Plastic deformation during fatigue of two types of stainless steel

by Tadashi Aihara & Tomoyuki Ishii***

Summery

Fatigue fracture property of two types of stainless steel was tested by tension-compression type testing machine. One is 17-4 PH steel hardened by precipitation of copper and another is 18-8 steel with austenite phase. For 17-4 PH steel the fatigue strength of present work shows somewhat higher value than that by conventional rotating bending testing. However, for 18-8 steel the fatigue strength level is smaller than that of another testing method, and the bending point of S-N curves is shown at lower number of cycles.

The strain amplitude during fatigue testing shows different manner for these two kinds of steel. The strain amplitude of 17-4 PH steel decreases and then increases with cycles, but that of 18-8 steel increases gradually. It is considered that this difference will depend upon the manner of plastic deformation and inner stress of materials.

1. Introduction

Fatigue tests have been made by several methods, for example, bending, tortion, rotating bending, shear, tension-compression, etc. However, only some results were appeared by stress amplitude controlled tension-compression test[1)2)]. Meantime, complicated and expensive equipments have come to be used for the testing machine, and recently, oil pressure controlling servo-valve also became just available. Such a kind of testing has some merits for comparison to static experimental results, because most static testings are performed by tension or compression and moreover, only unidirectional stress is given on the test piece. We can record the stress-strain curve which shows the fatigue behaviour of materials during fatigue testing.

Many of the studies, dealing with fatigue phenomena, paid the attention of the fracture of material, nucleation and propagation of crack. In these cases, it is recognized that the crack initiates at surface and there occurs small effect of inner plastic deformation. However, it seems that the fatigue initiation will occur at the inside of the material by plastic deformation, because the recent development of surface treatment protects the nucleation of crack at surface. Then some evidences of plastic deformation during fatigue[3)] and structural change appeare. It was observed the formation of dipole dislocation[4)], cell structure[5)] and slip band[6)] start in the metals after alternating stressing. The aim of the present work is directed to examine the manner of plastic deformation during fatigue process.

* 理工学部機械工学科教授　機械材料
** 理工学部機械工学科助教授　機械材料

For this purpose two types of stainless steel are selected. One is 17–4 PH stainless steel and another is 18–8 stainless steel. Former is hardened by precipitation of copper after aging treatment[7], and later has austenitic phase.

2. Material and experimental.

Commercial 17–4 PH and 18–8 stainless steel were prepared. The chemical composition and mechanical properties of steel samples are listed in Table 1. Solution heat treatments were carried about 17–4 PH steel at 1050°C for 0.5 hr, and about 18–8 steel at 1100°C for 1 hr and then for 17–4 PH steel hardening heat treatment was made at 550°C for 2 hr. Fatigue test was performed by tension-compression type fatigue testing machine (made by Tokyo Koki). The tests were made by the strain rate of nearly one Hz and were carried up to a few 10^4 cycles under constant stress amplitude of reversed cycles type. The size of test piece is shown in Fig. 1. The gauge length is set in a little longer for strain measurement by differential transformer. Stress-strain curves were recorded automatically.

Table 1 Chemical composition (wt %) and mechanical properties of steel samples.

Steel	C	Si	Mn	P	S	Ni	Cr	Cu	Nb+Ta	Tensile strength (kg/mm^2)	Elongation (%)	Heat treatment
17-4 PH	0.05	0.29	0.73	0.027	0.008	4.15	15.81	3.08	0.31	145	15	1050°C WQ-480°C AC
18-8	0.05	0.59	1.31	0.032	0.009	9.33	18.28	—	—	59.4	70.4	1080°C WQ

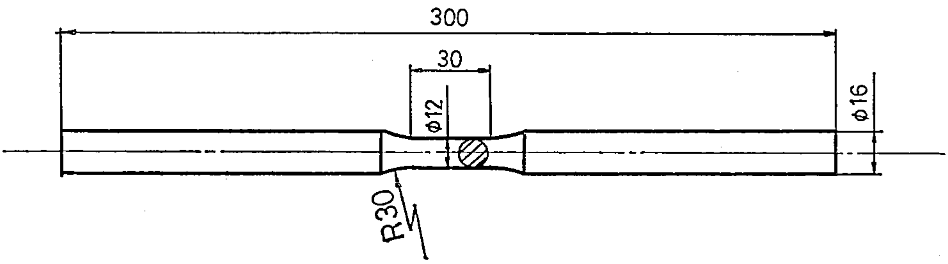

Fig. 1 Size of test piece for fatigue test.

