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PRE-YIELD LUDERS BAND FORMATION in PURE IRON

by

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Pre-upper-yield-point initiation of a Luders band in pure iron*

It has been shown by Suits and Chalmers[1] in silicon–iron and by Koppenaal and Evans[2] in niobium that a significant amount of microscopic dislocation generation and slip takes place prior to the upper yield point. The observations presented below are intended to illustrate the direct dependence of the formation of the initial Luders Band on the pre-yield microscopic slip in pure Iron, and to suggest a method for measuring the relative contributions of initiation and propagation of the Luders Band to stress relaxation. The material used for this test was Ferrovac "E" iron containing approximately 30 ppm carbon, the specimens were 0.050 inch diameter rod with a one inch gage length, and the grain size 30 μ.

The testing procedure involved the measurement of torsional stress–time curves for loading and stress relaxation cycles in which samples were stressed to various levels in the elastic region and then allowed to relax in the loaded condition by stopping the test machine. The critical grain-size–independent lattice resistance to generation and movement of dislocations in a slip plane before build-up of back stress was determined to be about 5000 psi by the extrapolation technique, as discussed by Lindley and Smallman.[3] The values of applied stress used were above this level to insure dislocation movement during the relaxation cycle.

Curves representing the type of behavior found are shown in Fig. 1. In specimens tested at levels (a) and (b) the rate of stress relaxation was finite but low indicating the presence of microscopic dislocation movement. At stress level (c) the relaxation rate showed an abrupt discontinuity after approximately 12 sec resulting in a large rate increase. Reloading increased the stress only to the level of the lower

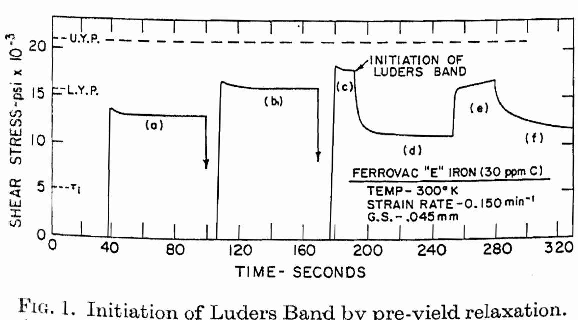

FIG. 1. Initiation of Luders Band by pre-yield relaxation. Specimens (a) and (b) showed slight stress relaxation upon stoppage of the test machine. Specimen (c) started to relax at about the same rate for 12 sec then the rapid relaxation (d) started which corresponded to initiation of the first Luders Band. Restressing, (e), brought the stress to the lower yield point. Subsequent relaxation at (f) was lower than (d). Note the disappearance of the upper yield stress.

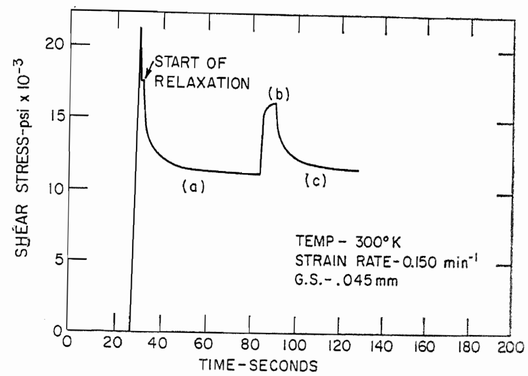

FIG. 2. Post-upper yield point relaxation. The test machine was stopped such that relaxation initiated at a stress between the U.Y.P. and L.Y.P. The magnitude of relaxation was intermediate between that of pre-yield relaxation of Fig. 1 (d) and after restressing to the lower yield point as in (c).

yield point and subsequent behavior was similar to a normal continuous stress–time test. The elimination of the upper yield point established the direct relationship between the portion (d) of the curve and the initiation of the first Luders Band.

Figure 2 (a) represents the stress relaxation caused by the Luders Band subsequent to straining past the upper yield point and after stopping the test machine to prevent the applied stress from dropping to the lower yield point. Restressing to the lower yield point resulted in the relaxation of (c). These results will be discussed in the next section. One further observation, as illustrated in Fig. 3, appears to be reduction of the time for initiation of the Luders Band produced at one stress level by prior relaxation at a lower stress level. This is not unexpected as dislocation motion at each stress level would have a similar effect on build-up of stress concentrations giving rise to a cumulative process.

Comparison of the relaxation curves as represented in Fig. 4 suggests that the pre-yield technique may be applicable for observing the effects of initiation as well as propagation of the Luders Band on release of strain energy. The three relaxation tests of Figs. 1 (d), 2 (a) and 3 (c) were initiated at about the same stress level of 18000 psi. The rates of relaxation, expressed as $r = \Delta\tau/\Delta \log t$, were approximately the same after 0.5 sec but the nearly instantaneous stress drop preceding the 0.5 sec value was greater in the two pre-yield samples than in the post-upper yield point-pre-lower yield point sample by about 1500 psi. This difference can be attributed to the instantaneous stress reduction coincident with initiation of the Luders Band. (When combined with the corresponding strain relaxation this provided an elastic energy release of about 7×10^4 ergs.) Once the Band had

