

# THE APPLICATION OF OPTICAL METHODS TO TECHNICAL PROBLEMS OF STRESS DISTRIBUTION.

IT is interesting, in the study of experimental work on the properties of engineering materials, to trace the general trend of the design of apparatus for research, as the need of more accurate knowledge has arisen. Much of our fundamental knowledge of materials has been gained from the study of strains in wires, bars and beams, under uniform conditions of loading; and the experimental apparatus employed has generally made these conditions necessary. The bulk of the technical problems which still require solution are, however, those in which the internal stress varies enormously from point to point; and hence the strain-measuring apparatus now employed in researches has been so increased in delicacy that it is possible to obtain average measurements over very small distances which approximate, if they cannot reach, to the measurement of the strain at a point.

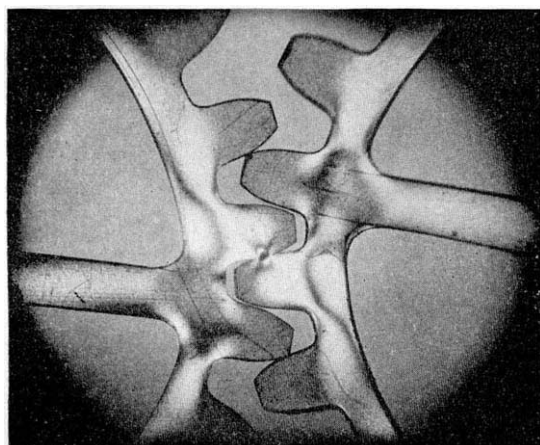


FIG. 1.—Transparent spur wheels in circularly polarised light.

Optical science has, however, provided a very perfect method for investigating the stress at a point, and the mathematical and physical investigations of physicists, among them Neumann, Clerk Maxwell, Mesnager and Filon, on the temporary double refracting properties of stressed glass have made it possible to enlist the aid of a valuable experimental means of studying internal stresses produced in models of structures and machines.

It is not necessary here to show that the stresses in glass of good optical quality agree very closely with the calculated values of the theory of elasticity. It is worth while, however, to point out that the apparent neglect of a valuable means of technical research has been due to almost unavoidable causes, the chief of which have been the great cost and fragility of glass specimens when shaped to forms adapted for investigations, and the necessity of employing very small models to suit the dimensions of the optical appliances available.

Some of these difficulties have been removed by

the substitution for glass of one of the nitro-cellulose compounds now available. These compounds approach glass in the perfection of their optical properties, and are considerably superior in ductility, and in the ease with which the material can be fashioned into complicated shapes at a fraction of the cost of glass specimens. An example of this is afforded by the accompanying photograph, Fig. 1, of a pair of toothed wheels of transparent material shaped in a gear-cutting machine in exactly the same way, and as accurately as their metal counterparts. They are shown here under somewhat heavy loads; and the condition of internal stress is marked by colour fringes, which appear as black bands in the photograph.

An important feature of this kind of material is its ability to sustain stresses of as much as several thousands of pounds per square inch without injury, so that the double refraction produced by the loading can be made much more intense than in glass, which usually fractures at very small loads.

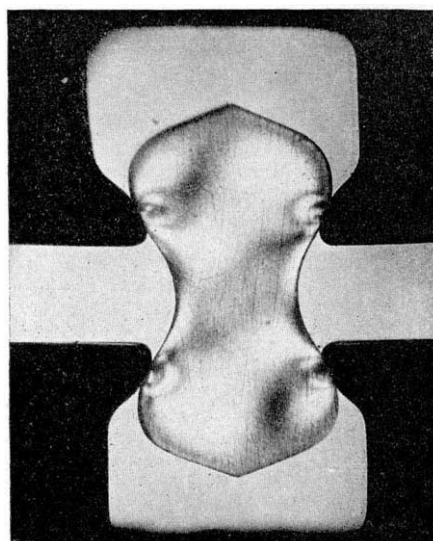


FIG. 2.—Model of cement briquette in plane polarised light.

The comparative rarity and great cost of large Nicol prisms have also restricted optical investigations to very small objects, but, as will be shown, this difficulty has been surmounted, and the size of the specimen illuminated by plane or circularly polarised light may be chosen at pleasure. Although not an essential feature, it may be mentioned that the brilliant colour effects of double refraction may be permanently recorded in a very convenient manner by any of the modern photographic plates now available.