3. Experimental results

3–1 17–4 PH stainless steel

The S-N curves of 17–4 PH steel with and without hardening heat treatment were shown in Fig. 2. Both the S-N curves scarecely show any clear fatigue limit in the range of 10^4 cycles, but they show the fatigue strength at 10^4 cycles $70 kg/mm^2$ and $80 kg/mm^2$ for without and with hardening heat treatment, respectively. This strength level is somewhat higher than that by conventional rotating bending test[6].

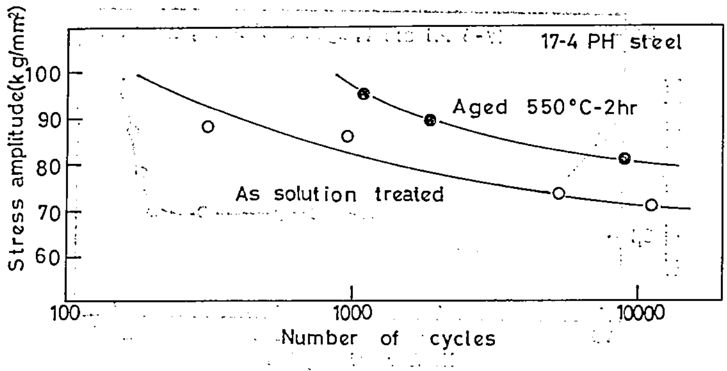

Fig. 2 S-N curves of 17-4 PH steel with and without hardening heat treatment.

The fact that the fatigue strength of aged steel is higher than that of unaged steel corresponds to the same tendency of hardness. The mild bending of S-N curves occurs between 10^3 and 10^4 cycles.

The strain amplitude during fatigue testing of solution treated steel is shown in Fig. 3. The strain amplitude decreases with increasing cycles and at the vicinity of

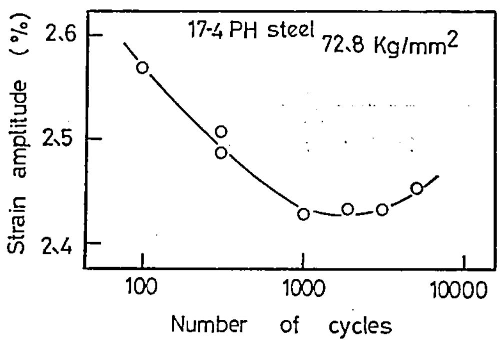

Fig. 3 Strain amplitude change during fatigue testing under constant stress amplitude for solution heat treated 17-4 PH steel.

rupture the strain amplitude increases rapidly. The mean strains of specimens were maintained almost unchangeable during fatigue testing. This test is made under constant applied stress amplitude, therefore the fact above mentioned means that the specimen is hardened by alternating stressing. The similar behaviour is observed for aged steel in Fig. 4, though the hardening by alternating stressing is not so obvious, since this steel is already hardened by heat treatment.

Fracture surface shows predominantly the typical fatigue pattern that is small elongation and brittle fracture, but cup and cone type fracture also is observed in the specimen which ruptured in short cycles.

3-2 18-8 stainless steel

The S-N curve of 18-8 steel is shown in Fig. 5. This curve shows that the

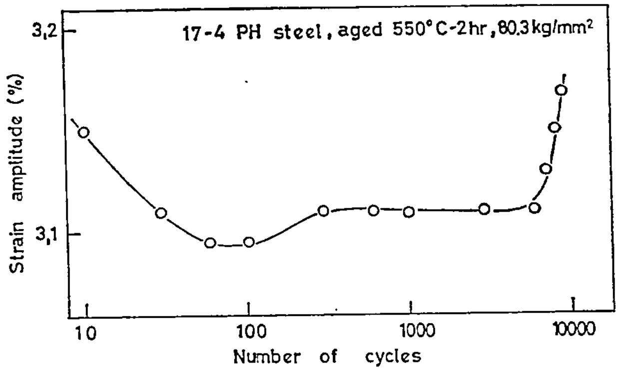

Fig. 4 Strain amplitude change during fatigue testing under constant stress amplitude for hardened 17-4 PH steel.

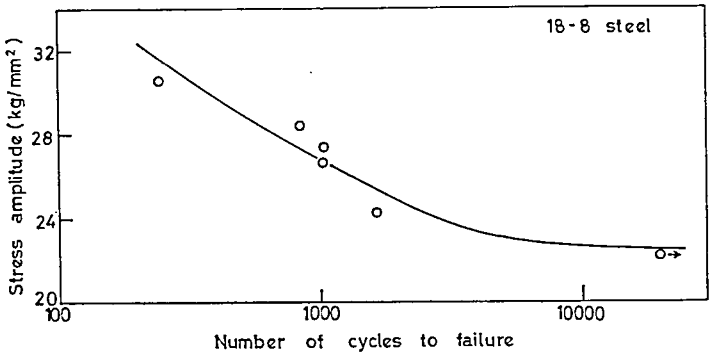

Fig. 5 S-N curve of 18-8 steel.

fatigue strength at 10^4 cycles is about $22\,kg/mm^2$. This fatigue strength level is smaller than that by another test method[9]. The bending of S-N curve is shown between about 10^3 and 10^4 cycles.