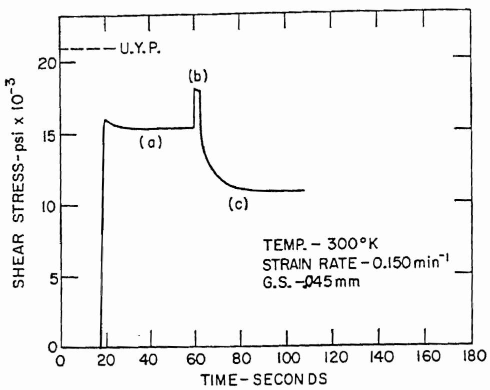

FIG. 3. Effect of relaxation at one stress on initiation of the Luders Band at a higher stress. The time of relaxation (b) before the Luders Band contribution (c) was decreased by relaxation (a). Compare with Fig. 1 (c) and (d).

formed the subsequent relaxation was the same in all specimens. Restressing the material to the lower yield point and adding a small increment of plastic strain, as in Fig. 2 (b), decreased the relaxation rate, 2 (c), suggesting pinning or locking of the dislocations within the Band as it proceeded axially in the sample.

Recent work by Noble and Hull[4] in iron–3.25% silicon has suggested the measurement of stress relaxation rate as a method of determining the "m" parameter in the dislocation velocity–stress relationship, $v = (\tau/\tau_0)^m$. They found "m" to be constant, at about 60, with change in strain in the Luders Band region of a stress-strain curve; an abrupt increase in

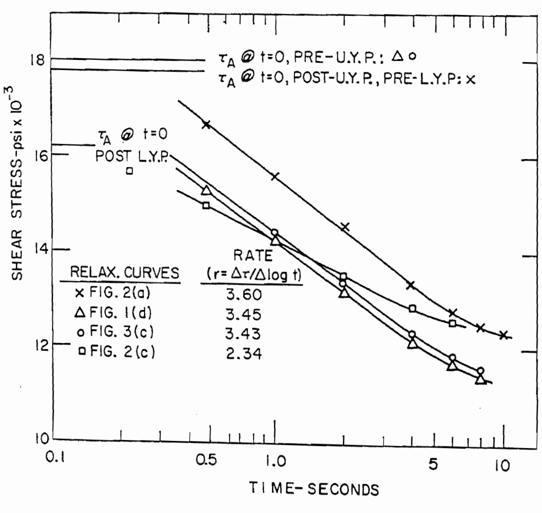

FIG. 4. Relaxation rates of pre-U.Y.P., post-U.Y.P. and post-L.Y.P. tests. The relaxation processes in the two pre-U.Y.P. samples (Δ, ○) and the one post-U.Y.P. sample (x) initiated at about the same stress level of 18000 psi. Note that after 0.5 sec, the rates were approximately the same, but the nearly instantaneous stress drop preceding the value of 0.5 seconds was greater in the pre-U.Y.P. samples by about 1500 psi.

"m" occurred at the onset of work hardening. present experimental results confirm this ge behavior in pure iron, "m" being lower, at a val about 20, during the Luders extension. Nobel Hull concluded, however, that existing techni were not acceptable for determining the "m" cons for zero strain; that is, movement of a Luders through virgin material. Use of the pre-yield da Fig. 4, which involved the initial movement o Band, provided a value of "m" about 0.6 time value obtained after restressing past the lower point. Thus, this testing method appears uni applicable for "zero strain" studies of disloc movements into undeformed material. As Noble Hull point out, after the Band has formed and b to move axially, relaxation is a combination of m ment of dislocations within the Band and at the front, the former causing an increase in "m".

The change in relaxation rate at a critical appears similar to the incubation creep phenom as discussed by Arsenault and Weertman,[5] here AW, in which a "rapid deformation" ensued af given incubation period at a constant load. behavior reported in the present note differs in respects from the results of incubation creep stud the type of deformation that is produced and transition region between the two relaxation per AW raised the stress in increments ranging from 1500 psi for their relaxation tests. At no time they observe a Luders Band and, in fact, slip were observed only after the first "rapid deforma was complete. The continuous formation of homogeneous slip lines found over the entire spec length by intermittent stress application precl the necessity for initiation of a Luders Band. I present experiment, local slip lines were present to the incubation period as the initial stress incre of about 15000 psi was more than an order of m tude higher than that used by AW. The high s elastic energy then resulted in the Luders Band than a homogeneous slip propagation. An characteristic of the present results indicati Luders Band formation was the abrupt chan relaxation rate observed as compared to the gradual increase reported by AW. Appa incubation creep studies measure the kinet formation of the microscopic slip which, i present work, is used to initiate the Luders Ba

The time–dependency of the formation Luders Band can be attributed to the contin increasing stress concentrations at Band nuc sites produced by movement of dislocatio grain boundary regions and clustering of grains. This accumulation of dislocations into localized grain boundary networks during relaxation takes place in the manner of logarithmic creep processes, as reviewed by McLean,[6] and gives rise finally to the critical stress for nucleation of the Luders Band and the observed catastrophic rate increase.

In summary, it has been shown that the initial Luders Band may be formed at applied stresses lower than the upper yield point, and under more controllable conditions, by allowing the microscopic slip taking place during pre-yield stress relaxation to produce the necessary internal stress concentrations. The discontinuous relaxation produced by the formation of the Luders Band provided an estimate of the effects of the initiation as well as propagation of the Band on stress release, and suggests a method for observing effects of changes in testing parameters and structure on the kinetics of the formation of the initial band.

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