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Influence of Compressive Pre-strain on Tensile Fatigue in Two Types of Aluminum Alloys

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The effect of pre-strain on fatigue behavior in various kinds of materials has been reported on several times thus far (Ref 1-11). That being said, however, the number of actual systematic research works on this topic is quite few, and it is still unclear whether pre-straining is of any benefit in fatigue properties, presumably depending on the material and its microstructure. Furthermore, in particular, the effect of compressive pre-strain on pulsative (tensile) fatigue behavior has not been reported on in correlation with cyclic plastic strain response for the materials strengthened by different mechanisms, which is very important in engineering application. However, it has so far been considered that the measurement of cyclic plastic strain response under the condition of tensile fatigue is extremely difficult because of its smallness. In the present study, the influence of compressive pre-strain on fatigue properties in two types of aluminum alloys (5056-H34 Al alloy and 6061-T6 Al alloy) has been investigated. 5056-H34 Al is the alloy strengthened mainly by solid solution, while 6061-T6 is the precipitation-strengthened alloy (H34: work-hardened and stabilized, T6: solid-solution treated and artificially aged).

The mechanical properties, which were obtained by the tensile test at the strain rate of about 1.5×10^{-2}/s, are shown in Table 1. The UTS and the 0.2% proof stress of 6061-T6 with precipitation strengthening are higher than those of 5056-H34. The specimen is cylindrical in nature with the gauge length of 13 and 7 mm diameter. Compressive pre-strains of 0.4 to 3.2% were applied to these alloys prior to fatigue testing and the fatigue lives have been measured and compared to those in the materials without pre-straining. The stress-controlled fatigue test was conducted using Dynamic Servo FT-5, SAGInoMIYA, Japan at a frequency of 10 Hz under the pulsative (zero-tension) condition of sine wave, i.e., the stress ratio $R = 0$ in air at room temperature. Furthermore, in order to study the cyclic stress-strain response (CSSR), similar fatigue tests were carried out during the repetitions until 1,000 cycles at the frequency of 1 Hz for both specimens with pre-straining and without pre-straining. Additionally, the fatigue property of the conventional low carbon steel containing 0.22%C (ferrite + pearlite structure) has also been studied for comparison.

Figure 1 shows the fatigue life (S-N curves) for three kinds of materials, presenting the relationship between the applied maximum stress normalized by UTS and the number of cycles to failure.

In 5056-H34 Al alloy (Fig. 1a) the influence of pre-straining on fatigue life appears to be insignificant or rather even favorable, although there has been considerable scatter in experimental data. In 6061-T6 alloy (Fig. 1b) the significant influence of pre-straining on fatigue life has been observed. 0.8% pre-straining produced the reduction in fatigue life more than 0.4% pre-straining, but even greater amount of pre-straining (3.2%) did not result in further reduction in fatigue life within the present experimental condition. The maximum reduction in fatigue life is 60-70%. In carbon steel the influence of pre-straining was not detected (Fig. 1c), as similarly shown in 5056-H34 Al alloy.

Figure 2 exhibits the CSSRs, i.e., the variation of plastic strain amplitudes during cycling, in two types of aluminum alloys. Eighty-five percent of UTS in each material is applied to the specimen as the maximum stress. Regardless of pre-straining, rapid decrease in plastic strain amplitude during early cycles and the subsequent gradual decrease have been observed for both alloys.

As seen in Fig. 2(a), it is of interest that in 5056-H34 Al alloy similar behaviors have been observed both in the specimens with pre-strain of 0.8% and without pre-strain, and that pre-straining of 3.2% reduces the plastic strain amplitude to some extent. As for 6061-T6 alloy, on the other hand, considerably higher plastic strain amplitudes in the pre-strained specimen (0.8 and 3.2%) than in the non-strained specimen are produced during cycling. It has been considered that such production of the higher plastic strain amplitude results in the reduction in the fatigue lives of pre-strained 6061-T6 alloy.

Stoltz and Pelloux (Ref 12, 13) have reported that the alloys having shearable precipitates shows a small Bauschinger effect, whereas the alloys containing nonshearable precipitates exhibits a very large Bauschinger effect. Furthermore, the hysteresis behavior of the materials containing nonshearable particles cycled at a high strain amplitude has been reported by Stoltz and Pelloux (Ref 12, 13) and Asaro (Ref 14, 15). These researchers have shown that such materials exhibit concave-shaped hysteresis loops, depending on the applied plastic strain amplitude, and have attributed this behavior to the back stress raised by the existence of the strong particles. The TEM observation has also revealed that

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Table 1 Mechanical properties of materials used

