The modulus of decay (τ) for waves of length 5 cms. when the surface of the mercury is covered by 4 mm. of glycerine is 4·9 secs. All modes become propagated for wave-lengths greater than some value between 5 and 10 cms. For a depth of 1 mm. of glycerine this limit lies between 10 and 20 cms., and thus we see that as the depth is increased this critical value of the wave-length approaches that for waves at the surface of deep glycerine, which lies between 2 and 3 cms.]

The Elastic Limits of Iron and Steel under Cyclical Variations of Stress.

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(Abstract.)

An explanation of fatigue is developed in the paper which is in accordance with all the researches on the fracture of materials by the cyclical repetition of stress. The theory was put forward by Bauschinger in 1886, when he suggested that the necessary condition of safety was that the repeated stresses applied should be within the limits of elasticity of the specimen, and that the least variation from this condition introduces fatigue and ultimately fracture occurs.

In order for this to be true for Wöhler's well-known experiments, the elastic limits must be variable within very wide limits, and the present paper describes observations made during the adjustment of the limits of elasticity to any particular condition of experiment.

It is now found that iron or steel is capable of adjusting itself to variations of stress, cyclically applied, after a sufficient number of repetitions. When the adjustment is complete, the specimen under test is found to have become perfectly elastic throughout the whole cycle, and fatigue does not occur.

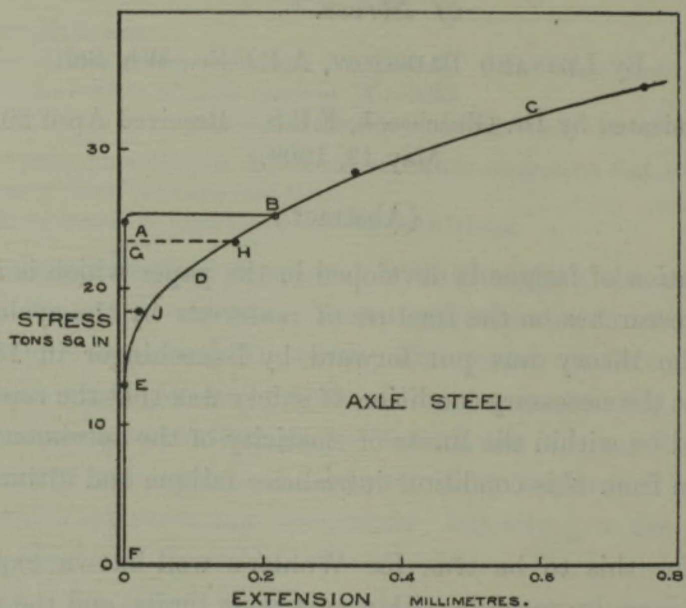
During the adjustment of the elastic limits to a given cycle of stress, a change of length occurs in the specimen, which corresponds to the extension observed in an ordinary tensile test when the yield stress is exceeded. For stress cyclically applied, this extension occurs even when the maximum stress in the cycle is less than the static yield stress.

The greater the extension of the specimen during adjustment, the greater is the amount by which the elastic limits are raised.

Limits can be found to this power of adjustment, and if the cycle of stress imposed exceeds these limits, the specimen becomes or remains inelastic and work is absorbed during each cycle. This work is expended in moving portions of the crystals of the material relatively to one another and is probably associated with microscopic slip lines, which gradually develop into cracks, and ultimately cause the fracture of the specimen.

As the elastic limits of a new specimen are in suitable positions for reversals of equal and opposite stresses, and consequently do not need adjustment, fracture occurs without any appreciable extension.

The figure illustrates the relation of the yield, produced by cyclical varia-



tions of stress, during adjustment of the elastic limits, to the extension in an ordinary tensile test. The ordinates are the maximum stresses applied to the specimen and the abscissæ the corresponding permanent extension. Starting with a new specimen, the line FEA shows that, at a stress of 25 tons per square inch, no permanent extension was observed. When the load was slightly increased, a sudden extension of about one-fifth of a millimetre occurred, this being the well-known yield. Further increase of stress extended the specimen still further, the changes being represented by a line which cannot differ appreciably from BC.

In producing the curve FEABC, no cyclical variations of stress are concerned, and the curve is identical with the usual stress elongation diagram frequently taken during a tensile test.

An experiment on a specimen of axle steel showed that, under cyclical variations of stress, an extension which was not measurable at the first application of the load gradually appeared, due to repeated applications of a range of stress slightly greater than the safe range. This extension continued for some time, any point on the line GH representing the extension at some particular time. When the adjustment of the elastic limits was complete, H represented the final extension, and no further extension occurred due to further repetitions of stress.

The point J was similarly obtained by repeating a cycle of stress having a less maximum value than that which produced the extension H. At E, which corresponds to the maximum safe stress during reversals, no extension occurred.

The points H, J, E are evidently on a continuation of the curve BC, and when cyclical variations of stress are considered, there is no break in the curve at B corresponding to the static yield point.

Above this point the whole extension is produced by the maximum stress only, independently of the range of stress, which may be zero. As HJE is continuous with BC, it seems possible that an extension such as GH may be produced by the repetition of a cycle of stress in which the range is less than the safe range.

Below the static yield point, iron and steel appear to be capable of maintaining their initial condition for a considerable time against cyclical variations of stress which ultimately produce a considerable change of length. The first application of the maximum load in a given cycle of stress may show only a scarcely measurable extension, in spite of the fact that an extension two or three thousand times as great as the permanent extension in the first cycle is necessary before stability is reached.

When the extension produced by a large number of cycles is itself small, *i.e.*, when the maximum stress in the cycle is not greatly in excess of the natural elastic limits, it does not seem surprising that the effect of the first cycle is not measurable and that ordinary determinations of the elastic limit fail to detect changes, which nevertheless are there.