) stainless steels have been widely used as structural materials for various components, such as nuclear, chemical, air craft, and naval industries due to their excellent mechanical properties, good fabrication characteristics and excellent corrosion resistance. 17-4 PH stainless steel is a martensitic stainless steel strengthened by the precipitation of copper in the martensite matrix, which is presently one of the most commonly used alloys [2, 3] and coded as JIS SUS630 and ASTM A563 Grade 630. Due to its favorable combination of good tensile strength, toughness and weldability, 17-4 PH stainless steel is a promising candidate material for use in pressure vessels. Generally, high pressure components like these experience pressurizing and relieving processes in service. Thus fatigue behavior of the material under cyclic loading is essential to ensure a safe design. One of the important characteristics of safe design is limiting the scatter in the fatigue strength and thus the fatigue life of the component.

Most of the previous studies on 17-4 pH stainless steels have focused on microstructure and mechanical properties at room temperature [4-9]. Very little work has been done on fatigue properties of this alloy [10-12] and there is still a lack of research on fatigue strength, especially in the long life region.

Recently, Nie and Mutoh [13] investigated the fatigue behavior of 17-4 PH stainless steel, JIS SUS630, and discussed the characteristics of fatigue strength from a viewpoint of fracture mechanics. They found that the SUS630 showed a duplex S-N curve consisting of two distinctly different S-N curves corresponding to the respective fatigue crack nucleation modes; surface-induced and subsurface-inclusion-induced crack nucleation modes.

There are also additional reports on scatter behavior of fatigue strength for the materials with single S-N curve [14]. However, relatively few reports for materials with duplex S-N curve are available [15, 16]. It is important to understand how different the scatter behavior of fatigue

strength between the two crack nucleation modes is controlled. However, in this context there are almost no reports which compare the scatter behavior of fatigue strength between the two crack nucleation modes in the same material.

Therefore, in the present study, fatigue tests were performed for the JIS SUS630 under tension-compression loading to investigate the statistical fatigue strength at 10^6 and 10^7 cycles, which corresponded to the cases for surface-induced and subsurface-inclusion-induced fatigue crack nucleation modes. In addition, the fracture surfaces obtained were observed using scanning electron microscope (SEM), JEOL JSM - 6360A and the fatigue fracture mechanism of the SUS630 was discussed from the viewpoint of the fractography obtained. Based on the results, the scatter behavior of fatigue strength for both the crack nucleation modes was considered. The empirical linear relationship with a scatter band is commonly known between fatigue strength and tensile strength [17, 18]. Therefore, scatter behavior of the tensile strength of the same material was investigated and then compared to that of fatigue strength.

2. Statistical analysis of fatigue strength data

The Weibull statistics [19] has been widely used to describe the statistical behavior of bending or tensile strength for many materials, such as ceramics [20], metal matrix composites [21], ceramic matrix composites [22]. The Weibull distribution has also been applied to the fatigue properties of metallic materials [23-28]. Two popular forms of this distribution are two- and three-parameter Weibull distributions. The advantages of two-parameter Weibull distribution are as follows [29]:

- It has been frequently used to estimate scatter of strength and life, and it is therefore easy to compare with the reported data.

- The two-parameter Weibull distribution function can be easily applied to the scatter of tensile and fatigue properties to obtain an effective regression analysis.
- It suggests the physical background to the failure by considering the slope of Weibull probability plots.

Therefore, in this study, the two-parameter Weibull distribution was used.

The (cumulative) distribution function of the two-parameter Weibull distribution is given as:

$$F(x; \alpha, \beta) = 1 - \exp\left(-\left(\frac{x}{\alpha}\right)^\beta\right), \alpha > 0, \beta > 0 \quad (1)$$

In the context of this study, $F(x; \alpha, \beta)$ represents the probability that the fatigue strength is equal to or less than x . Using the equality $F(x; \alpha, \beta) + R(x; \alpha, \beta) = 1$, thus the reliability $R(x; \alpha, \beta)$, is the probability that the fatigue strength is at least x . This can be defined as:

$$R(x; \alpha, \beta) = \exp\left(-\left(\frac{x}{\alpha}\right)^\beta\right), \alpha > 0, \beta > 0 \quad (2)$$

In the above equations:

x : Variable (fatigue strength, which is obtained either by the 0-1-2 or 0-2 combinations, as discussed in the section 4.2)

α : Scale parameter related to the mean fatigue strength at a given number of cycles.

