SOME EXPERIMENTAL OBSERVATIONS ON CYCLIC CREEP UNDER MAGNETIC FIELD

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The paper presents some experimental observations on the influence of an external magnetic field on cyclic creep of mild steel. The emphasis in the work has been strain accumulation rather than the total life of the test specimen. The experimental results support the predicted level of deformations developed by a simple phenomenological model for a constant load test.

INTRODUCTION

The studies of Kennedy (1) and Feltner (2) on cyclic creep suggest that the phenomenon occurs due to the dislocation re-arrangement which is responsible for cell wall formation. The studies of Chandler (3) and Lorenzo and Laird (4) have further shown that the changes that occur at the microlevel in copper during the process of cyclic creep are not continuous. These studies indicate that the process of cyclic creep is a phenomenon closely dependant on dislocation movement. Therefore, any factor that affects the mobility of dislocations should influence deformation in cycle creep. Experiments have been conducted to examine this aspect. The paper presents some specific experimental results. Full details of the work are, however, available elsewhere (5). An important aspect of the work presented here is the consideration of "yield drop" phenomenon. Yield drop phenomenon has been considered to arise due to the recovery within the material resulting in lower value of yield stress in the reloading cycle than a value of stress where from the unloading was done. Consideration of such a phenomenon is based on the works of Malkin (6) and Bolling (7). In the present paper this phenomenon is explained through the process of recovery, in which any one or more of the following mechanisms are operative:

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(i) migration of point defects,
(ii) plastic deformation,
(iii) annihilation of dislocations by interaction with vacancies and
(iv) generation and rearrangement of dislocation etc.

These mechanisms give the possibility of yielding starting earlier than point Y' of Fig.1. This would result in more deformation per cycle on reloading to the same stress level where from it was unloaded. The figure shows the difference in slopes of two curves YAX at A and Y'EF at E, thus difference in values of strength constants. The detailed procedure for evaluation of the microplastic strength constant K (for reloading cycle), which is analogous to strength constant K' of the usual work hardening equation $\sigma = K'\mathcal{E}^n$, is given elsewhere (5). It may be mentioned here, the evaluation of K is based on the accumulation of dislocations against a barrier and their subsequent release. This nonhomogeneous behaviour of the material during cyclic creep is seen from the sudden increase in extension referred to as "strain burst". Such a phenomenon was observed for copper by Lorenzo and Laird (4). In the present study as well such a phenomenon has been seen and are shown in Fig.2. These bursts arise due to the release of dislocations from the barriers holding them. Thus, the evaluation of microplastic strength constant "K" on the basis of assumption mentioned earlier is justified. With such a value of K the microplastic strain developed in Nth reloading cycle in cyclic creep has been given (5) by the following equation

$$(\Delta e_N)^m = \frac{\sigma_1}{70(1+e_1)} \cdot \frac{1}{K_n} (1 + e_N + 70\Delta e_N) \qquad (1)$$

where Δe_N is the microstrain developed in Nth reloading cycle,
e_1 is the strain developed in 1st cycle,
e_N is the strain developed in N cycles,
σ_1 is stress applied in the first loading cycle,
m is cyclic creep index,
K_N is microplastic strength constant for Nth reloading cycle and is given as (5).

$$K_N = \left(\frac{G}{\pi}\right)^{0,5} \left(\frac{\tau_a - \tau_e}{\sqrt{\tau_e}}\right) \qquad (2)$$

where G is shear modulus of elasticity, τ_a is applied shear stress and τ_e is the effective shear stress. The deformation in cyclic creep is thus found to get influenced by the state of internal stress in the material.The mechanisms which influence the cyclic creep are also found to get affected by an external magnetic field as discussed in next section. It is postulated therefore that the magnetic field influence on these mechanisms would lead to the enhanced deformation rate in the case of cyclic creep.

In ferromagnetic materials an external magnetic field increases the domains that are oriented favourably at the expense of unfavourably oriented ones Kittel (8). Friedel (9) suggested that dislocations act as a source of hindrance for the easy movement of domain walls and vice versa. This has been confirmed by Chebotkevich et al. (10,11), who found a positional shift in dislocations by the application of magnetic field. The stress field of dislocations interact with the associated stress field of the domain walls causing a change in magnetization process. So any phenomenon that reduces the interacting force would result in change in the behaviour of the material. Magnetic field which reduces the domain walls should therefore show an affect on dislocation movement. Muju and Ghosh (12, 13) , Allen and Donovan (14) have observed that the flow stress of mild steel (0.2% Carbon) is reduced by about $G\lambda \cong 0.8$ kg/mm^2 by the application of magnetic field, where G is the shear modulus of elasticity and λ is the magnetostrictive coefficient of the material. These studies have considered that the domain walls are an extra source of stress resisting the easy movement of the dislocations, and a methot that reduces (or eliminates) these domain walls results in higher mobility of dislocations. The reduction in the flow stress has been related to the drop in the internal stress. Although this drop is a very small quantity compared to the yield stress yet it plays a significant role in phenomena like creep, fatigue, wear which are sensitively dependant upon the internal stress. Cyclic creep which is also sensitively dependant upon the internal stress (15) is therefore expected to get significantly affected by a change in the internal stress. Magnetic field is therefore expected to result in a similar influence on the cyclic creep of ferromagnetic materials.

