The physics of the tensile breaking test

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The Physics of the Tensile Breaking Test.

Zur Physik des Zerreißversuchs.

La physique de l'essai de rupture par traction.

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Even to-day the basis of the testing of materials continues to be the tensile breaking test. Fundamentally it appears so simple a matter to indicate the connection between imposed load and resulting deformation of the test specimen that the physical condition of the loading procedure has tended to be relegated into the background compared with questions of a practical technical nature in the arrangement of the testing devices. The interpretation of the diagrams obtained with the testing apparatus now available nevertheless throws open a whole series of questions, with which a large proportion of the literature is concerned. For instance, even to-day the significance or insignificance of the elastic limit and of the upper and lower yield points are subjects for dispute. Again, the results of fatigue tests indicate that the conventional characteristics of materials as given by the tensile breaking test stand in no definite relationship to the fatigue strength which is of so decisive importance.

For the purpose of testing a material, or whole constructional members, the parts to be tested are clamped into a testing machine and are subjected by some means or other to gradually increasing load. Thus the test specimen is caused to participate with portions of the testing machine (which may be either rigid or sprung) in a common flow of forces. Closer examination indicates that the self-vibrating effect of the machine, the compressibility of the pressure fluid, and also the error of the apparatus used for measuring the force in the testing machines which are usual at the present time, are all factors which it is improper to neglect — the elastic yield of the testing apparatus usually being much greater than the deformation of the test specimen itself.[1] [2]

The effect of all this on the loading process is seen in Fig. 1. Here the line OA represents the increase in load in relation to increasing deformation of a specimen; in the loading apparatus itself there occurs a process of loading which may be represented by the straight line CA. At the point A statical equilibrium exists between the elastic load of the specimen and the elastic reaction of the loading apparatus. The specimen has deformed by the amount O B through

[1] *W. Späth:* Arch. Eisenhüttenwesen, Vol. 9, 1935/36, p. 277.

[2] *W. Späth:* Meßtechnik, Vol. XII, 1936, p. 21.

the imposition of the load AB, and the corresponding deformation of the loading device is represented by CB. Two angles α and β indicate the magnitude of the spring constants of the test specimen or of the loading apparatus respectively. If, now, a plastic deformation of the test specimen from A to D suddenly takes place, the specimen will endeavour to release its load along the line DO', and at the point E where this line cuts the load line of the testing machine the system again comes into equilibrium, for at this point the force acting upon the specimen again becomes equal to the elastic reaction of the loading device. Through the plastic yield from A to D two effects come into play; the original stress is diminished by an amount corresponding to AA′, while at the same time the externally measured deformation of the specimen is increased by the amount A′E. It will at once be apparent that this process depends not only on the specimen but also, to a very large extent, on the elastic properties of the testing machine — that is to say mainly according to the inclination of the lines CA —

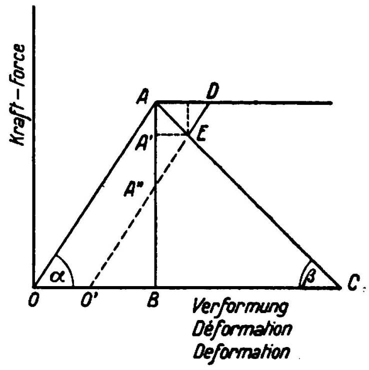

Fig. 1.

the results differ widely. In a very "soft" machine which suffers a large amount of self-deformation in order to develop the force AB, the line CA is practically horizontal in respect of very small deformations of the test specimen here in question; hence an increase in the length of the specimen by AD occurs under approximately constant stress and the externally measured increase in deformation corresponds to the amount AD. A "soft" machine of this kind may also be designated as a "delayed-action" machine since the yield, when it once begins, continues to develop under a load which remains constant. The conditions are altogether different in a "hard" machine characterised in the limit by indefinitely large spring constants as measured by the vertical AB; here the load drops from A to A″ owing to yielding of the specimen, while the externally measured deformation of the specimen remains unaltered. A "hard" machine of this kind may also be referred to as a "relaxation" machine, for in such a case the initial deformation is maintained and the occurrence of yield is attended by a reduction in the load. The machines in use to-day lie between these two limits, and their indications cannot be compared as between one machine and another unless account is taken of the elasticity proper to each.

These theoretical considerations have been confirmed by a series of experiments effected by the author, and the problems in question are now being pursued in several research institutions in view of their fundamental importance for the testing of materials.