β : Shape parameter or Weibull modulus that characterizes the degree of scatter of fatigue strength

The parameters α and β can be estimated from fatigue data by a number of methods. The most common used method is the ordering/ranking of the statistics combined with linear regression.

This will be the parameter estimation used in this study.

3. Experimental Procedure

3.1 Material and Specimen

The material used in the present study is a commercial precipitation hardening martensitic 17-4 PH stainless steel, JIS SUS630. The chemical composition and mechanical properties of this material are listed in Tables 1 and 2, respectively. As-received rolled material was heat-treated at 552⁰ C for 4 h followed by air cooling to achieve the JIS H1025 condition. The specimens were then machined to shape. The heat-treated material has a tempered martensite structure, which is shown in Fig. 1. The hour-glass type specimen with a minimum central diameter of 3.5 mm was used for fatigue tests. The geometry and dimensions of which are shown in Fig. 2. The specimen surfaces were polished by using abrasive papers up to a grade of #1200 before the test to ensure a smooth surface, thus minimizing any stress concentration effects.

3.2 Fatigue test

Tension-compression fatigue strength tests were carried out in an EMIC HSFTM-1 electro-magnetic fatigue testing machine under a sinusoidal wave form of loading with a stress ratio of -1 at a frequency of 100 Hz. To obtain the basic S-N curve, fatigue tests at various stress amplitudes were continued up to the complete failure of specimen. These tests were stopped when a specimen could survive up to 10⁸ cycles. The fracture surfaces of all the failed specimens were then observed in detail under an SEM, paying attention to the observed crack nucleation sites.

4. Results and Discussion

4.1 Choice of fatigue life for evaluating fatigue strength scatter

Figure 3 shows the S-N curve obtained from the tension-compression fatigue strength test. As seen from the figure, the S-N curve of the SUS630 can be divided into two distinct portions. Based on the SEM observations of the fracture surfaces, each specimen was classified into one of two groups: (i) crack nucleation from surface (here called as surface-induced crack nucleation), and (ii) crack nucleation from subsurface inclusions (here called as subsurface-inclusion-induced crack nucleation).

In the shorter life region ($N_f < 10^6$), fatigue fracture tended to occur in the surface-induced crack nucleation mode, whereas the subsurface-inclusion-induced crack nucleation mode took place in the longer life region ($N_f > 10^6$). In the present study, the crack nucleation due to presence of inclusion in contact with the specimen surface was very rarely found. The overall trend of the present S-N curve is well represented as a duplex S-N curve consisting of the respective S-N curves for the surface-induced crack nucleation mode and the subsurface-inclusion-induced crack nucleation mode. Similar duplex S-N curves have been reported elsewhere for high strength or high hardness steels [15, 16].

4.2 Fatigue strength scatter test procedure

From the viewpoint of structural design, it is of importance to investigate whether the scatter behavior of fatigue strength is different between the surface-induced crack nucleation mode and the subsurface-inclusion-induced crack nucleation mode. Therefore, in the present study, to elucidate the role of inclusion on fatigue strength dispersion in the SUS630, statistical fatigue strength tests were carried out at two different fatigue lives: (i) 10^6 cycles and (ii) 10^7

cycles. These correspond to the surface-induced and the subsurface-inclusion-induced crack nucleation modes, respectively. The JIS standard, JIS Z2273 [30], requests two data points at each stress amplitude and the fatigue strength could be determined based on the intermediate stress between two run-outs and two failures (here called as the 0-2 combination) or the intermediate stress at one run-out and one failure between two run-out and two failures (here called as the 0-1-2 combination). These are shown in Figs. 4(a) and 4(b), respectively. The scatter behavior of fatigue strength here has been determined according to the JIS standard Z2273. This is different to the ASTM standard E468-11 [31] in which the stair-case method [32] with 20-30 specimens is used for determining the mean fatigue strength under the assumption of normal distribution of fatigue strengths.

The fatigue strength scatter tests were carried out in the present study to obtain a sufficient number of 0-2 or 0-1-2 combinations to evaluate an appropriate number of fatigue strengths according to the definition of fatigue strength in the JIS Z2273 standard.