	UTS, MPa	0.2%PS, MPa	Elongation, %
5056-H34	292	204	21
6061-T6	323	290	14

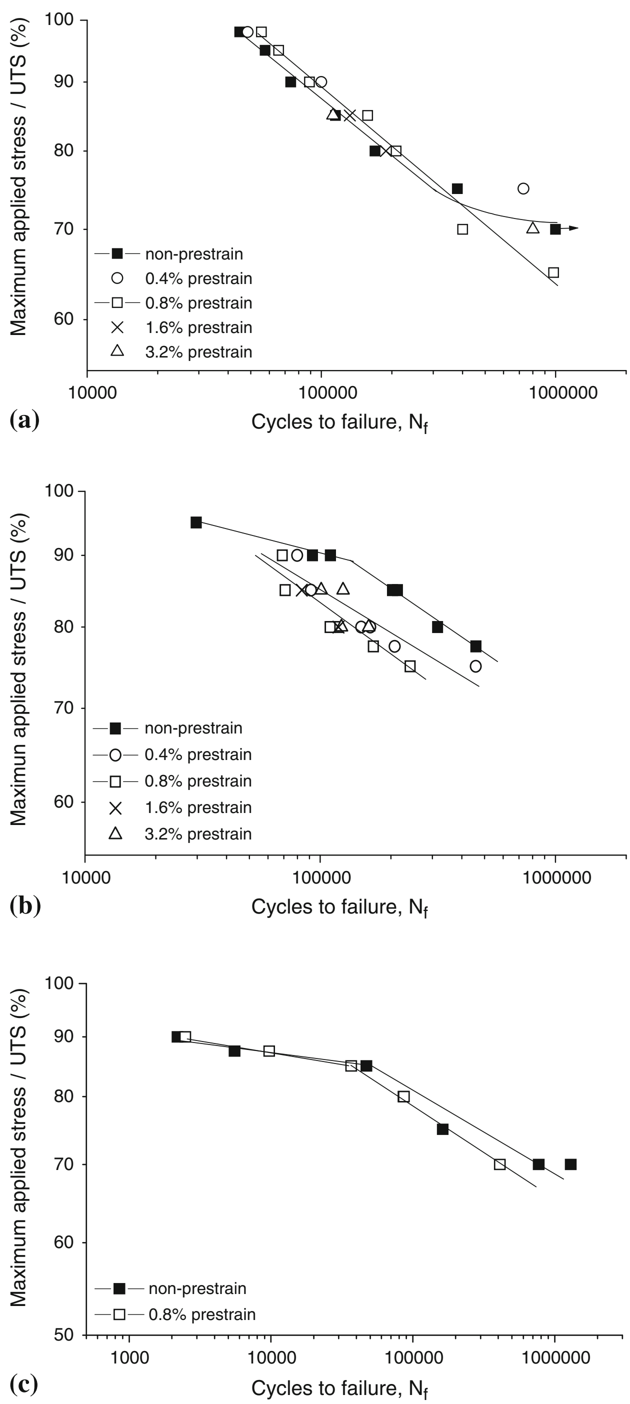

Fig. 1 Fatigue life curves (Applied maximum stress normalized by UTS is used). (a) 5056-H34 Al alloy, (b) 6061-T6 Al alloy, and (c) low carbon steel

many dislocations are located at the broad faces of the precipitates-plates in the alloy containing nonshearable precipitates cycled (Ref 16).

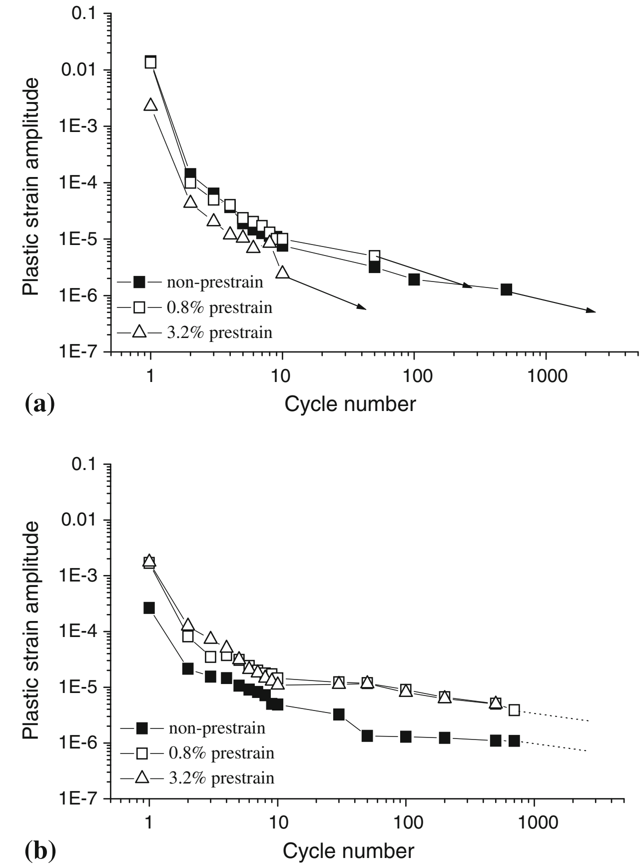

Fig. 2 The variation of plastic strain amplitude during cycling. (a) 5056-H34 Al alloy and (b) 6061-T6 Al alloy

Therefore, it is considered that the pile-up of dislocations to the precipitates in 6061-T6 alloy by pre-straining presumably causes the remarkable Bauschinger effect (Note the significant difference between the plots of specimens with and without pre-strain at the first cycle), and such production of larger plastic strain amplitude is not terminated in the first reversal but obviously continues during cycling, presumably leading to the shorter fatigue life in this alloy.

