other varieties of thermal treatment, as well as from the presence of other constituents in the steel, but to discuss these would be beyond the scope of the present article.

In experiments by Ewing and J. C. W. Humfrey (“ The Fracture of Metals under repeated Alternations of Stress,” *Phil. Trans.,* 1903) the microscope was employed to examine the process by which metals break through “ fatigue ” when sub­jected to repeated reversals of stress. The test-pieces were short rods overhanging from a revolving mandrel and loaded at the end so as to produce a bending moment. A part near the support, where the stresses due to bending were greatest, was polished beforehand for observation in the microscope. After a certain number of reversals the surface was examined, and the examination was repeated at intervals as the process continued. The material was Swedish iron following Hooke’s law (in ten­sion) up to 13 tons per sq. in. and having a well-marked yield­point at 14·1 tons per sq. in. It was found that the material suffered no damage from repeated reversals of a stress of 5 tons per sq. in., but that when the greatest stress was raised to 7 tons per sq. in. incipient signs of fatigue began to be apparent after many reversals, though the piece was still intact after the number of reversals had reached three millions. With a stress of 9 tons per sq. in., or more, repeated reversals brought about fracture. the first sign of fatigue as detected in the microscope was that slip lines began to appear on one or more of the crystals in the region of greatest stress: as the process went on these became more distinct and tended to broaden, and at length some of them developed into cracks which were identified as such because they did not disappear when the surface was repolished. Once a crack had formed it quickly spread, and finally the piece broke with a sharp fracture, showing practically no plastic change of form before rupture.

It may be concluded that under repeated alternations of stress fatigue, leading to fracture, is liable to occur if, and only if, the stress is such as to produce slips in some of the crystals: in other words if, and only if, the limit of elasticity is *locally* exceeded; but the limit for particular crystals may be consider­ably lower than what is usually taken as the limit for the metal as a whole. The resistance to slip in any one crystal depends on three things: (1) the inherent strength of its own substance,

(2) the amount of support it receives from its neighbours, and

(3) the orientation of the crystal with respect to the surfaces of maximum shearing stress. It may be inferred that even in the most homogeneous metal some crystals have a liability to develop slips more readily than others, and that it is with them we are concerned in dealing with the safe limits of alternating stress. The same considerations have a bearing on certain effects of heat treatment. It is well known that in steel which has been over­heated (by unnecessarily prolonged exposure to a high tempera­ture) a somewhat gross crystalline structure is developed, showing large ferrite areas not broken up by intermixture with pearlite. The resistance to slip in the large ferrite crystals is comparatively small, and hence the overheated metal has a low elastic limit and shows but little power of resisting alternating stress. By suitable heat treatment, on the other hand, it is possible to bring the metal into a state in which the crystals are small and the ferrite and pearlite are so intimately blended that there is much mutual support: the elastic limit is high and the metal is well adapted to endure stresses which would otherwise cause fatigue.

It may be asked, How is the crystal constituted to admit of elastic and plastic strain ? How can slip take place without destroying the adhesion between the faces until that is destroyed by many back and forth rubbings at the surface of slip? J. A. Ewing has endeavoured to picture a molecular constitution in which the molecules are assumed to possess polar quality along three axes, and to be free to turn except in so far as they are constrained by the mutual forces between the pole of each molecule and those of its neighbours. This theory, which was developed by its author in his presidential address to the engineering section of the British Association in 1906, accords well with many of the obscure phenomena of elastic and plastic strain, with what is known of fatigue, and with the loss of elasticity after overstrain and its subsequent recovery.

