Hardness Tests.

EVERY one has a general idea of what is meant by hardness—that the diamond is harder than steel, and steel harder than copper. The workman judges of hardness as the resistance of a material to the action of his cutting-tools or files. But there is as yet no rational definition of hardness. A property connected with hardness is resistance to abrasion or wear. As Sir Robert Hadfield has said, rails are demanded which will not wear out quickly and tyres which will not need renewing every few months. It was entirely for these reasons that modern qualities of steel were produced. To some extent hardness is opposed to ductility or toughness. Very hard materials are generally brittle. The engineer requires a material in which hardness is obtained without too great a sacrifice of toughness.

The earliest scale of hardness is that proposed by Moh. He selected ten minerals arranged in order such that each would scratch the one next below it in order and be scratched by the one above it in order. On this scale talc has a hardness 1 and diamond a hardness 10; iron has a hardness of 4·5. But the scale is qualitative only and arbitrary. Prof. Turner has used a balanced lever turning on a knife-edge. The free end carries a diamond. The surface to be tested is polished. The hardness is taken to be the weight in grams on the diamond necessary to produce a definite scratch. The method is useful, but there are practical difficulties in applying it. Recently Mr. Hankins, at the National Physical Laboratory, has modified this test. He uses a diamond shaped so as to produce an indentation furrow rather than a scratch.

The diamond is loaded with weights and drawn over the surface to be tested. The widths of the scratches with different weights is measured, and it is found that the square of the widths plotted against the weights fall on a straight line passing nearly through the origin. Hence Mr. Hankins takes as the hardness number the quantity

$$k=\frac{\mathrm{P}-p}{w^2-q},$$

where P is the load on the diamond, w the width of scratch, and p and q small constants not depending on the material tested.

Various investigators have used an indentation method for determining hardness. Such a test is very suitable for ductile metals, but how far it is applicable to brittle materials is uncertain, though this is not of practical importance. The indenting tool has been a knife-edge, ball, cone, or pyramid.

In 1895 and 1900 Lieutenant-Colonel Martel communicated two very interesting papers to the Paris Congress on Testing Materials. He used chiefly a falling monkey with various forms of indenting points and various heights of fall. He concluded that (1) for a given material the work of indentation is proportional to the volume of the indentation and independent (within limits) of the form of indenting tool; (2) that the pressure causing indentation is at each instant proportional to the area of the indentation normal to the pressure. If V is the volume of the indentation, P the weight of the monkey, and h the height of fall, then Martel's hardness number is

$$\mathrm{D}=\frac{\mathrm{P}h}{\mathrm{V}}$$

in kilogram-millimetre units.

About 1900 Brinell introduced the indentation test, which has been most widely used. A very hard steel ball 10 mm. in diameter indents the material by a gradually applied load of 3000 kilograms, which rests on the ball for some seconds until the indentation is complete. The radius of the indentation is measured by a microscope. If P is the load, a is the radius of the indentation, and r the radius of the ball, then Brinell's hardness number is

$$\mathrm{H}=\frac{\mathrm{P}}{2\pi r(r-\sqrt{r^2-a^2})}.$$

The quantity in the denominator is the spherical surface of the indentation; and the units are kilograms and millimetres. In practice it is necessary to use a smaller load for soft materials and sometimes to use a smaller ball. Then the hardness number obtained is not the same unless the load P_1 and the ball radius r_1 satisfy the condition

$$\frac{\mathrm{P}}{r^2}=\frac{\mathrm{P}_1}{r_1^{\,2}}.$$

This is Meyer's law confirmed by Mr. Batson, of the National Physical Laboratory. If the law is complied with the indentations are geometrically similar.

Prof. Ludwik uses a right-angled cone instead of a ball, so that the radius and depth of the indentation are equal and the indentations for different loads are similar. He also takes the hardness number to be the load divided by the conical area of the indentation.

Prof. Föppl placed two cylinders of the material to be tested at right angles and pressed them together in a testing machine. The pressure per unit of flattened surface is taken as the hardness number. Prof. Henderson, of Greenwich, has introduced a similar test, the material being in the form of square prisms.

For ordinary materials of construction, Brinell's test has proved most useful. It rather fails for very hard materials from the smallness of the indentation and the distortion of the ball, and efforts have been made to find another test or to revive the scratch test for such cases.

