elasticity, it is hardened, and (in some cases at least) its physical properties go on slowly changing for days or even months. Instances of the hardening effect of permanent set occur when plates or bars are rolled cold, hammered cold, or bent cold, or when wire is drawn. When a hole is punched in a plate the material contiguous to the hole is severely distorted by shear, and is so much hardened in consequence that when a strip containing the punched hole is broken by tensile stress the hardened portion, being unable to extend so much as the rest, receives an undue proportion of the stress, and the strip breaks with a smaller load than it would have borne had the stress been uniformly distributed. This bad effect of punching is especially noticeable in thick plates of mild steel. It disappears when a narrow ring of material surrounding the hole is removed by means of a rimer, so that the material that is left is homogeneous. Another remarkable instance of the same kind of action is seen when a mild-steel plate which is to be tested by bending has a piece cut from its edge by a shearing machine. The result of the shear is that the metal close to the edge is hardened, and, when the plate is bent, this part, being unable to stretch like the rest, starts a crack or tear which quickly spreads across the plate on account of the fact that in the metal at the end of the crack there is an enormously high local intensity of stress (see Elasticity, § 72). By the simple expedient of planing off the hardened edge before bending the plate homogeneity is restored, and the plate will then bend with­out damage.

36. The hardening effect of strain is removed by the process of annealing, that is, by heating to redness and cooling slowly. In iron, very mild steel, and most other metals the rate of cooling is a matter of indifference ; but in steel that contains more than about 0·2 per cent. of carbon another kind of hardening is produced if the metal, after being heated to redness, is cooled suddenly. When the proportion of carbon is considerably greater than this, steel may be rendered excessively hard and brittle (“ glass-hard ”) by sudden cooling from a red heat. Further, by being subsequently heated to a moderate temperature, it may be deprived of some of this hardness and rendered elastic through a wide range of strain. This process is called the tempering of steel ; its effects depend on the temperature to which the steel is heated after being hardened, and the grade of temper which is acquired is usually specified by the colour (blue, straw, &c.) which appears on a clean surface of the metal during this heating, through the formation of a film of oxide. In the ordinary process of rolling plates or bars of iron or mild steel the metal leaves the rolls at so high a temperature that it is virtually annealed, or pretty nearly so.@@1 The case is different with plates and bars that are rolled cold : they, like wire sup­plied in the hard-drawn state (that is, without being annealed after it leaves the draw-plate), exhibit the higher strength and greatly reduced plasticity which result from permanent set.

37. The extension which occurs when a bar of uniform section is pulled is at first general, and is distributed with some approach to uniformity over the length of the bar. Before the bar breaks, however, a large additional amount of local extension occurs at and near the place of rupture. The material flows in that neighbour­hood much more than in other parts of the bar, and the section is much more contracted there than elsewhere. The contraction of area at fracture is frequently stated as one of the results of a test, and is a useful index to the quality of materials. If a flaw is pre­sent sufficient to determine the section at which rupture shall occur the contraction of area will in general be distinctly diminished as compared with the contraction in a specimen free from flaws, although little reduction may be noted in the total extension of the piece. Local extension and contraction of area are almost absent in cast-iron and hard steel ; on the other hand they are specially prominent in wrought-iron, mild steel, and other metals

that combine plasticity with high tensile strength. An example is shown in fig. 16, which is copied from a photograph of a broken test-piece of Whitworth soft fluid-compressed steel.

38. Experiments with long rods show that the general extension which occurs in parts of the bar not near the break is somewhat irregular ;@@2 it exhibits here and there incipient local stretching, which has stopped without leading to rupture. This is of course due in the first instance to want of homogeneity. It may be

supposed that when local stretching begins at any point in the earlier stages of the test it is checked by the hardening effect of the strain, until, finally, under greater load, a stage is reached in which the extension at one place goes on so fast that the hardening effect cannot keep pace with the increase in intensity of stress which results from diminution of area ; the local extension is then unstable, and rupture ensues. Even at this stage a pause in the loading, and an interval of relief from stress, may harden the locally stretched part enough to make rupture occur somewhere else when the loading is continued.