The procedure for the fatigue strength scatter determination test at 10^7 cycles, for example, is as follows:

- (a) Initially, three stress amplitudes are selected with a stress step size, $\Delta\sigma$, of 10 MPa taken from the basic S-N curve (i.e., 635 MPa, 645 MPa, and 655 MPa). Two specimens are then tested at each stress amplitude.
- (b) The stress step size, $\Delta\sigma$, is then reduced by half, from 10 MPa to 5 MPa, and again two specimens are tested at each stress amplitudes of 640 MPa and 650 MPa.
- (c) The stress step size, $\Delta\sigma$, is further reduced by half, from 5 MPa to 2.5 MPa, followed by testing of two additional specimens at each stress level of 637.5 MPa, 642.5 MPa, 652.5 MPa, and 657.5 MPa. In all the cases mentioned above, the fatigue test is continued up to

complete failure of the specimen, while the test is stopped when a specimen does not fail up to 10^7 cycles.

- (d) The possible 0-2 or 0-1-2 combinations are selected from the above fatigue test results for determining fatigue strengths. Then fatigue strengths determined are then used for the scatter behavior analysis.

4.3 Fatigue strength scatter at 10^6 cycles

The fatigue strength scatter at 10^6 cycles was obtained for a stress range of 680 MPa to 715 MPa. The result is shown in Fig. 5. The arrows in the figure indicate the specimens whose failure did not occur before 10^6 cycles. Based on the data points indicated in Fig. 5, all possible combinations were selected and the fatigue strengths were determined using the 0-2 or the 0-1-2 combinations, where 17 combinations and then 17 fatigue strength data could be obtained. The scatter behavior was then analyzed by using a two-parameter Weibull distribution. Figure 6 shows the Weibull plot of fatigue strength data at 10^6 cycles. As can be seen in Fig. 6, a good linear correlation with a high regression coefficient ($r^2 > 0.90$) is obtained for the $\ln(\text{fatigue strength})$ versus $\ln(1/(1-F(x; \alpha, \beta)))$ plot. The Weibull parameters obtained through regression analysis are given in Table 3. Generally, the Weibull modulus (β) is related to the scatter of the data: the higher the value of β the smaller the scatter. As can be seen from Table 3, the Weibull modulus (β) is about 131, which clearly indicates that the scatter of fatigue strength at 10^6 cycles is significantly small. To support this, the normal distribution parameters obtained through regression analysis using the same fatigue strength data shown in Fig. 5 are also indicated in Table 3. The COV (Coefficient of Variation = Standard Deviation (σ) $\div$ Mean (μ) $\times$ 100) is also related to the scatter of the data: again the smaller the value of COV the smaller the scatter. As

seen in Table 4, the Weibull modulus of 131 corresponds to the COV of 1.0. The COV value of 1.0 means that the most of scatter of strength (68.27%) is within 1% of the mean strength, which we can consider the scatter of strength is very small and use the mean strength for strength design without consideration of the scatter of strength.

It is known that the specimen surface is a favorable site for crack nucleation, which can be induced by the intrusion-extrusion mechanism [33]. Therefore, all fracture surfaces of the specimens below 10^6 cycles were observed using SEM to understand the crack nucleation mechanism. An example of the observations is shown in Fig.7. It was found that the fatigue cracks were nucleated at the surface with no significant defect or inclusion at the crack nucleation site for all the specimens observed. Therefore, single crack nucleation mechanism from the specimen surface could be one of the main controlling factors for the small scatter in fatigue strength. It is known that surface roughness influences fatigue strength especially for high strength materials. In the present specimen, the final polishing was conducted in the longitudinal direction of the specimen using very fine abrasive paper of the #1200 grade, as mentioned in the section 3.1. Therefore, it is speculated that surface processing effect is minimized and hardly influences the scatter behavior of fatigue strength.

4.4 Fatigue strength scatter at 10^7 cycles

The scatter behavior of fatigue strength at 10^7 cycles was investigated in the stress range from 635 MPa to 657.5 MPa. The results are shown in Fig. 8. The fatigue strength data were obtained by using the 0-2 and the 0-1-2 combinations, where 11 combinations and then 11 fatigue strength data could be obtained. The scatter behavior was again analyzed using a two-parameter Weibull distribution. Figure 9 shows the Weibull plot of fatigue strength at 10^7 cycles.

