flow continues, more slowly than before, until presently the pumps recover their lost ground and the increase of stress is resumed. Again, near the point of

rupture, the flow again be­comes specially rapid ; the weight on the lever has again to be run back, and the specimen finally breaks under a diminished load.

These features are well shown by fig. 12, which is copied from the auto­graphic diagram of a test of mild steel.@@1

30. But it is not only ; through what we may call

the viscosity of materials that the time rate of load­ing affects their behaviour under test. In iron and steel, and probably in some other metals, time has an­other effect of a very re­markable kind. Let the test be carried to any point *a* (fig. 13) past the original limit of elasticity. Let the load then be removed ; during the first stages of this removal the material continues to stretch slightly, as has been explained above. Let the load then be at once replaced and loading continued. It will then be found that there is a new yield-point *b* at or near the value of the load formerly reached ; up to this point there is little other than elastic strain.

The full line *be* in fig. 13 shows the sub­sequent behaviour of the piece. But now let the experiment be repeated on another sample, with this dif­ference, that an inter­val of time, of a few hours or more, is al­lowed to elapse after the load is removed and before it is re­placed. It will then be found that a process of hardening has been going on during this interval of rest; for, when the loading is continued, the new yield-point appears, not at *b* as formerly, but at a higher load *d.*

Other evidence that a change has taken place is afforded by the fact that the ultimate extension is reduced and the ultimate strength is increased (c, fig. 13).

31. A similar aud even more marked hardening occurs when a load (exceeding the original elastic limit), instead of being removed and replaced, is kept on for a sufficient length of time without change. When loading is resumed a new yield-point is found only after a considerable addition has been made to the load. The result is, as in the former case, to give greater ultimate strength and less ultimate elongation, Fig. 14 exhibits two experiments of this kind, made with annealed iron wire. A load of 231/2 tons per square inch was reached in both cases ; *ab* shows the result of continuing to load after an interval of five minutes, and *acd* after an interval of 451/2 hours, the stress of 23½ tons being maintained during the interval in both cases.

32. It must not be supposed that in a material hardened by strain the elasticity is perfect up to the yield-points which are shown in fig. 13 at *b* and *d* or in fig. 14 at *c.* In experiments made for this article, it has been found that, after a piece of very soft iron wire has been hardened (as in fig. 14) by the continued appli­cation of a load which had caused stretching, if a small addition be made to the load (bringing it to a value between *a* and the new yield-point), although there is at first no apparent drawing out, nevertheless if time be given the wire begins again to draw, and a large amount of stretching at an increased pace may ensue. In this way wires have been broken with loads considerably short of

those which would have been required had the process of loading, from the point *a* onward, been continued at a moderately rapid rate. A slow process of viscous deformation may in fact be occur­ring at the same time that the metal shows a quasi-elasticity with respect to rapid alteration of stress. Bauschinger’s micrometric experiments have shown that after a piece has been hardened by rest the true limit of elasticity, or the point at which Hooke’s law begins to fail, comes far short of the yield-point. He has also shown that a long interval of rest after the set has taken place produces a slow rise of the true limit of elasticity,@@2 apparently a slower rise than the lapse of time causes in the yield-point itself.

33. In the testing of iron and steel the time during which any state of (pull) stress (exceeding the original elastic limit) exists affects the result in two somewhat antagonistic ways. It augments exten­sion, by giving the metal leisure to flow. This may be called the viscous effect. But, on the other hand, it reduces the amount of extension which subsequent greater loads will cause, and it increases the amount of load required for rupture in the way which has just been described. This may be called the hardening effect. When a piece is broken by continuous gradual increment of load, these two effects are occurring at all stages of the test. If the viscous effect existed alone, or if the hardening effect were small, the material would show to greater advantage as regards elongation, and to less advantage as regards ultimate strength, the more slowly the load were applied. Tin and lead may be cited as mate­rials for which this is the case. But when the hardening effect is relatively great, as in iron and steel, the material shows less elongation and a higher breaking strength the more slowly it is tested. An excellent illustration of this is given by the following experiment of Mr Bottomley. Pieces of iron wire, annealed and of exceptionally soft quality, when loaded at the rate of 1 lb in 5 minutes, broke with 441/4lb and stretched 27 per cent. of their original length. Other pieces of the same wire, loaded at the rate of 1 lb in 24 hours, broke with 47 lb and stretched less than 7 per cent.@@3 Again, it has been found that an excessively rapid application of stress (by the explosion of gun-cotton) makes soft steel stretch twice as much as in ordinary testing.@@4 The case is very different, however, if the material has been previously hard­ened by strain. It

does not appear

that such varia­

tions in the rate

of loading as are

liable to occur in

practical tests of

iron or steel have

much influence on

the extension or

the strength, great

as the effects of

time are when the

metal is loaded

either much more

slowly or much

more quickly. In

fig. 15 the results

are shown of tests

of two similar

pieces of soft iron

wire, one loaded

to rupture in 4

minutes and the

other at a rate

about 5000 times

slower.

34. The hard­ening effect which

intervals of rest ... , .

from load or of constant load produce, once the primitive elastic limit is passed, has been examined by Beardsley,@@5 Thurston,5 Bauschinger,@@6 Ewing,@@7 and others. The effect of even a few minutes pause is perceptible, an hour or two of constant stress has a very marked influence, and after 24 hours or so there appears to be little further hardening. The American Board found that iron bars, previously stressed to about 50,000 lb per square inch, gained in strength, by intervals of rest from stress, to the extent of about 9 per cent. in one day, 16 per cent. in three days, and 18 per cent. in six months.@@8

35. It may be concluded that, when a piece of metal has in any way received a permanent set by stress exceeding its limits of

@@@1 The increase of strain without increase of stress, which goes on without limit when a test-piece under tension approaches rupture, is a special case of the general phenomenon of “ flow of solids,” which has been exhibited, chiefly for compressive stresses, in a series of beautiful experiments by Tresca *(Mémoires sur l'Écoulement des Corps Solides,* also *Proc. Inst. Mech. Eng.,* 1S67 and 1878).

@@@2 *Mitth. aus dem Mech.-Tech. Lab. in München,* Heft 13, 1886.

@@@3 *Proc. Roy. Soc.,* 1879, p. 221. See also Elasticity, § 80 .

@@@4 See remarks by Col. Maitland, *Min. Proc. Inst. C.E.,* vol. lxxvi. p. 104.

@@@5 See *Report of the U.S. Board on Tests of Metals,* vol. i. section 4.

@@@6 *Loc. cit.*

@@@7 *Proc. Roy. Soc.,* June 1870. The autographic diagrams given in figs. 13 aud 14 are taken from these tests.

@@@8 *Loc. cit*., p. 111.