*Influence of Foreign Matter.—*It is a well-known characteristic of metals that small Quantifies of foreign matter may produce an altogether disproportionately large influence on their mechanical and other properties. The effect of small quantities of carbon in iron, of nickel in iron, of aluminium in copper, are important practical instances where a highly beneficial effect, in respect of strength and ductility, is produced. The wide and varied range of qualities possessed in steel from pure iron at one end to tool steel at the other is due to quantities of carbon which lie, for the most part, under 1%*.* The addition of about 3 or 4 % of nickel to mild steel has given an important new structural material possessing increased strength and a high elastic limit, and retain­ing ample capacity for plastic strain. The presence of manganese in small quantities is known to be an essential condition of strength in mild steel. The addition of from 11/2 to 3% of chromium enables steel to acquire, under suitable heat treat­ment, the excessive hardness desirable in armour plate and armour-piercing shell. Small quantities of vanadium added to steel improve it sufficiently to be advantageous in certain applications where saving of weight is important, notably in steel for motor carriage engines, notwithstanding the extra cost.

*Data as to Strength of Steel.—*A few figures may be quoted as to the strength and plasticity of steel, some of which arc taken from the reports of the Engineering Standards Committee (1906-1907) specifying tests to which the material should conform.

Ordinary plates and bars of mild steel for structural purposes (bridges, ships, &c.), containing as a rule not more than 2 % of carbon, have a tensile strength of 28 to 32 tons per sq. in., and an 8-in. specimen with a cross-section of from 3/4 to 11/2 sq. in. should stretch at least 20%. They should stand being bent cold through 180° on a radius 11/2 times the thickness of the specimen, the test-piece for bending being not less than 11/2 in. wide. Rivet bars, of somewhat softer steel, have a tensile strength of 26 to 30 tons, with 25% of elongation on 8 in. Steel rails, containing 0∙4 or 0∙5% of carbon, have a tensile strength of 38 to 48 tons and stretch 15% on a 2-in. length, the area of section of the test-piece being 1/4 sq. in. Steel for axles has a tensile strength of 35 to 40 tons and stretches 25 to 30% on the 2-in. length. The elastic limit should be at least 50 % of the breaking load. Steel for tires may in some cases have a tensile strength as high as 60 tons with about 8 to 10 % extension in 2 in. Steel castings commonly range in tensile strength from 26 to 35 tons, with about 15% extension in 2 in. The strength of steel wire is considerably higher than that of bar or plates: 70 to 100 tons per sq. in. is not unusual, and in steel pianoforte wire it may be as high as 150 tons per sq. in.

Steel for guns, containing generally 0∙3 to 0∙4 % of carbon, has a tensile strength of 33 to 44 tons per sq. in., with at least 17 % extension in. 2 in., the test-piece having the usual cross-section of i.sq. in. Nickel steel for guns, containing 0∙4% of carbon and 4% nickel, has a strength of 45 to 55 tons and an extension of at least 16% in 2 in. Much the same figures apply to nickel-chromc steel for the same purpose, with 1 % of chromium, 4 % of nickel and 0∙3 % of carbon. Flat specimens of gun steel 3/4 in. wide and 0∙375 in. thick stand bending cold through 180° on a radius of 11/2 in. All these tests of gun steel are made after forging and after the normal heat treatment, which consists first of oil-hardening by plunging the steel at a temperature not lower than 1500° F. into a bath of oil, and then tempering, by reheating to a temperature generally about 900° to 1000° F. This heat treatment brings the metal into a con­dition in which the granular structure is minute and the constituents are very thoroughly intermixed, with the result of giving a high elastic limit. Tests made on gun steel containing about 0∙35 % of carbon show that the yield-point occurred at 18 tons per sq. in. before the heat treatment, and at 25 tons after it, the extension remaining practically unchanged at 30% in 2 in. In nickel steel the yield-point is initially higher, but in it too the heat treatment effects a considerable improvement in this respect without reducing the extension.

It is remarkable that though the strength of wrought iron and steel may range from 20 tons per sq. in., or even less, up to 150 tons, the moduli which measure its elastic quality are nearly tne same in all grades. Young’s modulus Eranges from about 12,500 to 14,000 tons per sq. in., and the modulus of rigidity C from 5000 to 3700 tons per sq. in.

*Graphic Representation of Distributed Stress.—*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.