IMPACT OF SUPERPLASTIC STATE ON FATIGUE OF AN ALUMINIUM BRONZE

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WE report here two unusual features observed during low cycle fatigue of an aluminium bronze (referred to by the trade name ALRONZE) containing by weight per cent, besides copper, 9·5 aluminium and 4·0 iron. This alloy, in the hot rolled condition, has been found to exhibit superplastic behaviour during slow tensile deformation at elevated temperatures[1]. At 800° C and strain rate of 6×10^{-4} sec^{-1}, round tensile specimens made from hot rolled plate of this alloy exhibit elongations in excess of 700%. The fine scale microstructure (average phase size ~ 10 μm) in this situation is characterised by the presence of an α phase, which is a face centred cubic solid solution of aluminium in copper, $(\alpha + \gamma_2)$ eutectoid microconstituent in which γ_2 is an intermetallic compound with the γ brass structure, and δ particles of iron rich phase with the body centred cubic structure. Superplasticity in tension tests has been explained in terms of a high strain rate sensitivity of flow stress (σ) of this alloy for which the strain rate sensitivity index *'m'* (*vide* equation $\sigma = k\,\dot{\epsilon}^m$ where k is a constant and $\dot{\epsilon}$ is the strain rate) has been found to be as high as 0·6 at the conditions of temperature and strain rate mentioned above. There are negligibly few investigations[2] on post-formed fatigue characteristics of superplastic materials. The present investigation was therefore aimed at an examination of the alternate strain behaviour of superplastic ALRONZE. The two unusual features reported here concern the shape of the mechanical hysteresis loop and the shape instability of the test specimen when subjected to low cycle fatigue deformation in the superplastic condition.

Low cycle fatigue tests were conducted at 800° C and at room temperature using extension cycle control and a frequency of 1 cpm. Necessary modifications to the available Floor Model TT-CM-L Instron Universal Testing Machine were designed and fabricated by us[3] and consisted essentially of massive pull rods, a split furnace, cooling system to maintain the Instron load cell below 65° C and specimen locknuts to enable rigid holding of the specimen during push-pull fatigue. An hour-glass type geometry was chosen for the specimen with a gauge length of 3·81 mm and diameter of 3·18 mm.

The mechanical hysteresis loops recorded at 800° C and at ambient temperature (30° C) are shown in Figs. 1 and 2 respectively. The hysteresis loop in Fig. 1 corresponding to the superplastic temperature may be characterised by three features : (1) maximum stress does not differ significantly from that at zero strain ; (2) extremely low stresses with the maximum being 0·65 kg/mm^2 ; and (3) near absence of elastic deformation (the magnitude of plastic strain range $\Delta \epsilon_p = 4{\cdot}2\%$ is to be compared with that of the total imposed strain range $\Delta \epsilon_t = 4{\cdot}6\%$). These features may be contrasted with the corresponding ones of the hysteresis loop in Fig. 2 in which may be seen the following : (1) maximum stress is thrice as much as that at zero strain ; (2) much higher stresses with the maximum being 60 kg/mm^2, two orders higher than that in Fig. 1 and (3) considerably larger elastic strain component ($\Delta \epsilon_t = 13{\cdot}4\%$ and $\Delta \epsilon_p = 5{\cdot}6\%$). Clearly the observed transition in the hysteresis loop at the higher temperature is a consequence of the much