39. Local stretching causes the percentage of elongation which a test-piece exhibits before rupture (an important quantity in en­gineers’ specifications) to vary greatly with the length and section of the piece tested. It is very usual to specify the length which is to exhibit an assigned percentage of elongation. This, however, is not enough ; the percentage obviously depends on the relation of the transverse dimensions to the length. A fine wire of iron or steel, say 8 inches long, will stretch little more in proportion to its length than a very long wire of the same quality. An 8-inch bar, say 1 inch in diameter, will show something like twice as much the percentage of elongation as a very long rod. The ex­periments of M. Barba@@3 show that, in material of uniform quality, the percentage of extension is constant for test-pieces of similar form, that is to say, for pieces of various size in which the transverse dimensions are varied in the same proportion as the length. It is to be regretted that in ordinary testing it is not practicable to reduce the pieces to a standard form, with one proportion of transverse dimensions to length, since an arbitrary choice of length and cross-section gives results which are incapable of direct comparison with one another.

40. The form chosen for test-pieces in tension tests affects not only the extension but also the ultimate strength. In the first place, if there is a sudden or rapid change in the area of cross section at any part of the length under tension (as at AB, fig. 17), the stress will not be uniformly distributed there.

The intensity will be greatest at the edges A and B,

and the piece will, in consequence, pass its elastic

limit at a less value of the total load than would be

the case if the change from the larger to the smaller

section were gradual. In a non-ductile material, rup­

ture will for the same reason take place at AB, with

a less total load than would otherwise be borne. On

the other hand, with a sufficiently ductile material,

although the section AB is the first to be permanently

deformed, rupture will preferably take place at some

section not near AB, because at and near AB the con­

traction of sectional area which precedes rupture is

partly prevented by the presence of the projecting

portions C and D. Hence, too, with a ductile material

samples such as those of fig. 18, in which the part of smallest section between the shoulders or enlarged ends of the piece is short, will break with a greater

load than could be

borne by long uni­

form rods of the

same section. In

good wrought-iron

and mild steel the

flow of metal pre­

ceding rupture and

causing local con­

traction of section

extends over a length six or eight times the width of the piece; and, if the length throughout which the section is uniform be materially less than this, the process of flow will be rendered more difficult and the breaking load of the sample will be raised.@@4

These considerations have of course a wider application than to the mere interpretation of special tests. An important practical case is that of riveted joints, in which the metal left between the rivet-holes is subjected to tensile stress. It is found to bear, per square inch, a greater pull than would be borne by a strip of the same plate, if the strip were tested in the usual way with uniform section throughout a length great enough to allow complete freedom of local flow.@@5

41. The tensile strength of long rods is affected by the length in quite a different way. With a perfectly homogeneous material, no difference should be found in the strength of rods of equal

@@@1 In several of Mr Kirkaldy’s papers, a comparison is given of the elastic limit, ultimate strength, and ultimate extension of samples which were annealed before testing, and of samples which were tested in the commercial state ; in general the annealed samples are distinctly, though not very materially, softer than the others *(on the Relative Properties of Wrought-Iron Plates from Essex and Yorkshire,* London, 1876 ; also *Experiments on Fagersta Steel,* London, 1873).

@@@2 See Kirkaldy’s *Experiments on Fagersta Steel,* London, 1873 ; also *Report of the Steel Committee,* part i.

@@@3 *Mém. de la Soc. des Ing. Civ..* 1880 ; see also a paper by Mr W. Hackney, “Οn the Adoption of Standard Forms of Test-Pieces,” *Min. Proc. Inst. C.E.,* 1884.

@@@4 The greater strength of nicked or grooved specimens seems to have been first remarked by Mr Kirkaldy *(Experiments on Wrought Iron and Steel,* p. 74, also *Experiments on Fagersta Steel,* p. 27). See also a paper by Mr E. Richards, on tests of mild steel, *Jour. Iron and Steel Inst.,* 1882.

@@@5 See Kennedy’s “Reportson Rivetted Joints," *Proc. Inst. Mech. Eng.,* 1881-5. In the case of mild steel plates a drilled strip may have as much as 12 per cent. more tensile strength per square inch than an undrilled strip. with punched holes, on the other hand, the remaining metal is much weakened, for the reason referred to in § 35.