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TEST OF FATIGUE BEHAVIOR AND VERIFICATION OF S-N CURVE FOR SA372-J70 STEEL

Weiming Sun
Zhejiang University of Technology
No.6 district, Zhaohui Xincun
Hangzhou, Zhejiang, P.R.China
Phone: +86-0571-88320201
Fax: +86-0571-88320763
E-mail: wmsun@zjut.edu.cn

Xing Ren
Zhejiang University of Technology
No.6 district, Zhaohui Xincun
Hangzhou, Zhejiang, P.R.China
Phone: +86-0571-88320201
Fax: +86-0571-88320763
E-mail: ipece@zjut.edu.cn

Kangda Zhang
Zhejiang University of Technology
No.6 district, Zhaohui Xincun
Hangzhou, Zhejiang, P.R.China
Phone: +86-0571-88320201, Fax: +86-0571-88320763
E-mail: ipece@zjut.edu.cn

ABSTRACT

Design fatigue curve is used in low-cycle fatigue design widely. The required basic strain-controlled data for SA372-J70 steel were obtained in room temperature condition. The “cyclic” stress-strain properties of the material were also obtained and were found to differ quite significantly from conventional properties. The monotonically increasing strain accompanies the cyclic strain. The effects of such a gradually accumulating increment of strain were investigated and were found to be adequately covered by the adjustment for maximum mean stress. Design curve were constructed from the mean failure curve by applying safety factors to cover the effects of size, environment, surface finish and scatter of data. Compared the design fatigue curve with the curve in ASME Code Sec. VIII Division 2, the results show it is suitable and safe to adopt ASME design fatigue curve for homemade SA372-J70 steel.

Keywords: SA372-J70 steel, Material property, Fatigue behavior test

1. INTRODUCTION

The methods of designing for low-cycle fatigue have been used for component made of various metals. Some difficulties were encountered in attempting to apply these same procedures to home made SA372 -J70 steel. This paper presents the general mechanical properties, fatigue behavior and design fatigue curve of SA372-70 steel, so that this material may be used in engineering correctly and safely.

2. TENSILE TESTS IN ROOM TEMPERATURE CONDITION

The material selected for the study was a batch of SA372 -J70 quenched and tempered steel tube. Table 1 shows the chemical composition of the steel. The test specimens were machined from the axial direction of bar. Limited by the shape and dimension of the bar, the section of tensile test specimens, made in accordance with ASTM E8M and E21, is round. Its diameter is 10 mm.

Table 1 Chemical composition of SA372-J70 quenched and tempered steel (wt %)

C	Mn	Si	Cr	Mo	S	P
0.48	0.102	0.30	1.09	0.20	≤0.010	≤0.020

Tensile test was carried out in accordance with ASTM E8M. In strain control phase, strain rate in specimen parallel length is 0.08%/s.   In the displacement control phase, the rate in specimen parallel length is 2mm/min. The test results are indicated in Table 2.

Table 2 Tensile test results at room temperature

Specimen No.	0.2% yield strength[MPa]	ultimate tensile strength[MPa]	Total elongation[%]	Percent reduction in area[%]
1	792.3	892.3	21.1	54.1
2	826.0	932.0	20.4	62.6
3	794.0	893.8	22.0	64.7
Average	804.1	906.0	21.2	60.5

3. FATIGUE TEST CONDITION AND RESULT

All specimens were finished through fine mechanical polishing before fatigue tests.
Low cycle fatigue properties were established through push-pull Strain-controlled test at a constant strain rate with a triangular cycle and for strain ranging between 2.5×10^{-3} and 1.0×10^{-2}. Three tests per strain level were performed. Table 3 shows test data and the number of cycle to failure.

The test result shows that the “cyclic” stress-strain properties of the material were also obtained and were found to differ quite significantly from conventional properties.

Following GB6399-86[1], the fatigue strength curve equations are given by the relationship:
Elastic strain ~ life equation:

$$\frac{\Delta\varepsilon_e}{2} = 0.3750\left(2N_f\right)^{-0.04109} \quad (1)$$

Plastic strain ~ life equation:

$$\frac{\Delta\varepsilon_p}{2} = 18.32\left(2N_f\right)^{-0.5462} \quad (2)$$

Total strain ~ life equation:

$$\frac{\Delta\varepsilon_t}{2} = 0.3750\left(2N_f\right)^{-0.04109} + 18.32\left(2N_f\right)^{-0.5462} \quad (3)$$

Stress amplitude ~ life equation:

$$\frac{\Delta\sigma}{2} = 1091\left(2N_f\right)^{-0.08243} \quad (4)$$

Stress amplitude ~ plastic strain equation：

$$\frac{\Delta\sigma}{2} = 635.1\left(\frac{\Delta\varepsilon_p}{2}\right)^{0.08423} \quad (5)$$

Fatigue properties of SA372-J70 steel are given by the above relationship and shown in table 4. $\frac{\Delta\varepsilon}{2} \sim 2N_f$ curve is shown in Fig 1.