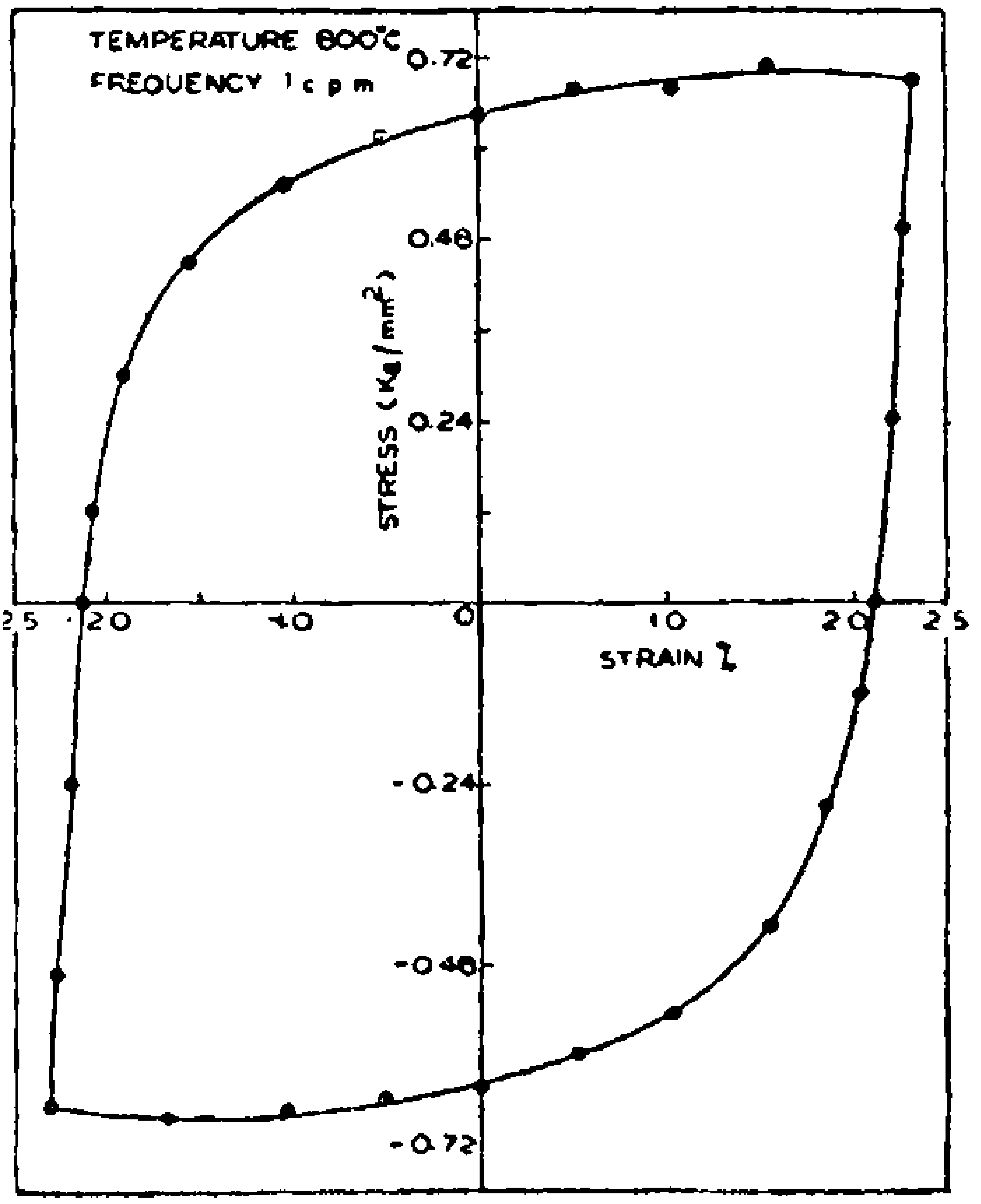

FIG. 1. Mechanical hysteresis loop at 800° C.

higher strain rate sensitivity of flow stress at 800° C ($m = 0{\cdot}6$)[1] as compared to that at room temperature ($m = 0{\cdot}03$ as determined by us using the stress relaxation technique).

Generally, we can express the dependence of flow stress (σ) on strain (ϵ) and strain rate ($\dot{\epsilon}$) as

$$\sigma = k' \epsilon^n \dot{\epsilon}^m \qquad (1)$$

where n is the strain hardening exponent, k' a constant and m is the strain rate sensitivity index. At ambient temperatures m is very small and the flow stress is strongly dependent on strain owing to work hardening. Thus in Fig. 2 maximum stress occurs at maximum strain. When a material is in the superplastic state characterised by negligible work hardening and high strain rate sensitivity, equation (1) essentially becomes $\sigma = k\,\dot{\epsilon}^m$. In view of our experiments having been performed on the Instron at constant cross head speed (v) the strain rate is maximum at the commencement of the test and varies ($\dot{\epsilon} = v/L$ where L is the gauge length of the specimen) somewhat during tension and compression of the specimen. In the superplastic state the flow stress of the alloy is strain rate dependent as stated in the foregoing, and thus exhibits nearly maximum flow stress at zero strain (Fig. 1). The low flow stresses of superplastic alloys arise due to deformation at elevated temperatures (0·82 Tm in the present instance) of extremely fine grained (~ 10 μm in the present instance) microstructures. Most of the deformation is plastic in this situation owing to extremely low yield stress.