A new instrument which appears to be very sensitive has been introduced recently by Messrs. E. G. Herbert, Ltd., of Manchester (see NATURE, April 28, p. 583). This consists of an arched pendulum weighing 2 or 4 kilograms. At its centre is a ball 1 mm. diameter of ruby or steel. By adjusting screws the centre of gravity of the instrument can be made to coincide with the centre of the ball. A weight over the ball can be adjusted to lower the centre of gravity of the instrument to 0·1 mm. below the centre of the ball when the time of swing on a very hard surface is 10 sec. A level tube over the ball is graduated from zero at one end to 100 at the other. Two scales of hardness are proposed: (1) Inclined to zero and left, the reading of the level bubble at the end of the first swing is taken as the hardness number. The softer the material, when the indentation due to the weight of the instrument is deep, the shorter is the swing. (2) The time period of an oscillation is another measure of hardness. The time in making ten swings is taken as the hardness number. Thus the time of ten swings on glass is 100 sec., on hardened steel 50 to 85 sec., on soft steel 20 to 40 sec., on lead 3 sec. The pendulum is set in oscillation through a small arc by the touch of a feather. The sensitiveness of the instrument is very great, and it gives definite indications with the hardest materials.

Dr. Stanton has designed an ingenious instrument in which the deformation of a very hard ball used in the indentation test is substituted for the deformation of the material. This gives a much opener scale for hard materials. But the instrument is one for laboratory rather than workshop use.

W. C. U.

Structural Colours in Feathers.[1]

By Prof. WILDER D. BANCROFT.

IN pigment colour we have absorption of light due to the molecular structure of the substance under observation. We speak of structural colours when the observed colour is due to, or is modified strongly by, the physical structure. Typical cases of structural colour are observed with prisms, diffraction gratings, thin films, and turbid media. In the case of feathers we find that the blacks, reds, oranges, yellows, and browns are pigment colours, but that the ordinary blues and greens are not blue and green by transmitted light, and that the so-called metallic or iridescent colours, such as those of the peacock, are structural colours.

Biologists have often talked of prismatic or diffraction colours, apparently because those were the only structural colours that they knew about; but they have never tried to show that any arrangement of prisms or gratings would give the actual colours observed. Since prisms and gratings give no colour in a uniform diffused light, it is only necessary to look at a feather on the north side of a house, preferably on a grey day, and all prismatic or grating colours will disappear. Nothing of the sort happens, except to an almost negligible extent, with some moths.

If we have a turbid medium with fine particles, the scattered light is predominantly blue—Tyndall blue—and the transmitted light is reddish. Familiar examples of this are skimmed milk and cigarette smoke. The blue of the sky is also a Tyndall blue, the scattering being due in large part, however, to the molecules of nitrogen and oxygen, as was shown by the late Lord Rayleigh. In feathers of the non-iridescent type, Haecker showed that we have myriads of tiny bubbles in the horn which scatter the light, and a black backing which cuts off all transmitted light. On filling the bubbles with a liquid having approximately the same index of refraction as the horn, the scattering ceases and the blue colour with it. On putting in carbon bisulphide, which has a much higher index of refraction than the horn, the blue reappears because we again have a turbid medium. The blue of the feathers can be reproduced wonderfully by heating a hard glass tube until it begins to devitrify. The myriads of small crystals which are formed scatter the light, and a beautiful blue is obtained if the inside of the tube is coated with a black varnish to eliminate transmitted light.

In almost all cases of non-iridescent green feathers, there is no green pigment and the effect is due to the superposing of a yellow pigment on a structural blue. This can be shown in a number of ways. If we take a green feather and boil it long enough in alcohol, the yellow pigment dissolves and the feather turns blue. If we expose the green feather long enough to an intense light, the yellow pigment bleaches and the feather becomes blue. If we scrape the surface of the feather with a sharp knife, we can peel off a layer of yellow horn and the feather again turns blue.

The metallic or iridescent colours, such as those of the peacock, were considered by Rayleigh to be the interference colours of thin films like those observed with oil films on the streets, while Michelson believed that they were so-called surface colours from solid pigments. Fuchsine gives a yellow-green surface colour quite different from the magenta colour by transmitted light. Our experiments have satisfied us that Rayleigh was right and Michelson wrong. There are no bright-coloured pigments in peacocks' feathers or in any feathers of that type. In the case of the peacocks there are triple films, but this is not so in the neck feathers of the pigeon.

Nobody has ever extracted any bright-coloured pigment from any iridescent feather, and we have confirmed this, using a large number of organic solvents. The change of colour with the angle of incidence is what it should be for thin films, while magenta shows practically no change of colour with changing angle of incidence if one does not use polarised light. If one swells the feather by exposing it to phenol vapour, the change of colour is what one would predict from a thickening of the film. If one destroys the dark pigment, the colour disappears almost completely, though it can still be seen at certain angles. It can be brought back by staining the feather with a dark pigment. In the white pigeon, the iridescence of the neck feathers is very difficult to see, but it can be brought out vividly by staining the feather. Unfortunately the physical structure of the tail feathers of the white peacock is quite different from that of the ordinary peacock, and consequently staining does not develop brilliant colours.

The average thickness of the films in the iridescent feathers is about 0·5 μ or 1/50,000 inch.

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[1] Synopsis of a lecture delivered at University College, London, on June 1, at the University of Aberdeen on June 7, and before the Manchester Literary and Philosophical Society on July 19.