NOTE ON THE SHAPE OF THE LOAD-ELONGATION CURVE FOR MILD STEEL IN THE REGION OF THE YIELD POINT

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ABSTRACT: The authors give an analysis of the "spike" in the loading range of the load-strain curve for mild steel with reference to the interaction between the localized Lüders-line plastic deformation and the elastic reaction of the adjacent parts of the test piece.

1. Introduction. This note on the yield point on the load-elongation curve is based on tensile tests on mild steel and deals with the correspondence between the discontinuities on the curve and the nonuniformity of deformation. It relates only to macroscopic effects observable directly on the extended specimen, and not to the accompanying dislocation processes.

2. Details of the tests. We investigated a mild steel containing 0.10% C, 0.2% Si, 0.46% Mn, 0.011% P and 0.035% S. The round test pieces were 10 mm in diameter and the working section was 60, 96, or 200 mm long. An Instron testing machine with a "rigid" loading system was used. The heads of the test pieces were held in the machine by means of grips with crossed blades. The strain rate remained constant during the test and varied in different tests from 0.1 to 10mm//min. Load changes could be recorded at rates up to $1.3 \cdot 10^6$ kg/sec. This sensitivity was sufficient for observing the reduction of load near the yield point, which takes place at rates of $1.8 \cdot 10^5$ to $3 \cdot 10^5$ kg//sec.

In order to observe the localized Lüders-line deformation during extension at the yield point, the surface of the test pieces was given a coat of lacquer. The presence of a Lüders-line was indicated by the cracking of the lacquer coating.

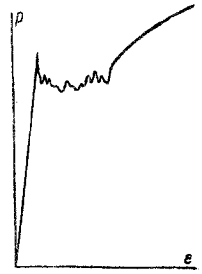
3. Observations. In analyzing the load p versus strain ε curve at the yield point (see Fig.) the following observations should be borne in mind. Each maximum or decrease of the load on the part of the curve corresponding to the yield point was found to correspond to the formation of a new Lüders-line. On the other hand, we also observed a small number of Lüders-lines which did not produce a discontinuity in the curve. The first peak invariably had the maximum value, while subsequent peaks varied in magnitude.

Where the load falls, the curve has a finite increasing slope down to the minimum or to the level of the lower yield point; sometimes the curve is more or less discontinuous. As the working length of the test piece increases, the initial part of the curve becomes zig-zag shaped. The number of peaks decreases with increasing strain rate, whereas the total elongation at the yield point and the height of the maximum with respect to the minimum increase.

4. Discussion of results. The first reduction of stress at the yield point results from plastic deformation and the formation of a Lüders-line. At the same time, the strain recorded between the maximum and the next minimum is part of the deformation due to the Lüders-line. Parts of the test piece near the Lüders-line remain in the elastic state. In tensile tests the elongation takes place at a constant rate with respect to the entire test piece; hence the localized deformation in the Lüders-line leads to compression of the elastically stressed parts of the test piece and, consequently, to stress relaxation. The load also decreases because the stress needed to effect deformation in the Lüders-line is lower than the stress corresponding to the upper yield point. Thus, while the elongation during decrease of load is determined by the deformation in the Lüders-line (after deducting a certain elastic shortening of other parts of the test piece), the load is determined by the relaxation of elastic stresses due to rapid localized yield and also by the stresses needed for deformation in the Lüders-line.*

The dependence of the slope of the region of the curve with falling load on the elastic compression of the parts of the test piece close to Lüders-lines is confirmed by observations of the changes in the slope of the curve resulting from change in the working length of the test piece. Discontinuities in the slope of the curve in the region of falling stress, referred to above, apparently reflect changes in the rate or direction of propagation in the Lüders-line.*

The increase of load needed for further Lüders-line deformation exceeding the minimum deformation indicates the existence of strain hardening. This conclusion is substantiated by the tests carried out by Elam [3]. The load deformed the tensile test piece slightly more than necessary to reach the upper yield point, which resulted in the formation of a Lüders-line; then the test piece was unloaded. During repeated loading and unloading, it was observed that the strain corresponding to the Lüders-line first appears at constant load at the lower yield point, and then increases with increasing load.



Normally, identical smooth horizontal sections corresponding to the propagation of Lüders-lines without strain hardening are not observed on the load-strain curves. According to the interpretation of the fall in load given above, this must be associated with after-effect in the elastically deformed parts of the test piece. Thus, the twisted part of the experimental curve, corresponding to minimum load, is not necessarily the true lower yield point corresponding to the minimum stress needed for the deformation associated with the Lüders-line.

The lesser height of the maximum following the upper yield point, compared with that at the upper yield point, can be explained by the activation effect, which is needed to initiate the formation of a Lüders-line and depends on the stress and time.

The stress needed to initiate the propagation of a Lüders line must decrease with increase in the time for which the test piece remains under high stress. This also explains the observation that an increase in the rate of extension leads to an increase in the differences between the maxima and minima on the curve and reduces the number of maxima.

The fact that the total strain corresponding to the yield point increases with increasing strain rate can be associated with the lesser

*However, it should be pointed out that the existence of an upper and a lower yield point is not always necessarily associated with a fall in load [1]. When the tensile test piece begins to deform plastically, the rate of increase of load needed to maintain a constant strain rate decreases. The adaptability of existing tensile testing machines to this variation of the loading conditions differs so that a reduction in strain rate may ensue. The stress needed for plastic deformation decreases with increasing strain rate [2]; therefore the corresponding manifestation on the load-strain curves is a fall in load.

degree of Lüders-line strain hardening due to the smaller ratio of cross-sectional area to volume for each line, which is important for the dissipation of the heat generated during rapid deformation.

As has already been pointed out in the introduction, this analysis is not concerned with the fundamental aspects of deformation. It should be pointed out, however, that Hahn has derived an equation describing the stress-strain curve for mild steel based on the dislocation model [4]. The graphical representation of this equation yields a curve, which is close to the experimentally obtained stress-strain curve for mild steel. However, this does not invalidate the present note, since Hahn does not consider the interrelation between the different regions where elastic and plastic deformation takes place, as we have done.

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