Authors consider that the internal state of stress during cyclic creep is affected by the magnetic field through the process of recovery. The magnetic field is considered to reduce the internal stress in the material which may be due to: (i) the enchanced self-diffusion (16) leading to higher dislocation activity, (ii) large reverse susceptibilities after plastic deformation (17) and (iii) reduction in the activation energy under the influence of magnetic field (13). This has lead to the different value of microplastic strength constant "K" in equation 2 under the influence of magnetic field K^H (H denotes the presence of magnetic field). The value of K^H is evaluated from the equation (2) with a modification that internal stress acting is reduced by 0.5 kg/mm^2 under the influence of magnetic field. Thus equation (2) reduces to

$$K^H = \left(\frac{G}{\pi}\right)^{0,5} \left[\frac{\tau_a - \tau_e - 0,5\,(kg/mm^2)}{\{\tau_e + 0,5\ (kg/mm^2)\}^{0,5}}\right] \tag{3}$$

Assuming there is no change in the value of cyclic creep index m, equation (1) is modified as

$$(\Delta e_N^H)^{m_N} = \frac{\sigma_1}{70(1+e_1)} \cdot \frac{1}{K_N^H}\left(1 + e_N^H + 70\Delta e_N^H\right) \tag{4}$$

EXPERIMENTAL RESULTS AND DISCUSSIONS

In order to test the validity of equations (2) and (4) the experiments were conducted in presence and absence of the magnetic field. All the tests have been conducted on Material Testing System (MTS-810). At room temperature (25°C). The specimen have been made from mild steel (0.2% Carbon) bars of 20 mm diameter. The samples were annealed at 875°C for one hour. After the machining, the specimen were mirror polished to remove any machining marks. Each test has been carried out at least five times. Tha magnetic field, whenever required was applied by means of solenoids surrounding the specimen, such that it acts along the axis of the specimen.

The cyclic creep tests have been carried out at a load level of 0.828 to 0.86 ultimate tensile load both in presence and in absence of the magnetic field. A constant magnetic field of 650 $\frac{A.T}{cm}$ has been used during these experiments. The accumulation of the deformation has been measured by using extensiometers. The deformation values have been monitored till a stage where failure is seen to be immenent. However, during the last few cycles it was not possible to monitor the deformation accumulation accurately. The accumulation of the deformation has been estimated in an identical manner in both the cases (magnetic and nonmagnetic).

The results of deformation accumulation for the two cases have been plotted in Fig.3. The corresponding strain values have been plotted in Fig.4.

An important feature immediately observed from the Fig.4 is that there exists a critical value of deformation (e_u) which is almost independant of the load level. Beyond the catastrophic failure starts. The strain corresponding to this critical deformation is found to be around 0.18. Lukas (18) has suggested that the strain at failures lead to the fracture strain values also. In order to check whether this critical limit was linked to the mechanism of deformation accumulation or whether it was purely a gross physical feature (attainable in other ways), other tests were conducted. Fresh samples were put under tensile load till strain reached the same level as that of a critical value. The load was removed and samples put to cyclic creep loading. It was observed that no further accumulation of deformation was observed even when the material was subjected to 1500 cycles of loading. Normally a lesser number of cycles would have resulted in the fracture of the sample, had this level of deformation got accumulated through cyclic creep. This explains the view that structural damage is done by cyclic creep.

Just like the upper critical strain e_u there exists a strain magnitude (e_L) representing the start of steady state of the deformation curve in cyclic creep as shown in Fig.4. This strain level is also seen to be independant of the load level used.

As expected from equation (4) it is clearly observed that the strain rate is enhanced in presence of a magnetic field. The pattern of deformation is similar in both magnetic and nonmagnetic samples as seen in Fig.4. Further, both e_L and e_u limits are seen to remain almost unchanged at 0.11 and 0.18 respectively. However, the number of cycles required to reach these values of critical strain limits are reduced in presence of the magnetic field.

