Scripta METALLURGICA Vol. 11, pp. 193-195, 1977 Pergamon Press, Inc. 18
Printed in the United States

CONCERNING STRESS RELAXATION EXPERIMENTS IN COMMERCIAL PURITY TITANIUM

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(Received December 6, 1976)

The stress-time relation obtained in stress relaxation experiments of BCC metals and alloys was interpreted by Li and Gupta (1-3) by means of an assumed power relationship between dislocation velocity and effective stress; the dislocation velocity - stress exponent was successfully obtained therefrom. Since then, investigations (4,5) have shown that the power law breaks down for a number of FCC and HCP metals and alloys, including commercial purity titanium. Recently, Reed-Hill and Donoso (6) (heretofore abreviated as R-H&D) compared the results of continuously and incrementally (7) relaxed titanium of commercial purity, introducing the necessary corrections for machine relaxation. Even so, disagreement was found between the results of both techniques. R-H&D concluded that the negative dislocation velocity-stress exponent (physically impossible), the failure of the power relation and the disagreement between the results of continuous and incremental relaxation could not be simply ascribed to machine relaxation.

The basic assumption underlying Li and Gupta's (1-3) treatment is the substructure constancy during the test; the failure of this assumption would render any parameter derived therefrom of doubtful value. Substructural changes during the relaxation experiments could be responsible for the results obtained by R-H&D. This note describes a few simple experiments devised to verify a possible substructure change during similar experiments. The experimental conditions were maintained as close as possible to those of R-H&D. Tensile specimens (useful gage dimensions of 26 x 6 x 3.2mm) of commercial purity titanium of Grade I (comp. in Wt. pct determined by Ti Tech, Pomôna, Ca: 0.168% O; 0.0022% H; 0.010% N; 0.029% Fe) obtained in the form of 3.2mm thick sheets were heat treated in vacuum (1073 K for 1 hour), yielding an average grain diameter - as measured by the linear intercept method - of 52 μm. Both composition and grain size are fairly close to those of the titanium used by R-H&D (8). Tensile tests were conducted in an Instron TT-DM machine at a nominal strain rate of 1.3×10^{-4} sec^{-1} for both loading and unloading, at ambient temperature (298 K); 10.000 Kg capacity, wedge-action grips (model 10 F) were used to secure the tensile specimens. True-stress, true-strain curves were obtained by suitable processing of the load-elongation data from the Instron chart; strain developed during relaxation was ignored. In analogy with the two experiments by R-H&D the following tests were performed:

a) Loading the specimen to approximately 2 pct plastic strain (421 MN/m^2) and allowing it to relax continuously from this load for 4.3 hours.

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b) Loading the specimen to the same stress as in (a) (421 MN/m^2) and incrementally unloading it, in steps of 11.5 MN/m^2 to zero load. At each load level the specimen was allowed to relax for one minute. The total duration of the unloading was of about 30 minutes.

c) Loading the specimen to the same stress as in (a) and (b) (421 MN/m^2), completely unloading and keeping it for 4.3 hours.

The critical experiment applied to verify a possible change in the mechanical response of the substructure was simply to continue the tensile test after each interruption. Fig. 1 shows the curves A, B and C, for procedures a, c and b, respectively. Reloading yield point formation is clearly visible for the

