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Stress Analysis Using the Brittle Lacquer Process

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This paper describes an experimental method of stress analysis, known as the brittle lacquer process, which enables both qualitative and quantitative results to be obtained. This process provides a comprehensive picture of the stress distribution existing in a member under load, since the lacquer develops a series of cracks which lie normal to the principal tensile stresses; the intensity of these cracks being dependent upon the value of the strain.

The lacquers, which can be used on members of any size, are capable of recording load impulses of very short time interval.

In this paper, a chronological review is made of the development of this process as a tool of the stress analyst. The properties, limitations, methods of application, etc., of the various lacquers available today are dealt with in detail.

Finally, the author gives details of the results he has obtained by heat treating two different lacquers. It is shown that by suitable heat treatment a very high degree of sensitivity to strain is obtained. A number of photographs illustrate the results obtained with these heat-treated lacquers.

INTRODUCTION

The rapid development which has occurred in many of the applied sciences since the beginning of the present century has resulted in the scientist requiring to know more fully the nature and magnitude of the forces with which he is dealing. This is particularly true in the field of engineering, where performances higher than those which had hitherto been required, have been imposed upon both material and machine. It is therefore only natural that much theoretical and experimental work has been conducted in attempts to determine the true distribution of stress in machine or structural members. Unfortunately, however, due to the complicated form of the majority of engineering components, it is impossible even with the aid of modern mathematical analysis to forecast with any absolute certainty the stress distribution in them. As a result, in recent years experimental stress analysis has become increasingly popular with design and production engineers. Consequently for a long time there has been urgent need for an experimental method of stress analysis; which would enable the true stress distribution in a loaded member to be determined quickly and accurately. This has resulted in the development of a large number of mechanical lever type extensometers and electrically operated strain gauges. Unfortunately the majority of these are too large to be applied to complicated machine parts, especially when dynamic stresses are being investigated. The only strain recording instruments available at present which are exempt from the above statement are the electrical resistance strain gauges and the brittle lacquer process.

To determine the stress distribution in a substantial machine part with the aid of electrical resistance strain gauges requires the use of a large number of gauges, which in turn necessarily involves the use of expensive apparatus. In addition the analysis of the results is a very lengthy and tedious process, requiring the attention of highly trained personnel. Moreover, unless a large number of gauges are used on each test specimen, there is every possibility of the gauges not being concentrated at the positions of highest strain, and consequently the results obtained can be misleading. In contrast, the brittle lacquer process gives an immediate overall picture of the stress distribution, distinguishing between areas of high and low strains. From the intensity of the developed cracks, it is possible to determine quantitative values of the stresses at selected positions. Once the stress distribution is known, more accurate strain recording instruments can be used at selected positions, if this is considered necessary. However, with a large proportion of engineering problems such additional work is not normally found to be necessary. Although the brittle lacquer process has been widely used in the United States, it has not become very popular in this country and it is hoped that this paper, by drawing further attention to the process and to the

THE BRITTLE LACQUER PROCESS

The brittle lacquer process consists of the application of a layer of material, normally fluid when applied but solid and very brittle when it has fully dried out, to the surface of a specimen. The brittle material adheres to the specimen and thus when the latter is tested the coating is subjected to the same deformations; the coating, not being so elastic as the specimen, possesses the property of developing well defined cracks at strains below the yielding strain of the material, these cracks always being normal to the principal tensile strain. Thus, knowing the initial strain response of the lacquer to cracking, it is possible, by observing the growth of the cracks, to determine the relative values of the stresses throughout the member at any particular load, providing it is elastically stressed.

There are a number of materials which can be classed as brittle lacquers and, in general, they possess the following additional properties:—

(1) The cracks once developed, remain open when the straining load has been removed.
(2) The initial cracking response to strain is independent of the thickness of the coating, within reasonable limits.
(3) The intensity of the cracks at a given strain varies with the thickness of the coating. The thicker the coating, the fewer the number of cracks per inch, for a given strain.
(4) The coating does not flake until the specimen has been plastically strained.

The brittle lacquer process measures the tensile strain in the surface of a member and is thus extremely useful when investigating fatigue problems, since it is now accepted that fatigue failure usually correlates with high tensile surface stresses. It is also possible, by the use of the brittle lacquer process, to determine the type of residual stress developed in a member during its manufacture or subsequent assembly. The method distribution in order to establish equilibrium once again. The procedure adopted is to drill a number of small holes in the surface of the member, and then to observe the stress pattern set up in the lacquer. If a star pattern is developed, then residual tension existed, compression strain being indicated by a series of concentric circles (see Figs. 1 and 2).