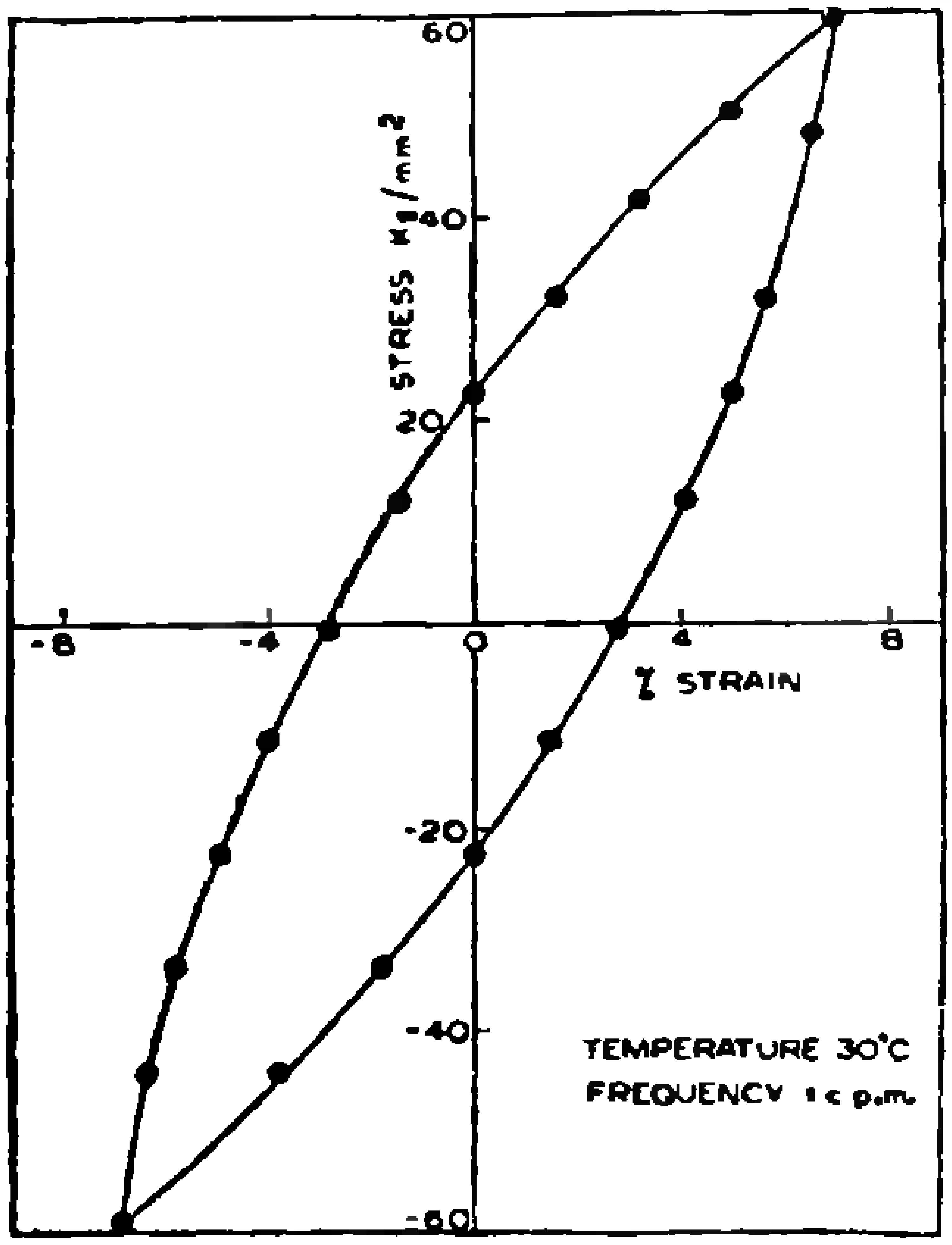

Fig. 2. Mechanical hysteresis loop at 0° C.