A good linear correlation was found from the figure ($r^2=0.96$). The Weibull parameters obtained through regression analysis are given in Table 3. From the table, it is found that the Weibull modulus is 158 with scale parameter (mean fatigue strength) of 651 MPa. It is also found that the degrees of fatigue strength scatter, that is the Weibull modulus, at 10^6 cycles and 10^7 cycles are comparable each other, regardless of the crack nucleation mode. Once again to support this, the normal distribution parameters obtained through regression analysis using the same fatigue strength data shown in Fig. 8 are also indicated in Table 3.

Fractographic examination was performed to analyze the feature of crack nucleation site in all the fractured specimens. In the very high-cycle regime ($10^6 < N_f < 10^8$), the inclusions were always found at the crack nucleation sites inside the specimen, as seen in Fig. 10. It has been reported that the fatigue strength scatter of cast material is large compared to that of extruded material, as seen in Table 4, where cracks nucleate from cast pores of various sizes [34]. Generally, the inclusion chemistry, size, shape, location in relation to the surface and density influence fatigue crack nucleation. Considering the effect of inclusion chemistry on fatigue crack nucleation, the most harmful inclusions are calcium aluminates, alumina, and spinel [35]. In the previous study [13], the constitutive elements of the inclusion were analyzed by using an energy dispersive spectroscopy (EDS). EDS mapping clearly showed the inclusion mainly consists of aluminum and oxide. Inclusions close to or on the surface are more harmful than the subsurface inclusions since the deformation of surface is more free and then the principal stress distribution around a buried inclusion is changed and the principal stress is increased under axial loading [36]. Parameters such as the location in relation to the surface and the inclusion size, i.e., the square root of area projected onto the plane perpendicular to the specimen axis, were measured from the SEM photographs. It was found that the inclusion size variation is rather small and in

the range 10 μm to 19 μm . The inclusion location in relation to the surface varies from 50 μm to 485 μm in depth, which is far enough from the surface compared to the size of the inclusion itself. Therefore, the scatter of inclusion size in the present SUS630 is likely to have less impact on fatigue strength scatter.

4.5 Comparison with the staircase method

As mentioned previously, the scatter behavior of fatigue strength for the two different crack nucleation modes was clarified based on the fatigue strengths obtained according to the definition of fatigue strength in the JIS standard Z2273. There have been several methods proposed to estimate statistical fatigue strength [32, 37]. The staircase method proposed by Dixon and Mood [32] is the most common method among them and adopted in the ASTM E468-11. The staircase method utilizes a simple protocol in which a specimen is tested at a given starting stress for a specified number of cycles or until fracture, whichever comes first. If the specimen survives, the stress level is increased for the next specimen; likewise the stress is decreased if the specimen fails. This protocol is continued for a batch of specimens. The Dixon and Mood's equations [32] are applied to the results in order to estimate the mean fatigue limit (μ_{SC}) and the standard deviation (σ_{SC}) at the specified number of cycles, where the normal distribution is assumed. The equations for the mean and standard deviation are given as:

$$\mu_{SC} = \sigma_{f=0} + \Delta\sigma \left(\frac{A}{F} \pm 0.5 \right) \quad (3)$$

$$\sigma_{SC} = \begin{cases} 1.62 \Delta\sigma (F_{BA} + 0.029) & F_{BA} \geq 0.3 \\ 0.53 \Delta\sigma & F_{BA} < 0.3 \end{cases} \quad (4)$$

$$F_{BA} = \frac{FB - A^2}{F^2} \quad (5)$$

Where;

$$A = \sum_{t=0}^{t_{max}} t m_t \quad (6)$$

$$B = \sum_{t=0}^{t_{max}} t^2 m_t \quad (7)$$

$$F = \sum_{t=0}^{t_{max}} m_t \quad (8)$$

In the above equations, the parameter t is an integer denoting the stress level, with t_{max} corresponding to the highest stress level in the staircase method. If the majority of specimens failed, then the lowest stress at which survival occurs corresponds to $t = 0$. m_t corresponds to the number of specimens which survived each stress level. σ_0 is the stress value at $t = 0$, $\Delta\sigma$ is the step size; the plus sign in Eq.(3) is used when the analysis is based on survivals, and the minus sign when it is based on the failures.

