worked at a blue heat not only run a much more serious risk of fracture in the process than when worked either cold or red-hot, but become deteriorated so that brittleness may afterwards show itself when the metal is cold.@@1

52. The following table gives a few representative data regarding the strength of the more important materials used in engineering (the figures are gathered from the writings of Barlow, Hodgkinson, Kirkaldy, Thurston, Rankine, Unwin, Clark, and others) :—

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Ultimate Strength.  Tons per Square Inch. | | | Elasticity. Tons. per sq. in. | |
| Young's  Modulus  E. | Mod. of Rigidity C. |
| *ft* | *fc* | *f*8 |
| Cast-iron | 51/2 to 101/2 | 25 to 65 I | 9 to 13 |  |  |
| ,, average | 42 | 11 | 5000 | 1300 |
| ,, American (ordnance)... | 14 | 36 to 58 |  | to | to |
| ,, ,, strengthened | 15 to 20 | 60 to 75 |  | 6000 | 2500 |
| by successive fusions. |  |  |  |
| Wrought-iron— |  |  |  |  |  |
| Finest Lowmoor and York- | 27 to 29 along the fibre | | |  |  |
| shire plates ( | 24 across the fibre | |  |  |  |
| Staffordshire | 26 along |  | 18 to |  |
|  | 24 across ,, | | 12,000 to |  |
| Bridge iron | 22 along ,,  19 across | | 22, or about | 5000 |
| Bars, finest | 27 to 29 |  | 4/5 of *ft* | 13,000 |  |
| Ordinary good | 25 | 20 |  |  |
| Soft Swedish | 19 to 24 |  |  |  |  |
| Wrought-iron wire | 25 to 50 |  |  |  |  |
|  |  |  |  |  |
| ,, ,, average about | 35 | ... |  |  |  |
| Steel—  Mild steel plates (Siemens or | 26 to 32 | ... |  |  |  |
| Bessemer) | about 30 |  | *about 3/4* |  |  |
| Axle and rail steel (do.) | 30 to 45 |  | of *ft* |  |  |
| Crucible tool steel | 40 to 65 |  |  | 12,000 | 5000 |
| Steel castings | about 28 |  |  |
| Chrome steel | 80 |  |  | to | to |
| Tungsten steel | 72 |  |  | 13,000 | 5200 |
| Whitworth's fluid-compressed |  |  |  |  |
| steel (mild) | 40 |  |  |  |  |
| ,, ,, (hard) | 48 to 68 |  |  |  |  |
| Steel wire, ordinary, about  Tempered steel rope wire | 70 |  |  |  |  |
| (highest) | 124 |  |  | 13,000  13,000  7000 |  |
| Pianoforte steel wire | 150 |  |  |  |
| Copper, cast | 10 to 14 | 35 | 10 to 14 |  |
| ,, rolled | 15 to 16 |  |
| ,, wire, hard-drawn | 28 |  |  | 8000 | 2800 |
| Brass | 8 to 13 |  |  | 5500 | 1500 |
| ,, wire | 22 |  |  | 6400 | 2200 |
| Muntz metal | 22 |  |  |
| Gun metal | 11 to 23 |  |  | 4500 to | 1700  2400 |
| Phosphor bronze | 15 to 26 |  |  | 6500 6000 |
| ,, wire | 33 to 70 |  |  |
| Manganese bronze | 28 to 32 |  |  |  |  |
| Zinc, cast | 2 to 3 |  |  |  |  |
| ,, rolled | 7 to 10 |  |  | 5500 |  |
| Tin | 2 |  |  |  |
| Lead | 0∙9 | 3 |  | 1000 |  |
| Timber— |  |  |  |
| Oak | 3 to 7 | 4 | 1 | 800 |  |
| White pine | 11/2 to 31/2 4 | 21/2 |  | 600 |  |
| Pitch pine |  | 950 |  |
| Riga fir | 21/2 to 51/2 4 to 7 |  |  |  |
| Ash | 2 to 4 | 4 | 750 |  |
| Beech |  | 4 |  |
| Teak | 4 to 7 | 4 |  | 950 |  |
| Spanish mahogany | 4 to 7 | 31/2 |  | 650 |  |
| Stone— |  |  |
| Granite |  | 21/2 to 5 11/2 to 21/2 2 to 21/2 11/2 to 3 1/4 to 3/4 |  |  |  |
| Sandstone |  |  |  |  |
| Limestone |  |  |  |  |
| Slate |  |  | 7000 |  |
| Brick |  |  |  |
|  |  |  |  |  |

53. Space admits of no more than a short and elementary account of some of the more simple straining actions that occur in machines and engineering structures.