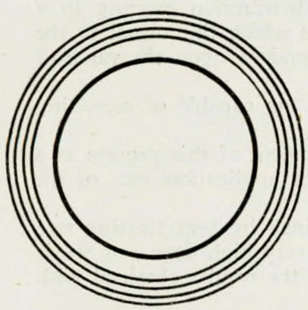

FIG. 1—*Crack pattern due to residual compression*

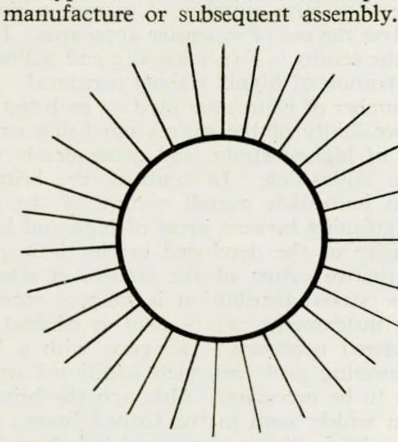

FIG. 2—*Crack pattern due to residual tension*

HISTORY OF THE BRITTLE LACQUER PROCESS

The earliest form of brittle coating was probably mill scale which spalls off rolled steel members when the parent metal is subjected to large deformations. The early workers in steel are known to have used this occurrence as a guide when working on steel members. Early in the present century, many investigators started to coat steel members with whitewash in an attempt to obtain an earlier indication of spalling. Though this was found to be an improvement, in that the cracks became more prominent, the results obtained were still unsatisfactory. Moreover, whitewash when placed on a polished specimen behaves in an erratic manner when under strain. Although there is evidence that many attempts were made to discover a suitable brittle coating, this task appears to have given considerable trouble, and no success was obtained until 1932. In that year Dietrich and Lehr* in Germany published the first real work on the use of brittle coatings for the indication of strains within the elastic range. The lacquer used by them appears to have commenced to crack at stresses from 3·2-12·7 tons per sq. in., and was employed with considerable success by the Maybach firm in Germany. This work, and that by Cymboliste and Porteven[2] in 1934, resulted in the process becoming more popular, and in 1936 Kayser[3] used this process when investigating the stress distribution in steel members. But although further efforts were made to improve upon these lacquers no substantial improvement was achieved until 1937, when Greer Ellis[4] of the Massachusetts College of Technology developed his series of lacquers. These lacquers, twelve in number, cover a wide range of humidity and temperature conditions and it is possible, by choosing the lacquer most suited to the prevailing conditions, to determine accurately the stresses in a member. A chart is supplied by the manufacturers which enables the correct lacquer for the existing temperature and humidity conditions to be chosen. The average initial response to strain, that is the first sign of cracking, of these lacquers when the above chart is employed, commences at a strain of 0·0007 which corresponds to a stress of 9 tons per sq. in. in steel. However, it is possible by heat treatment to increase the sensitivity of the coating. These lacquers, which have been developed commercially by the Magnaflux Corporation of America under the name of "Stresscoat" have been widely used in America and elsewhere (references 5, 6, 7, 8 and 9 in the bibliography are publications which contain interesting examples of the application of these lacquers). It is claimed that it is possible, by using these lacquers under optimum conditions of temperature and humidity, to obtain quantitative values of stresses to an accuracy of ± 15 per cent.

Greer Ellis and Stern[5] have shown that the lacquers are capable of recording dynamic strains, where the impulses of load are of as short a time interval as 0·002 seconds. This, as can be appreciated, is an important quality and opened up a new field of operation for this method of stress analysis.

These lacquers, however, possess the grave disadvantage that they are susceptible to temperature and humidity changes. They are, therefore, only 100 per cent efficient when used in temperature controlled rooms. This is one of several reasons why these particular lacquers have not become very popular in this country. In addition, the lacquers contain carbon disulphide which is emitted when the lacquers are being applied. Since carbon disulphide can be very harmful to an operator's health it is essential that the spraying and drying processes be conducted in a well-ventilated room and that the operator wear a suitable mask.

* See references p. 47.

Since 1937, many investigators have endeavoured to determine the composition of lacquers which would possess at least the same degree of sensitivity to strain as Stresscoat and in addition would be less susceptible to temperature and humidity changes. Tylecote[10, 11], in this country, has made a very extensive review of available materials and finally came to the conclusion that a varnish No. 108* was the best coating available, other than Stresscoat. He found that by heat treating this coating at 70 deg. C. for sixteen hours its initial response to strain or cracking occurred at a strain of 0·0015. This strain corresponds to a stress of 6·5 tons per sq. in. in duralumin and approximately 19·5 tons per sq. in. in steel. Although this coating was found to be successful while dealing with aluminium alloys, it was still not sufficiently sensitive to be of use when dealing with steel members, since the strain of 0·0015 approximately corresponds with the yield point for most steels.

