Stresses in Wheels.

By Prof. E. G. COKER, F.R.S.

THE stresses imposed on wheels during construction are usually not inconsiderable, and the loads, borne by them later, add greatly to the stress intensities. Although wheels are in universal use, comparatively little appears to be known of the stress distributions in them, although long practical experience has enabled constructors to satisfy exacting modern conditions.

In the vast majority of cases a wheel is built up with a central hub connected by spokes to a circular rim, a combination usually known as a wheel centre, on which is secured an outer tyre. Until the bicycle era, spokes were almost always in compression, and the invention of the wired wheel with all spokes under considerable tension was a notable advance in construction for light vehicles.

seen owing to the vertical stand used for photography, although the stress distribution it causes in the wheel centre is made visible by a beam of circularly polarised light. The photograph shows great stress intensity in the hub and very little in the spokes, except where they join the hub, while at the outer rim the stress, although of small intensity, is of such a nature that the rim experiences a maximum stress at its outer edge opposite to a spoke, and another maximum stress at its inner edge at places midway between adjacent spokes. The chief feature of interest, however, is at the contact surface between the axle and the hub, where the isochromatics show, and the measurements confirm, that the radial pressure P (Fig. 2, a) is variable round the axle with maximum values at the spokes,

FIG. 1.— a : Wheel centre stressed by an axle forced into the hub. b : Stress distribution in a tyre and wheel centre before the axle is forced in. c : Stress distribution in a completed wheel.

Modern conditions, however, appear to favour the use of the older form for all heavy traffic, with a well-marked difference between wheels for road and rail vehicles, in that for the former the wheel almost invariably revolves on a fixed axle, while for the latter the axle is secured to the wheel and revolves with it.

The determination of the stress distribution in any form of built-up spoked wheel is difficult, either by analysis or experimental means. It has, however, become a matter of some urgency to know accurately what are the maximum stresses in wheels for very heavy duties such, for example, as occur in present-day railway practice.

With the object of showing the general nature of the stresses produced in construction, a simple illustration is chosen of a railway wagon wheel, consisting of a wheel centre of the form shown in the photograph (Fig. 1, a), having eight spokes connecting the central hub with the rim, into which an axle is forced and an outer tyre is shrunk on. Into the hub of this model wheel centre, which is constructed of transparent material to a scale of one-twelfth full size, an axle has been forced, but this latter is not

so that this pressure waxes and wanes in the manner shown. In the hub, however, the circumferential tension Q at the axle reaches a minimum value opposite a spoke with only slightly greater values between.

If, instead of forcing an axle into a wheel centre, a tyre is shrunk on first, some interesting features are observed in the wheel centre, due to two separate groups of principal stress differences of zero value, and shown in the photograph (Fig. 1, b) by symmetrically placed black dots, one set in the hub and the other in the spokes near their junctions with the rim.

These stress effects, due to the identity in magnitude and sign of the principal stresses, are traced along a spoke in Fig. 2, b , where the measured values of the radial stress distribution P , and the corresponding circumferential stress distribution Q , not only confirm the existence of these two groups of stress difference zeros at points A and B , but also show that a third group of low stress intensity exists at points C . The occurrence of this last group is a matter of practical importance, as will appear later.

The principal feature, however, is the high stress intensity in the tyre, which, over a spoke, has a maximum intensity at its outer edge, and a minimum at the inner edge, as shown in Fig. 2, *b*, while midway between the spokes this state of stress is reversed, as we then find a maximum stress at the inner edge with a corresponding minimum at the outer circumference.

In railway work it is the usual practice to force the axle into the wheel centre first, and then shrink on the tyre. When this is accomplished, a stress distribution is found of the kind shown in the photograph (Fig. 1, *c*), in which both the hub and the tyre are highly stressed, while the spokes are still

to exert great tractive force at the rails, it is found necessary to fasten the tyres more securely to the rim of the wheel centre by additional devices, in order to prevent circumferential slipping.

Formerly it was the practice to screw radial studs *D* (Fig. 2, *c*) through the rim of the wheel centre and into the tyre at places midway between the spokes, as indicated here, thereby making holes in the tyre at places where the stress is already intense, and therefore adding to it very greatly, owing partly to the lessened cross-section of the tyre, and also to the effect of the discontinuity, necessitating changes of direction of the tensional stress in passing round the hole so formed. This practice

FIG. 2.—*a*: Stress distribution in the hub of a wheel at the axle, when the latter is forced on. *b*: Stress distribution in a wheel, along the line of a spoke, when a tyre is forced on to a wheel centre. *c*: Stress distribution in a wheel when the axle has been forced into the wheel centre and the tyre shrunk on.

only moderately loaded. As will be noticed here, the two outer groups of stress difference zeros are still present, although in slightly different positions radially. This is seen more clearly in Fig. 2, *c*, where the measured principal stresses *P* and *Q* are shown with reference to a radial plane through the centre of a spoke.

These distribution curves also show that the combined effect of both axle and tyre is to increase the radial stress on the axle greatly. In the tyre, increased stress is also apparent, although it remains of the type already described with reference to Figs. 1, *b*, and 2, *b*. This latter distribution is more particularly interesting in its application to much larger wheels, such as the driving wheels of locomotives, where, on account of their size and the necessity of supporting the tyre at short intervals, the number of spokes is much increased, and since, unlike wagon wheels, they are required

has now been given up in favour of transverse rivets *E* inserted in holes made in the wheel centre rim, very close to the stress difference zeros *C*, and passing through a flange formed on the tyre, which is now constructed to lap over the rim, as indicated by a dotted line in Fig. 2, *c*.

The photoelastic effect shows clearly the advantage of this method of fastening, for the discontinuity now produced by boring a hole at a place near the position of the stress difference zero *C*, where the principal stresses *P* and *Q* are both small, only causes a very moderate increase in both stresses, while no inroad is made into the main cross-section of the tyre. Practical experience has shown that tyres fastened in this way are much stronger and safer than those secured to the wheel centre by the older method, and the advantages of this new form of fastening have secured its very general adoption.

Oxidation by Living Cells.*

By Prof. J. B. S. HALDANE.

UNTIL recently our knowledge of the chemistry of respiration stopped abruptly at the boundary of the cell. We knew how the oxygen was carried to it in vertebrate blood, and the carbon dioxide carried away. We also knew that the rate of oxygen consumption by the body as a whole,

and by certain organs, was a function of numerous variables, such as temperature, hydrogen ion concentration, nervous stimulation, and so on. A certain number of partially oxidised metabolites, such as β -hydroxybutyric acid, had been isolated. But such quantitative knowledge as existed with regard to the details of oxidation was mainly confined to reactions in which coloured molecules were

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