Further, during fatigue at 800° C, specimens of ALRONZE exhibited considerable shape instability in the form of specimen shortening and diameter fattening (Fig. 3). Coffin[4] has reported observation of similar specimen shape instability in 2S aluminium, nickel, 304 stainless steel and 1010 steel at elevated temperatures. According to Coffin's explanation, second order non-zero mean stresses, which arise because of a difference in the response of the material during tension and compression, cause superposed monotonic deformation and lead to specimen instability. It is possible that the same reason applies in the present instance with the non-zero mean stress being compressive in nature. The very low flow stress and large plasticity of the material due to the superplastic condition obviously accentuate shape instability for ever-so-small a value of the non-zero mean stress.

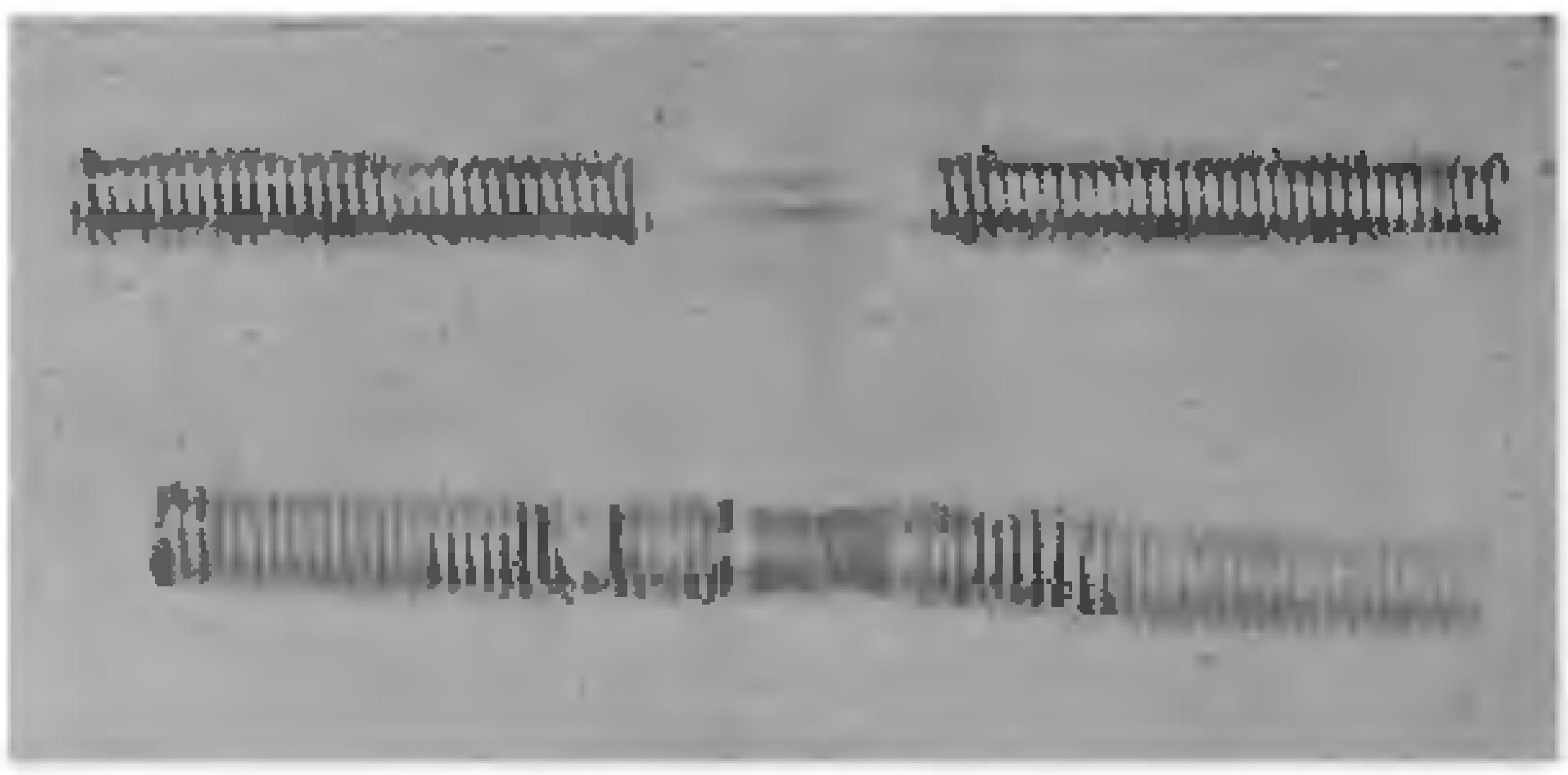

Fig. 3. Specimen instability at 800° C.

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