Meanwhile Professor Haigh[12] had been experimenting with plumber's resin. Haigh's procedure was to cover the specimens with powdered resin which was then melted by means of a fierce flame, the molten resin covering the specimen in an even coat. Unfortunately, this coating as used by Haigh does not appear to give any response within the elastic range of the parent metal. It has, however, been found to be quite useful when investigating behaviour after yield[13], the resin coating enabling the presence of Luder's lines to be observed without difficulty. However, there have been reports from Germany and elsewhere, that quantitative analysis within the elastic range has been achieved by workers using heat-treated plumber's resin. Unfortunately, very little of this work appears to have reached the technical press up to date.

In Russia, the brittle lacquer process has received attention from many workers and brief details are given in an abstract[14] by G. S. Smith of Goncharov's book "Stress Determination in Machine Parts by means of Tensometers and Lacquers".

A wide range of materials were tested by the Russians and a number of lacquers found to be quite suitable, provided the correct technique was used with each. An initial strain response of 0·0004 was apparently obtained, which, according to standards in this country, is quite good. However, due to the brief details given, it is impossible to compare the results obtained with those of other workers. One point of interest is that in Russia painting the lacquer on to a heated specimen was favoured, the claim being that the heat treatment which followed removed all traces of brush marks.

In 1948 the author required a method of strain measurement which would enable him to determine the stress distribution in thin plate structures. Recourse was made to the brittle lacquer process which appeared to be the only satisfactory and economical method available. Many materials were experimented with and finally two lacquers were found to be satisfactory. These were a resin-based lacquer, No. 1† and the strain sensitive lacquer, No. 108 the latter being the coating used by Tylecote in his experiments. It was found that by heat treating these coatings a very large degree of sensitivity was obtained. Lacquer No. 1 was found to have an initial strain response of 0·0003, which corresponds to a stress of 4 tons per sq. in. in mild steel, when heated at 115 deg. C. for twenty-four hours and then allowed to cool, this being a big improvement on the previous values which have been obtained in this country. The resin in this lacquer has a melting point within the range 90-100 deg. C. Similarly, lacquer No. 108 was found to have an initial strain response of 0·0004 when given similar heat treatment. This value of initial strain response is equivalent to a stress of 5·2 tons per sq. in. in steel, which compares very favourably with that obtained when using Stresscoat. It is seen, see reference 10, that by increasing the stoving temperature from 70 deg. C. to 115 deg. C. that a marked improvement in the sensitivity is obtained. It is thus obvious that the sensitivity of the coating is dependent on the stoving temperature, the sensitivity improving with increased temperature. In addition, both of these coatings when cool do not appear to be unduly susceptible to moderate changes of room temperature and humidity, which in this country's climate is a very desirable property. After the initial tests it was decided to concentrate on one of the lacquers, and the lacquer which has been used in all the subsequent tests has been lacquer No. 1.

The author has not attempted at this stage to provide graphs giving the relationship between temperature and sensitivity, since such graphs can only be safely compiled from a very extensive series of tests. Such tests are, however, being conducted with this aim in view and it is hoped that in the near future this additional information will be available. It is possible, however, at the present stage to obtain qualitative and quantitative results when using the heat-treated lacquers. Whilst accurate temperature and humidity control is not essential, it must be appreciated that if such control is available, then more accurate results will be obtained. However, with reasonable care and under normal room conditions, it is found that results to an accuracy of ± 15 per cent are obtainable.

Examples of experimental tests, using brittle lacquer No. 1 are given later in this paper.

TECHNIQUE OF APPLYING LACQUERS

There has been a certain amount of disagreement in the past concerning the best method of applying the lacquer on to the specimen. A number of experimenters have stated that spraying of the lacquer on the specimen is by far the best method available, it being suggested that the process of spraying entrains air bubbles in the coating, this being conducive towards greater sensitivity and uniformity of the crack formations. On the other hand, some are of the opposite opinion and consider the inclusions of the air bubbles detrimental. In Russia, as stated earlier, the painting of the lacquer on to the specimen is favoured.