In the present study, there were a number of fatigue test data near the fatigue strengths at 10^6 and 10^7 cycles, as shown in Figs. 5 and 8, respectively. Virtual tests according to the staircase method were attempted using the present fatigue test data. However, only two fatigue test data were obtained at the same stress level, this was too small a number to construct the up-and-down diagram according to the staircase method. Therefore, the nearest two stress levels were used and were assumed to be the same single stress level between the two stress levels. Figure 11 shows examples of the virtual staircase diagrams at 10^6 and 10^7 cycles. The values of mean fatigue strength, standard deviation and COV based on the present virtual staircase method were evaluated, these are listed in Table 5. As seen from the table, the values of mean fatigue strength, standard deviation and COV obtained were very similar to those obtained in the previous sections based on the definition of fatigue strength in the JIS Z2273, as shown in Table 3. However it must be remembered that the number of fatigue test data in the present virtual staircase method was rather small to be conclusive.

4.6 Comparison of scatter between fatigue strength and tensile strength

An empirical linear relationship with a scatter band is commonly used to correlate fatigue strength with tensile strength [17, 18]. However, this approach does not consider the difference in scatter between fatigue strength and tensile strength. To investigate the difference of scatter behavior between fatigue strength and tensile strength, the scatter behavior of tensile strength was investigated. Tensile tests were carried out using standard tension test specimens with a gauge diameter of 6 mm and a gauge length of 25 mm. A crosshead speed of 1 mm/min at room temperature was used. Before the tensile test, the surfaces of specimens were polished to a smooth finish using abrasive papers up to #1200. The results indicate a good linear relationship in the Weibull plot, as shown in Fig. 12. The obtained Weibull distribution parameters are listed in Table 3 in addition to those for fatigue strength. The authors have investigated the scatter behavior of both fatigue strength and tensile strength for some other materials, which are shown in Table 4 [34, 38]. Based on these results and the present result, the comparison of Weibull modulus and COV values between fatigue strength and tensile strength is shown in Fig. 13. As seen in Fig. 13, the Weibull modulus and COV values for fatigue strength was almost equal to those for tensile strength regardless of material, while the die-cast AM60B showed some deviation from the linear correlation. It is speculated that an empirical linear correlation exists between the scatter behavior (Weibull modulus and COV) of fatigue strength and the tensile strength as well, as between their values for the rolled or extruded materials. The physical nature of these linear correlations has not yet been considered and clarified.

Based on the results obtained during this investigation, it is confirmed that scatter of fatigue strength is very small and almost equal to that of tensile strength. Therefore, it can be speculated

that the fatigue strength obtained by the 0-2 or 0-1-2 combinations according to the JIS Z2273 has the same high reliability, with very small scatter, as the tensile strength.

5. Conclusions

In the present study, the scatter behavior of fatigue strength for stainless steel JIS SUS630 exhibiting duplex S-N curve behavior was investigated at 10^6 and 10^7 cycles. The main conclusions obtained are summarized as follows:

1. The SUS630 exhibited the bi-modal failure mechanism. The surface-induced crack nucleation took place for the fatigue lives shorter than 10^6 cycles, whereas subsurface-inclusion-induced crack nucleation took place in very high cycle fatigue regime ($N_f > 10^6$).
2. Small scatter in fatigue strength at 10^6 cycles ($\beta=131$, COV=1.0) was observed, which would result from single crack nucleation mechanism from the specimen surface.
3. Similar small scatter of fatigue strength at 10^7 cycles ($\beta=158$, COV= 0.8) was found, while fatigue crack nucleates from subsurface inclusions with various sizes and locations from the specimen surface. However, the variation of inclusion size was small and in the range 10-19 μm , which results in small scatter of fatigue strength.
4. The degree of fatigue strength scatter at 10^6 cycles almost identical to that at 10^7 cycles, while the fatigue crack nucleation mechanisms at 10^6 cycles and 10^7 cycles were different.
5. The scatter of the fatigue strength was very small and almost equal to that of tensile strength.