The stress which acts on any plane surface AB (fig. 25), such as an imaginary cross-section of a strained piece, may be represented by a figure formed by setting up ordinates A*a*, B5,

&c., from points on the surface, the length of these being made proportional to the intensity of stress at each point.

This gives an ideal solid, which may be called the stress figure, whose height shows the distribution of stress over the surface which forms its base. A line drawn from *g,* the centre of gravity of the stress figure, parallel to the ordinates A*a*, &c., determines the point C, which is called the centre of stress, and is the point through which the resultant of the distributed stress acts. In the case of a uniformly distributed stress, *ab* is a plane surface parallel to AB, and C is the centre of gravity of the surface AB. When a bar is subjected to simple pull applied axially—that

is to say, so that the resultant stress passes through the centre of gravity of every cross-section,—the stress may be taken as (sensibly) uniformly distributed over any section not near a place where the form of the cross-section changes, provided the bar is initially in a state of ease and the stress is within the limits of elasticity.

54. Uniformly varying stress is illustrated by fig. 26. It occurs (in each case for stresses within the elastic limit) in a bent beam, in a tie subjected to non-axial pull, and

in a long strut or column where buckling

makes the stress become non-axial. In

uniformly varying

stress the intensity

*p* at any point P is

proportional to the

distance of P from

a line MN, called <

the neutral axis, whieh lies in the plane of the stressed surface and at right angles to the direction AB, which is assumed to be that in which the intensity of stress varies

most rapidly. There is no varia­

tion of stress along lines parallel

to MN. If MN passes through

C, the centre of gravity of the sur­

face, as in fig. 27, it may easily be shown that the total pull stress on one side of the neutral axis is equal to the total push stress on the other side, whatever be the form of the surface AB. The re­sultant of the whole stress on AB is in that case a couple, whose moment may be found as follows. Let *d*S be an indefinitely small part of the surface at a distance *x* from the neutral axis through C, and let *p* be the intensity of stress on *d*S. The moment of the stress on *d*S is *xpd*S But *p=p*1*x∕x*1*=p*2*x/x*2 (see fig. 27). The whole moment of the stress on AB is *∫xpd*S = (*p*1∕*x*ι∫*x*2*d*S=*p*1I∕*x*1 or *p*2I∕*x*2, where I is the moment of inertia of the surface AB about the neutral axis through C.

55. A stress such as that shown in fig. 26 or fig. 28 may be regarded as a uniformly distributed stress of intensity *p*0 (which is the intensity at the centre of gravity of the surface C) and a stress of the kind shown in fig. 27. The resultant is *p*0S, where S is the whole area of the surface, and it acts at a distance CD from C such that the moment *p*0S . CD =

(*p*2-*p*0)I/*x*1 = (*p*1+*p*0)I∕*x*2. Hence *p*2= *p*0(1+*x*2S . CD∕I), and *p*1= *p*0(1-*x*1S. CD∕I).

56. Simple bending occurs when a beam is in equilibrium under equal and opposite couples in the plane of the beam. Thus if a beam (fig. 29), supported at its ends, be loaded at two points so that W1*l*1 = W2 *l*2, the por­

tion of the beam lying between W1 and W2 is subjected to a simple bending stress. On any section AB the only stress consists of pul 1 and push, and has for its resultant a couple whose moment M=W1Z1=W2Z2. This is called the *bending moment* at the section. If the stress be within the elastic limits it will be distributed as in fig.

30, with the neutral axis at the centre of gravity of the section. The greatest intensities of push and of pull, at the top and bottom edge respect­ively, are (by § 54) *p*1= M*y*1∕I and *p*2*=*M*y*2/I*,* and the intensity at any point at a distance *y* above or below C is p=M*y*∕I.

57. Let the bending moment now be increased ; non-elastic strain will begin as soon as either *p*1or *p*2 exceeds the corresponding limit of elasticity, and the distribution of stress will be changed in consequence of the fact that the outer layers of the beam are taking set while the inner layers are still following Hooke’s law. As a simple in­stance we may consider the case of a material strictly elastic up to a certain stress, and then so plastic that a relatively very large amount of strain is produced without further change of stress, a case not very far from being realized by soft wrought-iron and mild steel. The diagram of stress will now take the form sketched in fig. 31. If the elastic limit is (say) less for compression than for tension, the diagram will be as in fig. 32, with the neutral axis shifted towards the tension side. When the beam is relieved from external load it will be left in a state of internal stress, repre­sented, for the case of fig. 31, by the dotted lines in that figure.

58. In consequence of the action which has been illustrated (in a somewhat crude fashion) by figs. 31 and 32, the moment required

@@@1 Stromeyer, “ The Injurious Effect of a Blue Heat on Steel and Iron,” *Jiin. Proc. Inst. C.E.,* vol. lxxxiv., 1886.