The result shows the monotonically increasing strain accompanies the cyclic strain. The effects of such a gradually accumulating increment of strain were investigated and were found to be adequately covered by the adjustment for maximum mean stress.

Table 3 Constant amplitude fatigue test result in room temperature condition

No.	$\Delta\varepsilon_t / 2$ [%]	Cycles to failure	Stable or half-life value		
			Elastic strain Amplitude $\Delta\varepsilon_e / 2$ [%]	Plastic strain Amplitude $\Delta\varepsilon_p / 2$ [%]	stress Amplitude $\Delta\sigma / 2$ [MPa]
1	0.125	>1000000	0.12470	0.00030	130.94
2	0.125	>1000000	0.12485	0.00015	131.09
3	0.150	588975	0.15000	0.00000	159.78
4	0.150	650000	0.15000	0.00000	164.08
5	0.175	102088	0.17055	0.00445	179.08
6	0.175	185842	0.17500	0.00000	205.97
7	0.175	>1000000	0.17020	0.00480	178.70
8	0.175	700000	0.15685	0.01815	164.69
9	0.200	177489	0.20000	0.00000	210.65
10	0.200	191347	0.18480	0.01520	194.06
11	0.200	178845	0.19615	0.00385	205.97
12	0.250	17954	0.24590	0.00410	258.18
13	0.250	29651	0.24665	0.00335	258.99
14	0.250	16281	0.25000	0.00000	265.10
15	0.300	6390	0.25610	0.04390	268.92
16	0.300	7613	0.25215	0.04785	264.77
17	0.300	3804	0.24860	0.05140	261.04
18	0.300	3305	0.23745	0.06255	249.33
19	0.300	5068	0.25955	0.04045	272.53
20	0.350	3369	0.25715	0.09285	270.00
21	0.350	2544	0.25270	0.09730	265.33
22	0.350	6092	0.24890	0.10110	261.33
23	0.400	2234	0.25660	0.14340	269.42
24	0.400	2345	0.27060	0.12940	284.12
25	0.400	16349	0.19900	0.20100	208.96
26	0.450	1273	0.25935	0.19065	272.30
27	0.450	910	0.26885	0.18115	282.30
28	0.450	782	0.27015	0.17985	283.68
29	0.500	1305	0.26330	0.23670	276.49
30	0.500	1142	0.26580	0.23420	279.09
31	0.500	791	0.26950	0.23050	282.98

Table 4 SA372-J70 Cyclic properties in room temperature condition

Fatigue Ductility Exp. c	Fatigue Strength Exp. B	Fatigue ductility Coeff. $\varepsilon_f^{'}$	Fatigue Strength Coeff. $\sigma_f^{'}$	Strain Hard Exp. $n^{'}$	Strength Coeff. $K^{'}$
-0.5462	-0.04109	18.32	1091MPa	0.08423	635.1MPa

4 DESIGN FATIGUE CURVE FOR SA372-J70

Fig.2 shows a plot of SA372-J70 steel design fatigue curve at room temperature. Design fatigue curve were constructed by applying a factor of safety of either 2.0 on the fictitious stress amplitude ($S_a = \frac{1}{2} E \Delta \varepsilon_t$) or factor of 20 on cycles to failure. Since the maximum stress that a material can maintain while being cycled is determined by its cyclic stress-strain properties, the large mean stress that can be maintained during cycling is equal to the yield stress. The curve that is less than the yield stress should be corrected for maximum stress by the relationship:

$$S_a^{'} = \frac{S_a (S_u - S_m)}{(S_u - S_a)} \qquad \text{for} \quad S_a < S_m \tag{6}$$