In describing in general outline a method of obtaining the stress distribution in a loaded body, it may be useful to recall that a glass or celluloid body under stress causes an incident beam of plane polarised light to divide into two rays, which have different phases at exit, and also have their planes of vibration in the directions of the principal axes of stress in the body. A stressed object between crossed Nicols, therefore, shows dark bands or brushes, and these mark the positions

of points in the body corresponding to definite inclinations of the principal axes of stress. If, for example, we take a transparent model of some stressed object, such as a cement briquette, Fig. 2, of the form used by engineers for testing the tensile strength of cements, we can observe the movements of the bands shown on this model as the Nicols are rotated, and can mark the positions of the axes of principal stress at every point in the specimen.

A series of positions of the central lines of these isoclinic bands is shown in Fig. 3a for this case, and from these curves we can readily obtain, by graphical or other processes, a map of the lines of principal stress (Fig. 3b) throughout the body. The isoclinic lines are especially valuable for verifying the results of mathematical calculations,<sup>1</sup> as only small loads need to be employed, thereby avoiding the fracture of costly glass specimens and the possible variation of the physical properties of the material

suggested,<sup>2</sup> but in many cases this may be accomplished fairly accurately by approximate methods, especially where one principal stress is very great compared with the other. In the present instance, the chief interest lies in the distribution of stress at the minimum section, where fracture is intended to take place. The minor principal stress at this section is small everywhere, and vanishes at the ends. Hence, the experimental curve of values of the difference of principal stresses at the section, Fig. 3c, also shows the tensions at the ends accurately, and very nearly so at other points.

If this stress curve is integrated and compared with the stress applied, a mean value of the minor principal stress may be determined, and an approximation to the minor principal stress distribution obtained. Even without this we can see that the stress across the section of a cement briquette probably varies very greatly, and that the universal method of reckoning the stress

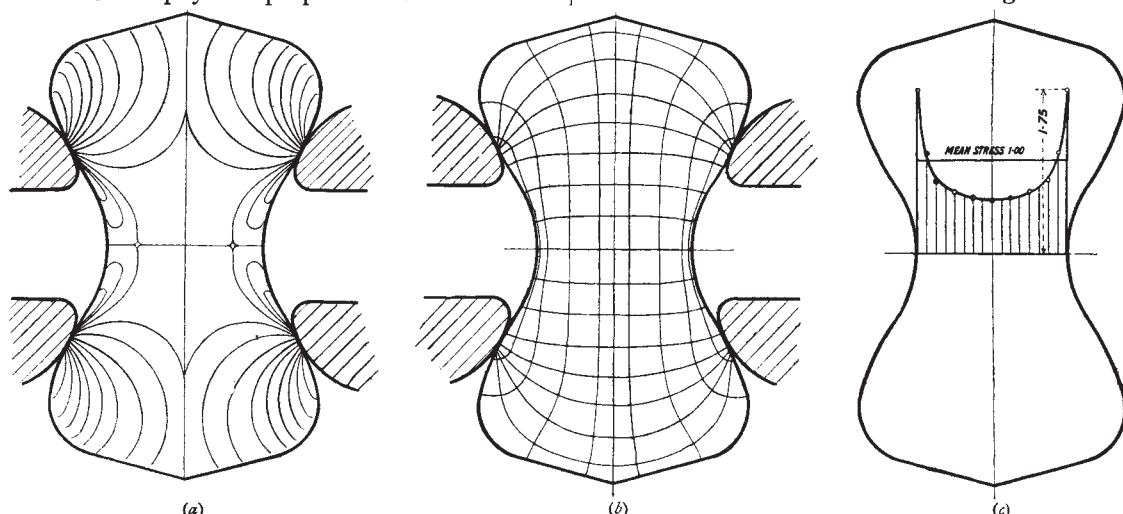


FIG. 3.—Model of a cement briquette: (a) Centre lines of isoclinic bands. (b) Lines of principal stress. (c) Approximate stress distribution at the section of fracture.

at high stresses. In technical problems, however, and in cases where a mathematical solution is not available, it is generally advisable, and it may be necessary, to measure the intensity of the double refraction produced by load.