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Captions of tables

Table 1 Chemical composition of the SUS630 (mass %).

Table 2 Mechanical properties of the SUS630.

Table 3 Weibull distribution and Normal distribution parameters for fatigue strength (at 10^6 and 10^7 cycles) and tensile strength

Table 4 Comparison of scatter behavior between fatigue strength and tensile strength for the same materials

Table 5 Scatter behavior estimated by the virtual staircase method

Captions for figures

Fig. 1 Microstructure of the SUS630

Fig. 2 Specimen shape and dimensions

Fig. 3 S-N curve for the SUS630

Fig. 4 Concepts for estimating fatigue strength: (a) 0-2 failure combination, (b) 0-1-2 failure combination

Fig. 5 Fatigue test results for estimating fatigue strength at 10^6 cycles

Fig. 6 Two-parameter Weibull plot for fatigue strength data at 10^6 cycles

Fig. 7 Fracture surface near the crack nucleation site for the SUS630

Fig. 8 Fatigue test results for estimating fatigue strength at 10^7 cycles

Fig. 9 Two-parameter Weibull plot for fatigue strength data at 10^7 cycles

Fig. 10 Subsurface crack nucleation from the inclusion for the SUS630

Fig. 11 Up-and-down diagram for the virtual staircase method

Fig. 12 Two-parameter Weibull plot for tensile strength data

Fig. 13 Relationship between scatter index for fatigue strength and scatter index for tensile strength

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Fig. 3 S-N curve for the SUS630

Fig. 4 Concepts for estimating fatigue strength: (a) 0-2 failure combination, (b) 0-1-2 failure combination (symbols with arrow: survived)

Fig. 5 Fatigue test results for estimating fatigue strength at 10^6 cycles

Fig. 6 Two-parameter Weibull plot for fatigue strength data at 10^6 cycles

Fig. 7 Fracture surface near the crack nucleation site for the SUS630

Fig. 9 Two-parameter Weibull plot for fatigue strength data at 10^7 cycles

Fig. 10 Subsurface crack nucleation from the inclusion for the SUS630

Fig. 11 Up-and-down diagram for the virtual staircase method

Fig. 12 Two-parameter Weibull plot for tensile strength data

Fig. 13 Relationship between scatter index for fatigue strength and scatter index for tensile strength

Table 1 Chemical composition of the SUS630 (mass %).

Cr	Ni	Cu	Mn	Nb	Si	C	P	S	Fe
15.48	4.74	3.32	0.75	0.40	0.33	0.04	0.03	0.01	Bal.

Table 2 Mechanical properties of the SUS630.

Yield strength (MPa)	Tensile strength (MPa)	Vickers Hardness (kgf/mm ²)
1056	1073	390

Table 3 Weibull distribution and Normal distribution parameters for fatigue strength (at 10⁶ and 10⁷ cycles) and tensile strength.

Material	Property	Fatigue life (cycles)	Weibull distribution			Normal distribution			COV
			r ²	Weibull modulus, β	Scale parameter, α (MPa)	r ²	Mean, μ (MPa)	Std. deviation, σ (MPa)	
SUS630	Fatigue strength	10 ⁶	0.92	131	703.8	0.98	700.9	6.8	1.0
		10 ⁷	0.96	158	650.5	0.99	648.3	5.1	0.8
	Tensile strength	-	0.90	128	1236.0	0.95	1225.7	11.0	0.9

Table 4 Comparison of scatter behavior between fatigue strength and tensile strength.

Material	Property	Weibull modulus, β	COV
Die-cast AM60B [34]	Fatigue strength	16	6.8
	Tensile strength	11	10.1
Extruded AZ61 [38]	Fatigue strength	159	0.7
	Tensile strength	175	0.6
SNCM439 [34]	Fatigue strength	61	1.8
	Tensile strength	69	1.7
SUS630 (present study)	Fatigue strength	131	1.0
		158	0.8
	Tensile strength	128	0.9

Table 5 Scatter behavior estimated by the virtual staircase method.

	Fatigue life (cycles)	Mean fatigue strength, μ_{sc} (MPa)	Standard deviation, σ_{sc} (MPa)	COV
SUS630	10^6	699	5.0	0.7
	10^7	651.5	5.8	0.9