The stress values in the present work are calculated using the original cross section area of the specimen. The effect of the change of the section area on fatigue life is negligible compared to the data scattering in the case that the compressive pre-load is less than 1%. However, in the case of large compressive pre-loading (3.2%), it seems that its effect should be taken care of, i.e., since the true applied stress due to the area increment caused by pre-straining should be lower than the conventional stress, the data points in the S-N curve (Fig. 1) of the specimens largely pre-strained should be slightly shifted to the lower side and those in CSSR (Fig. 2) should be shifted to the upper side.

From the above consideration, it has been concluded that the fatigue life reduction caused by compressive pre-straining is clearly produced in precipitation-hardened alloy (6061-T6) and not in solid-solution hardened alloy (5056-H34), and that the fatigue life reduction in 6061-T6 alloy is attributable to the higher plastic strain amplitude during cycling in the pre-strained specimen which is originally produced by the Bauschinger effect at the first stress reversal.

References

1. D.L. DuQuesnay, M.A. Pompetzki, T.H. Topper, and M.T. Yu, Effects of Compression and Compressive Overloads on the Fatigue Behavior of a 2024-T351 Aluminum Alloy and a SAE 1045 Steel, *Low Cycle Fatigue ASTM STP*, 1988, **942**, p 173–183
2. A. Gustavsson and A. Melander, Variable-Amplitude Fatigue of a Dual-phase Sheet Steel Subjected to Prestrain, *Int. J. Fatigue*, 1994, **16**, p 503–509
3. L. Kunz, P. Lukás, B. Weiss, and D. Melisova, Effect of Loading History on Cyclic Stress-Strain Response, *Mater. Sci. Eng.*, 2001, **A314**, p 1–6
4. H. Ni and Z. Wang, Effect of Pre-strain and Mean Stress on Cyclic Plastic Deformation Response of Iron-based Alloys, *Mater. Sci. Eng.*, 2001, **A314**, p 12–23
5. K. Schoeler and H.-J. Christ, Influence of Prestraining on Cyclic Deformation Behaviour and Microstructure of a Single-phase Ni-base Superalloy, *Int. J. Fatigue*, 2001, **23**, p 767–775
6. D.B. Lanning, T. Nicholas, and G.K. Haritos, Effect of Plastic Prestrain on High Cycle Fatigue of Ti-6Al-4V, *Mech. Mater.*, 2002, **34**, p 127–134
7. M. Kang, Y. Aono, and H. Noguchi, Effect of Prestrain on and Prediction of Fatigue Limit in Carbon Steel, *Int. J. Fatigue*, 2007, **29**, p 1855–1862
8. K.S. Al-Rubaie, M.A. DelGrande, D.N. Travessa, and K.R. Cardoso, Effect of Pre-strain on the Fatigue Life of 7050-T7451 Aluminium Alloy, *Mater. Sci. Eng.*, 2007, **A464**, p 141–150
9. C. Froustey and J.C. Lataillade, Influence of Large Prestraining of Aluminium Alloys on Their Residual Fatigue Resistance, *Int. J. Fatigue*, 2008, **30**, p 908–916
10. A.Q. Le, H.T. Kang, G. Kridli, A.K. Khosrovaneh, and B. Yan, Effect of Prestrain Paths on Mechanical Behavior of Dual Phase Sheet Steel, *Int. J. Fatigue*, 2009, **31**, p 607–615
11. M.T. Whittaker and W.J. Evans, Effect of Prestrain on the Fatigue Properties of Ti834, *Int. J. Fatigue*, 2009, **31**, p 1751–1757
12. R.E. Stoltz and R.M. Pelloux, Cyclic Deformation and Bauschinger Effect, *Scripta Met.*, 1974, **8**, p 269–276
13. R.E. Stoltz and R.M. Pelloux, The Bauschinger Effect, Monotonic and Cyclic Hardening in Precipitation-Strengthened Aluminum Alloys, *Work Hardening in Tension and Fatigue*, A.W. Thompson, Ed., Metallurgical Society of AIME, Warrendale, PA, 1977, p 224–239
14. R.J. Asaro, Elastic-Plastic Memory and Kinematic-type Hardening, *Acta Met.*, 1975, **23**, p 1255–1265
15. R.J. Asaro, Reversible Plasticity and Work Hardening, *Work Hardening in Tension and Fatigue*, A.W. Thompson, Ed., Metallurgical Society of AIME, Warrendale, PA, 1977, p 206–223
16. S. Horibe and C. Laird, Orientation and History Dependence of Cyclic Deformation in Al-Cu Single Crystals Containing θ′ Precipitates, *Acta Met.*, 1983, **31**, p 1567–1579