The colour fringes indicating the stress are observed more accurately with circularly polarised light as the isoclinic bands are then absent, and the difference of the principal stresses at a point can be obtained from a colour or a wave-length scale. A direct measure can also be obtained by stressing a simple tension member, set along one direction of principal stress, until the field is reduced to blackness at the point desired. This has the advantage of being a zero method, and is simple to carry out with ordinary mechanical appliances.

The problem of determining accurately the principal stresses separately is, in general, one of some difficulty, and a combined method depending on optical and thermo-elastic properties has been

intensity, by dividing the total applied load by the cross sectional area, is inaccurate and misleading. Experiment shows also that models of the standard briquettes of Continental Europe, America and England differ appreciably in their stress distribution curves, and have, in fact, no common basis for the comparison of results.<sup>3</sup>

For examining models of structures and parts of machines it is usually essential to obtain a field of view in circularly polarised light far beyond the scope of the largest Nicol prisms and quarter wave plates hitherto constructed. In collaboration with Prof. Silvanus P. Thompson these difficulties have been overcome by the construction of polariscopes and quarter-wave plates of a size beyond any immediate requirements.<sup>4</sup>

One of these instruments is shown in cross-

<sup>2</sup> "The Determination of the Stresses in Springs and other Bodies by Optical and Electrical Methods." By E. G. Coker, Brit. Assoc., 1912, and *Engineering*, September 20, 1912.

<sup>3</sup> "The Distribution of Stress at the Minimum Section of a Cement Briquette." By E. G. Coker, the International Congress for Testing Materials, New York, 1912.

<sup>4</sup> "The Design and Construction of Large Polariscopes." By Profs. E. G. Coker and S. P. Thompson, Optical Convention, London, 1912.

<sup>1</sup> "The Investigation of Stresses in a Rectangular Bar by means of Polarised Light." By L. N. G. Filon, *Phil. Mag.*, January, 1912.

section by Fig. 4. Light from a bank of lamps, *A*, is diffused by tissue-paper screens, *B*, and afterwards reflected from a black glass plate, *C*, set

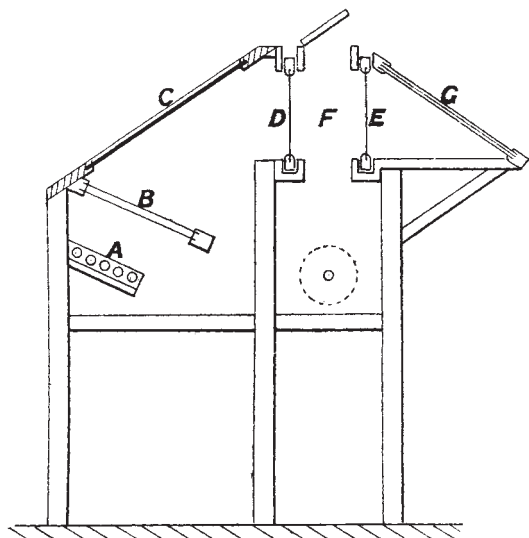


FIG. 4.—Cross-section of a polariscope for examining models of girders and ships.

at the polarising angle. Quarter-wave plates *D* and *E* are arranged to produce a circularly polarised field in the object space, *F*, and for demonstration purposes the analyser is constructed of thin glass plates, *G*, while a small Nicol prism is used for quantitative work. This apparatus, intended for models of bridge structures and ships, is capable of affording a clear field of view through quarter-wave plates of nearly a yard in length and a foot in depth, but so far no models of this size have been found necessary.

Polariscopes of a size adapted to show the whole of a model at one time appear to be essential for successful work in many instances. An example of their use is afforded by a determination of the distribution of stress in a long thin plate, *A*, Fig. 5, subjected to pure shear.<sup>5</sup> A plate of celluloid,  $\frac{3}{16}$  in. thick and 10 in. long, was rigidly clamped at the sides, *B*, and a maximum pull of about three tons was exerted by a centrally disposed weight, *W*, thereby affording a nearly pure shear over the free portions of the plate. The whole of the sheared area was visible in the field of view of the polariscope, and with the aid of a calibrating tension member the distribution of shear stress was plotted for different lengths

<sup>5</sup> "An Optical Determination of the Variation of Stress in a Thin Rectangular Plate subjected to Shear." By E. G. Coker, *Proc. R.S.*, vol. lxxxvi, 1912.

of plate. The mean shear applied was 800 lb. per square inch in all cases, and the results show some interesting peculiarities. In a long thin plate the shear stress rises slightly in value from the centre to near the ends, and then rapidly falls to a zero value at the extreme edges of the plate. The maxima become more pronounced as the plate is shortened, until a critical length is reached, where the distribution changes to one with a central maximum and ultimately becomes parabolic in character with a large increase of intensity, as the final curve shows.