In the present study the cyclic creep index "m" has been considered to be insensitive to the influences of magnetic field. Therefore for evaluation of microstrain developed in the Nth cycle an identical value of m has been considered for both cases. The microstrain obtained from equation (3) have been used to give the cyclic creep deofrmation curves under the magnetic field and are shown in Fig.5. The figure also shows the actual curve obtained from experiments. The comparision of the predicted and the experimental curves shows a close agreement.

CONCLUSIONS

1. A steady magnetic field of even small intensity significantly influences the deformation rate per cycle.
2. The beginning and the end of the steady state of the deformation plot are seen to be independant of the magnetic field and hence can be considered to be the material properties.
3. The micro-deformation mechanisms of cyclic creep is different than that of the uniaxial tension through both produce similar cell structure.
4. The strain burst phenomenon is seen to be present for mild steel at room temperature as well.

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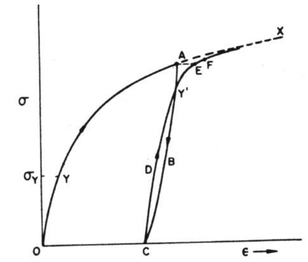

Fig.1. Schematic representation of loading, unloading and reloading in tension type test.

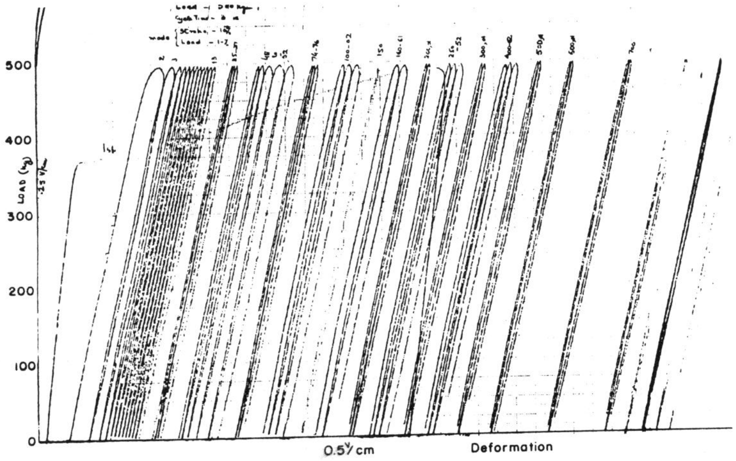

Fig.2. The strain burst observation on mild steel in cyclic creep at load of 0.9 P_{ult}.

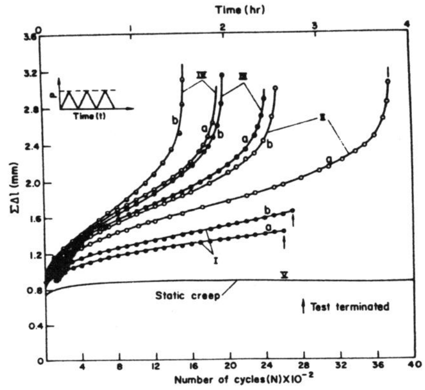

Fig.3.(A) Accumulation of cyclic creep deformation ( ) at load levels, (I) 1300 kg; (II) 1325 kg; (III) 1340 kg; (IV) 1350 kg: (a) without magnetic field, (b) with magnetic field of 650 amp.Turns/cm (B) Static creep curve at 1300 kg.

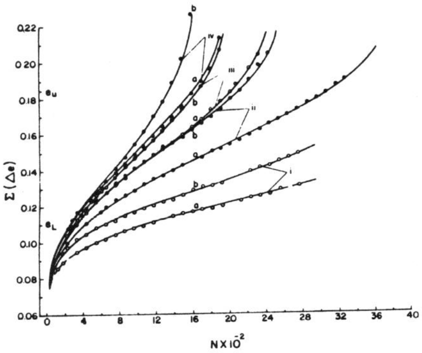

Fig.4.

The accumulation of strain with number of cycles (N) at different load levels: (i) 1300 kg, (ii) 1325 kg, (iii) 1340 kg, (iv) 1350 kg, (a) without magnetic field, (b) with magnetic field

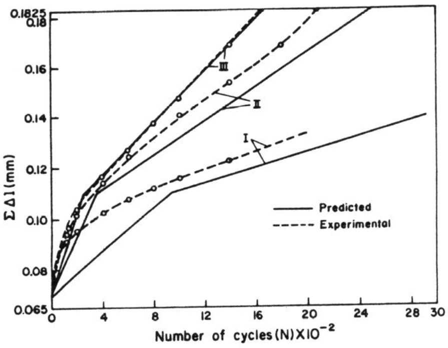

Fig.5.

Comparison between the predicted and experimentally observed strain growth curves at different load levels; (I) 1300 kg; (II) 1325 kg; under magnetic field.