As early as in the publication by the author denoted under[1] below it was suggested that an existing testing machine might be rendered "soft" by introducing a spring into the flow of force. Experiments of this kind were carried out by *G. Welter*[3] and the result corresponded with expectation. The introduction of a spring to make the machine artificially "soft" must, according to the argument above, have the effect of allowing a yield once begun to continue while the stress remains unaltered. For instance, a material which under the usual forms of tests exhibits an upper and a lower yield point will, when placed in a machine of this kind, show no reduction of stress to the lower yield point, and this was in fact found to be the case.

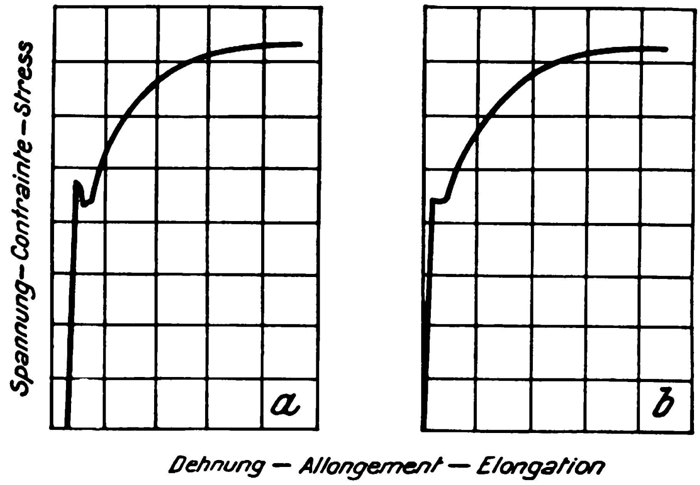

Fig. 2.

Yield as produced with an ordinary test machine (a)
" " " with a test machine with increased volume of water (b).

With very heavy loads it is not feasible to introduce a spring as the dimensions would have to be excessive. In the Losenhausen works at Düsseldorf, at the suggestion of Baurat *von Bohuszewicz*, a 60-ton hydraulic machine was accordingly rendered "soft" by connecting a large hydraulic accumulator to the pressure cylinder, and the result is shown in Fig. 2. On the left is the curve obtained by working the machine in the ordinary way, in which a clear development of upper and lower yield point is discernible. When the machine was artificially rendered "soft" by being connected to the pressure accumulator it was found that a second specimen of the same material gave the curve shown on the right, wherein it will be noticed that the yielding continues to progress under constant load as a result of the elasticity of the pressure water. A large number of further implication arise as to the dependence of upper and lower yield points on the conditions of testing, but these cannot be further considered here.

Some interest, however, attaches to a series of experiments lately concluded by the author from a precisely contrary point of view. When a machine is made very "hard" it may be hoped that considerably sharper phenomena may be caused

[3] *G. Welter*: Metallwirtschaft, Vol. XIV, 1935, p. 1043.

to occur in the loaded material.[4] It will be recalled that in rotary fatigue bending machines what are known as short period experiments are frequently carried out, in which the bending of the rotating bar is measured in relation to the load. The well known machine of *Schenck* at Darmstadt (and certain other machines) provide for the application of load by means of weights, and in this way the bending line gradually deviates from the straight. If such a machine is artificially rendered "hard" by applying the load through a spring considerably "harder" than the specimen itself, there is obtained a bending curve which approximates very closely to the breakage curve with an upper and a lower yield point. The stress drops off quite definitely from the "upper" to the "lower" range of loading, and in very plastic material — such as, for instance, aluminium — the load curve as a whole is made up of a large number of these jumps of load. It was further established that the sensitivity is sufficient to obscure even the important questions of notch effect. For details reference must be made to a publication which is about to appear.[5]

From these considerations there follow a number of important consequences for the further development of testing machines, and especially it will in future be necessary to produce considerably "harder" machines by taking systematic precautions in the design. Such machines offer the invaluable advantage that they give very sharp indications of the critical limits of load governed by the materials tested in the form of clearly discernible reductions in the stress. On the other hand the testing machines which are in common use at present possess so much resilience themselves that they tend to obscure these important transitions, sometimes to such an extent that the latter are quite undetectable.

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[4] *W. Späth:* Metallwirtschaft, Vol. XVI, 1937, p. 193.

[5] *W. Späth:* Z.V.D.I. Vol. 81 (1937), p. 710. — See also: *W. Späth,* Physik der mechanischen Werkstoffprüfung, Springer, Berlin 1938.