Another field of usefulness which suggests itself is the application of optical science to the design of structural members. If, for example, we take a model eye-bar of a type often used in suspension bridges and the lower chords of pin-connected trusses, we can readily obtain (Fig. 6a) a map of the lines of principal stress for this form, and their general resemblance to those obtained in a hook<sup>6</sup> at once suggests that across the principal section the stress is very badly distributed. It is apparently very intense at the eye and rapidly decreases until it ultimately changes to compression stress at the outer end of the section. Experiments now partly completed confirm this view, and they also show that another form (Fig. 6b) gives a much better stress distribution wholly tensional across the principal section, as the curves of principal stress indicate.

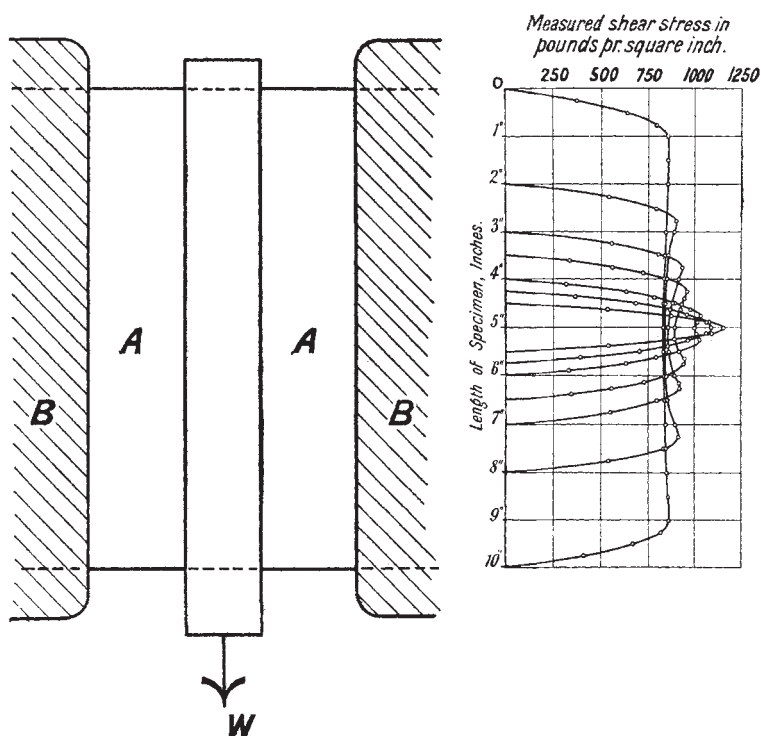


FIG. 5.—Distribution of stress in a long thin plate subjected to shear.

Both forms appear to restrict unduly the lines of stress where the head joins the main member,

<sup>6</sup> "The Optical Determination of Stress." By E. G. Coker, *Phil. Mag.*, 1910.



and it is inferred that the head ought to merge more gradually into the main body of the member than is at present the common practice. The applications of optical science may possibly be of use, therefore, in the design of structures and machines, as these examples indicate, especially where new problems arise, such as in the design and construction of aeroplane stays and struts,

fifty years ago showed that the disease can be transmitted by inoculation. Then in 1881 Robert Koch discovered the causative germ, the tubercle bacillus. Several species, or at least strains, of the tubercle bacillus are known, and piscine, avian, and mammalian forms are now recognised, and the bacilli of man and of bovine animals also exhibit differences, but the variety peculiar to man is the great source of human tuberculosis.

Tuberculosis is a common disease, but does not kill rapidly, and may take months or even years before ending fatally. The bacillus causes the formation in the tissues of cellular nodules, the tubercles, in which large multi-nucleated cells, the "giant" cells, are present, and perform a defensive function, ingesting and destroying tubercle bacilli, so that in favourable cases the nodules heal and disappear, or become fibrous or calcareous and inert.