$$S_a^{'} = S_a \qquad \text{for} \quad S_a \geq S_m \tag{7}$$

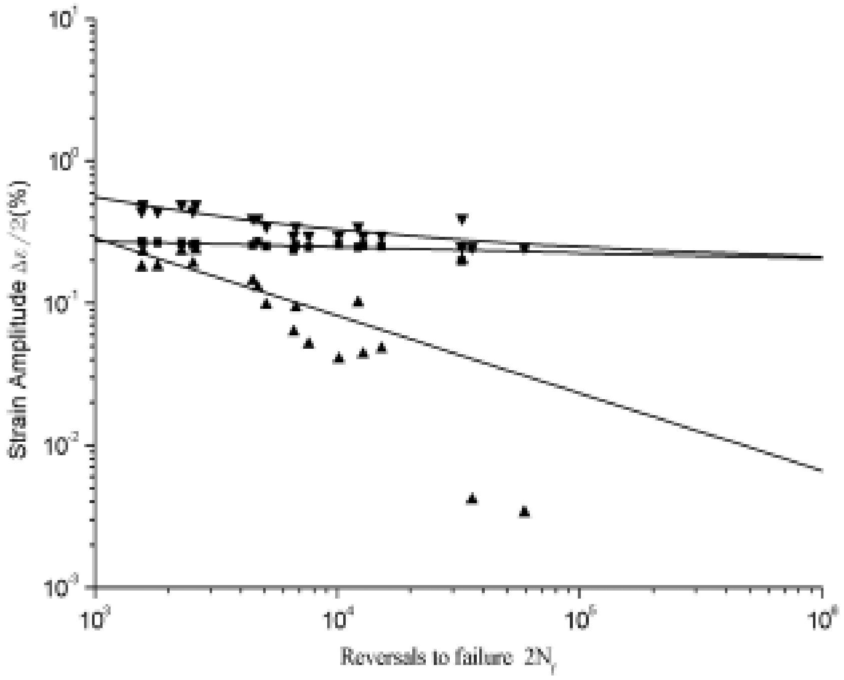

Fig.1 Strain-Life Curve of SA372 J70

where $S_a^{'}$ is fictitious stress amplitude corrected for influence of mean stress, S_u is ultimate strength at test temperature, and S_m is the cyclic yield strength at test temperature. In this test, the cyclic stress-strain curve closes to the monotonic tensile curve in test temperature. It isn't important to consider cyclic stress-strain response in estimating the effect of mean stress on fatigue life. S_m may approximate by 0.2% percent offset yield strength at test temperature. Compared the design fatigue curve with curve, for which ultimate tensile strength is greater than 793MPa, in ASME Code Sec. Ⅲ Division 2[2], the results show it is suitable and safe to adopt ASME design fatigue curve for homemade SA372-J70 steel.

5 CONCLUSIONS

1. In room temperature condition, the Total strain ~ life curve equations are give by the relationship:

$$\frac{\Delta \varepsilon_t}{2} = 0.3750 \left(2N_f\right)^{-0.04109} + 18.32 \left(2N_f\right)^{-0.5462}$$

2. The design fatigue curves at room temperature may be the basis of components fatigue analysis and design.
3. Compared with design fatigue Curve for steel of which ultimate tensile strength is greater than 793MPa in ASME Code Sec. Ⅷ Division 2, the results show it is suitable and safe to adopt ASME design fatigue curve for homemade SA372-J70 steel.

6 ACKNOWLEDGMENTS

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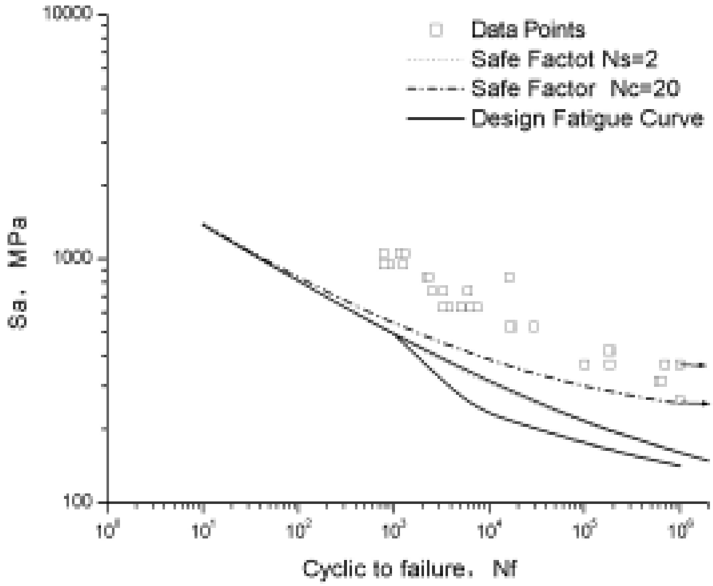

Fig.2 Design fatigue Curve of SA372 J70

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