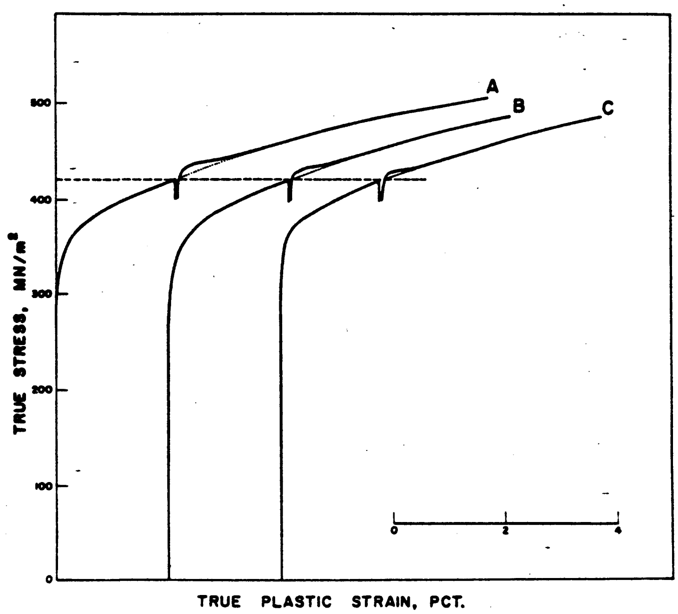

FIG. 1

True stress-true strain curves, interrupted at the stress where relaxation was performed. Notice the different degrees of work-hardening after the samples were reloaded. Curve A refers to the continuously relaxed test, curve B to the unloaded sample, and curve C to the incrementally relaxed sample.

three curves, showing that the mechanical response of the substructure was affected by the unloading schedules. After about 1 pct strain beyond reloading, the true-stress, true-strain curves returned to their normal path showing that the perturbation introduced by sequences a, b and c had been eliminated. The yield point was less evident for the incrementally unload test (curve C). It is suggested that such a behavior would be related to the time interval between stopping the cross-head and reloading. It was only around 30 minutes for schedule b while it lasted 4.3 hours in the other cases.

This kind of yield point formation in commercial purity titanium had been previously observed by Tung and Sommer (9) who accordingly introduced corrections in their measurements of internal stress. These corrections were introduced on the basis that the specimens exhibited 2 to 5 pct greater flow stresses upon reloading. This increase in flow stress is consistent with the values obtained in the present investigation, as can be inferred from Fig. 1. The observation that total unloading during 4.3 hours produced a yield point almost identical to the one after relaxation for the same amount of time supports the contention that the mechanism in the three schedules is the same static strain-aging. The two most widely accepted explanations for yield point formation are: either atmosphere formation (or precipitation) at dislocations or dislocation rearrangement. Both mechanisms would bring about a reduction in the mobile dislocation density. Thus one can easily conclude that the kinetics of relaxation would be accordingly affected.

A difference between continuous relaxation and incremental unloading experiments should be both expected and in the same direction as that shown by Fig. 4 of R-H&D. There, the relaxation rate, $\delta P/\delta t$, tends to zero at a faster rate during continuous relaxation than incremental unloading. If the mobile dislocation density is reduced with time, it will be lower, at a certain value of stress, for the continuously relaxed specimen, because the time elapsed since the substructure was formed is around 8 times the one for incremental unloading (4.3/0.5). A lower mobile dislocation concentration will necessarily result in lower relaxation rates ($\delta P/\delta t$).

In summary, it was shown that specimens of commercial purity Ti given 2 pct plastic deformation followed by (a) continuous relaxation for 4.3 hours, (b) incremental unloading to zero and (c) unloading and aging for 4.3 hours exhibited a reloading yield point. It is proposed that this effect is due to time dependent change in substructure. Since the constancy of substructure is a basic assumption in analyses such as Li and Gupta's (1-3) it is suggested that this failure in titanium, as well as the differences observed by R-H&D in the outcomes of continuous relaxation and incremental unloading experiments, could be related to aging.

Acknowledgements

This work was supported by the Brazilian Army, FINEP and BNDE through the IME Materials Research Center. Thanks are due to C.A.O.Soares and J.C.Gomes for helping in the execution of the experiments. Part of the chemical analysis of Ti was kindly performed at the Brazilian Air Force Research Center (PMR-CTA).

References

1. J.C.M.Li, Can. J.Phys. 45, 493 (1967).
2. I.Gupta and J.C.M.Li, Mat.Sci.Engr. 6, 20 (1970).
3. I.Gupta and J.C.M.Li, Met.Trans. 1, 2323 (1970).
4. C.C.Law and D.N.Beshers, Scripta Met. 6, 635 (1972).
5. P.Rodriguez, P.Dasgupta, S.L.Mannan, S.S.Vagarali and K.G.Samuel, Scripta Met. 7, 671 (1973).
6. R.E.Reed-Hill and J.R.Donoso, Scripta Met. 9, 1305 (1975).
7. G.B.Gibbs, Phil.Mag. 13, 317 (1966).
8. A.M.Garde, A.T.Santhanam and R.E.Reed-Hill, Acta Met. 20, 215 (1972).
9. P.P.Tung and A.W.Sommer, Met.Trans. 1, 947 (1970).