There is evidence that tuberculous infection is exceedingly frequent, for the healed or calcareous tubercles are very common at the apex of the lung of those dying from any cause, and can also be demonstrated by applying the Pirquet test. This consists in applying tuberculin to a scarified patch on the skin, which gives rise in tuberculous persons to an inflamed red spot, and 90 per cent. of the adult European population is shown in this way to

have been infected with the tubercle bacillus, yet only 15 per cent. die of tuberculosis. Among the Kalmuk Tartars, studied by Prof. Metchnikoff, however, tuberculosis is rare, but this is not due to a natural insusceptibility, for Kalmuk youths residing in towns in Russia for purposes of education contract tuberculosis freely.

Attempts to cure tuberculosis by drugs, diet, climate, serum, and tuberculin were discussed, but the conclusion was expressed that, though some of these are helpful, no real remedy or sure treatment for tuberculosis has been found. Nevertheless, the death-rate from tuberculosis in large cities, such as London, Hamburg, and Copenhagen, is steadily declining, and this result Prof. Metchnikoff ascribes to unconscious inoculation by infection with mild or benign strains of the tubercle bacillus, which serves to protect against the virulent organism. It is on these lines that Prof. Metchnikoff believes that the stamping out of tuberculosis is to be attempted, viz., the discovery or artificial production of strains of the tubercle bacillus having but slight virulence, which, on inoculation in suitable doses, will serve to protect the inoculated against the virulent organism.

R. T. H.

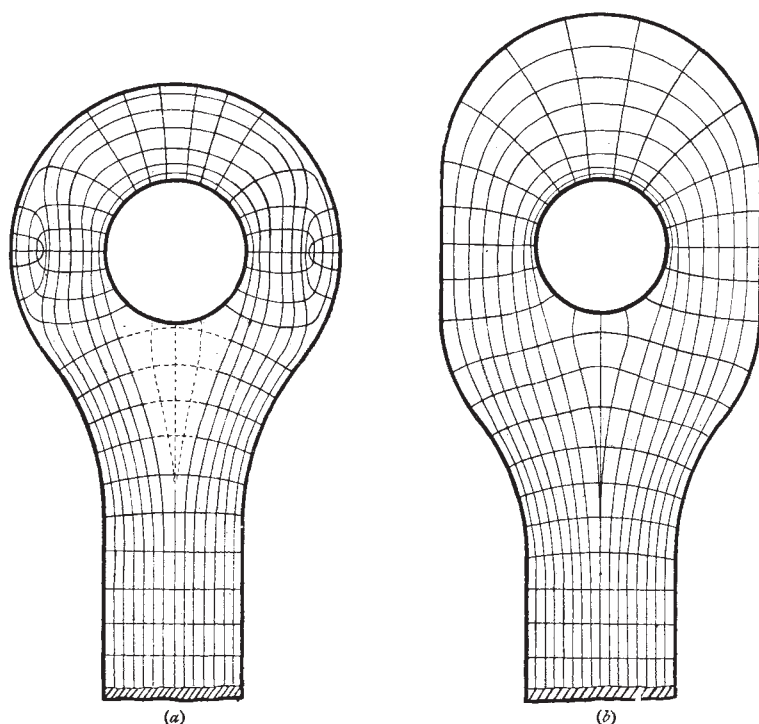


FIG. 6.—Lines of principal stress in two standard types of eye-bars used in bridge structures.

where a poorly designed member adds weight without corresponding strength, and may by its failure result in a serious loss of life.

E. G. COKER.

#### THE WARFARE AGAINST TUBERCULOSIS.

PROF. METCHNIKOFF delivered the Lady Priestley Memorial Lecture for 1912-13 under the auspices of the National Health Society at the Royal Society of Medicine on November 29. Sir Crichton Browne presided, and among others present were Sir Thomas Barlow, President of the Royal College of Physicians, Sir Rickman Godlee, President of the Royal College of Surgeons, Sir Ray Lankester, Sir James Goodhart, Sir Almroth Wright, Sir Lauder Brunton, Dr. and Mrs. Priestley, Sir Edward and Lady Busk, and Mr. and Mrs. Stephen Paget.

The subject of the lecture was the campaign against tuberculosis, and subjoined is a summary of Prof. Metchnikoff's remarks.

Although tuberculosis had been regarded by some as contagious, particularly in southern countries, it was a French observer, Villemin, who

NO. 2249, VOL. 90]