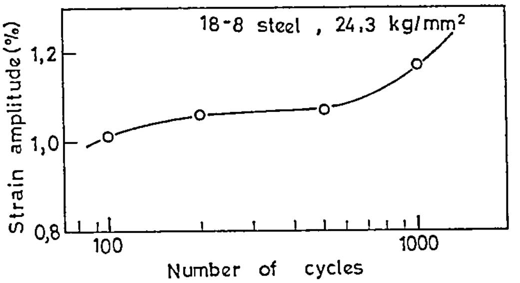

Fig. 6 Strain amplitude change during fatigue testing under constant stress amplitude for 18-8 steel.

Fig. 6 shows the change of strain amplitude during alternating stressing. The strain amplitude increases progressively with cycles. This increase of strain means the weakening of material, since this test was made under constant stress amplitude, but exactly speaking, the reduction of area of test piece must be considered.

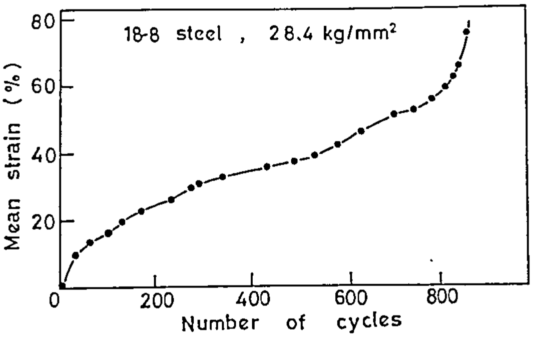

Fig. 7 Mean strain with number of cycles for 18-8 steel.

Fig. 7 shows the mean strain of test piece with number of cycles. The mean strain increases with number of cycles and at the vicinity of rupture it increases abruptly. However, this curve is not smooth and it contains many discontinuous steps. This irregular increase of strain is observed sometimes in this investigation.

The fracture surface of this steel is brittle at low stress amplitude, and cup and cone type is shown at high stress amplitude.

4. Discussion

The bending of S-N curves by present work was observed at about 10^3 to 10^4 cycles. However, by rotating bending testing it is shown at 10^5 to 10^7 cycles. This difference depends on the type of stress and strain rate, too. Present work is carried out by about 1 Hz, however, conventional rotating bending test is done by 15 Hz or more.

Strain amplitude during fatigue testing shows quite different manner for two types of stainless steel. For 17–4 PH steel it decreases and then increases with number of cycles and for 18–8 steel it increase progressively with number of cycles. This fact shows that former is work-hardened and later is work-softened. However, many facts show usually that 18–8 steel also is hardened by working. So the plastic deformation plays some roles in fatigue process, and the influence of internal stress is never neglected for this behaviour.

The mean strains of specimens are kept almost unchangeable for 17–4 PH steel, but it increases remarkably for 18–8 steel. At the later case fatigue has a progress with cycles of stressing. In this phenomenon the plastic deformation does not restore the original state. However, it is now not clear that this deformation step corresponds to the striation pattern or not.

By the fracture surface observation, typical brittle fatigue surface and fracture surface of cup and cone type were both shown. However, the phenomenon will become complicated for stress level, sort of steel, and heat treatment. In our range of study the typical nonelongated fracture was observed at low stress amplitude.

5. Conclusions

The tension-compression type fatigue test was made for 17–4 PH and 18–8 stainless steel. The fatigue strength of 10^4 cycles for 17–4 PH steel is about 70 kg/mm^2 and after hardening heat treatment it becomes about 80 kg/mm^2. In the range of test the clear bending of S-N curves is not observed. The fatigue strength of 18–8 steel is 22 kg/mm^2, and the bending of S-N curve is observed at about 10^3 or 10^4 cycles.

Under constant stress amplitude testing, the strain amplitude of 17–4 PH steel decreases and then increases with number of cycles and the mean strains of test pieces are almost unchangeable. On the contrary the strain amplitude of 18–8 steel increases progressively with number of cycles and mean strain also increases. This difference should be caused by the effect of plastic deformation and internal stress of materials.

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