The author has found that spraying of the lacquer on to the specimen is the most convenient method of application. Attempts were made to paint the lacquer on to the specimens, but it was found that this resulted in a streaky appearance, unless heat treatment was used. Moreover, it was found by using a spray gun that a coating of uniform thickness was obtained. With practice a coating can be applied which has a constant thickness to within a tolerance of ± 0·001 inch.

With small specimens it was found very convenient to apply the lacquer directly on to the specimens and to spread it evenly over the surface by tilting of the specimen.

Normally the lacquer is applied direct on to the specimen, but when using materials with a dull surface finish it is desirable to give the specimen a thin coat of aluminium primer before applying the lacquer. The presence of the aluminium

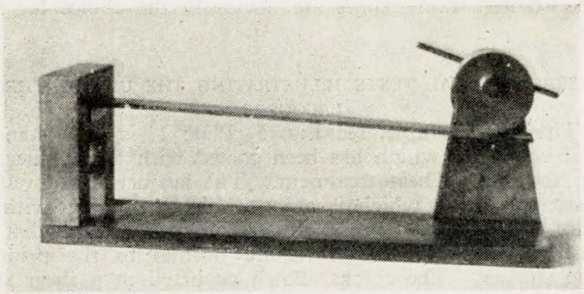

FIG. 3—*Cantilever beam apparatus for calibration strips*

base enables the cracks which form in the semi-transparent lacquer to be more readily observed. Providing the metal surface is free from loose mill scale and grease it is found that the aluminium coating does not lead to irregular results. It must be remembered, however, that the presence of oil or grease will prevent the lacquer or paint from adhering to the specimen.

After the lacquer has been applied, the specimens are heated

* Pinchin, Johnson and Co.

† Websters, Ltd., of Hull.

to 115 deg. C. by electric resistance heating elements and maintained at that temperature for twenty-four hours, after which they are allowed to cool slowly. The cooling process has to be carefully controlled if the lacquer is not to "craze". Whilst the presence of craze lines do not affect the sensitivity of the coating, they do prevent the formation of well defined crack patterns; since any crack formation will end at their junction with craze lines.

The sensitivity of the coating can be determined by coating a number of calibration strips at the same time as coating the specimen and then subjecting them to the same stoving and cooling processes. The author tests his calibration strips in apparatus based on the cantilever beam principle, see Fig. 3. Since the strain varies along the beam, it is possible to obtain the initial response to cracking and the intensity of the cracks at varying values of strain. Fig. 4, Plate 1, illustrates a typical calibration strip.

TESTING TECHNIQUE

The specimen when tested is carefully observed and the load at which the first sign of cracking occurs is noted. This and subsequent areas of cracking are noted, together with the corresponding loads. It is then possible, providing that the specimen has been tested within its elastic range to apply the law of proportionality and so determine the stresses in the various parts of the member at any chosen load. The specimen should be well illuminated during testing if the cracks are to be observed with comparative ease. If desired, the boundaries of the various regions of cracking can be marked with the aid of a wax pencil, which is effective on the lacquer coating. If the specimen is photographed at varying stages throughout the test, a permanent record is obtained which enables a careful survey to be made at leisure when the tests have been completed. Generally, however, it will be found that it is very difficult to photograph the cracks unless some form of strong side lighting is used. It is therefore normally more convenient to interrupt the tests at chosen stages and to make a detailed study of the crack formations.

When dealing with dynamic stresses, the cracks can be observed with ease if some form of stroboscope is used. If this is not a practical proposition, then the normal policy is to run the apparatus for a very short period, shut down and then observe the crack formations; it being recalled that the lacquer possesses the property whereby the majority of the cracks formed during the test remain visible after the straining forces have been removed.

Once having obtained the direction of the principal stresses from the crack formations, it is possible to apply more accurate strain recording instruments at chosen positions in order to obtain the exact stresses if this is considered necessary. Electrical resistance strain gauges are obviously the choice for such work.

EXPERIMENTAL TESTS ILLUSTRATING THE USE OF THE LACQUERS

The first example, see Fig. 5, Plate 1, is of a standard torsion specimen which has been coated with the lacquer and given the normal heat treatment. The lacquer has developed a crack formation which is at an angle of 45 deg. with the axis of the specimen; thus illustrating once again that the lacquer develops cracks which are normal to the principal tensile stresses. The cracks shown occurred at a shear stress of 12 tons per sq. in.

Figs. 6 and 7, Plate 1 are examples of direct tensile tests on strip metal specimens and illustrate the manner in which the intensity of the crack formations increase with a rise in strain. Fig. 6, Plate 1 shows the crack intensity at a strain of 0·0004, whilst Fig. 7, Plate 1 shows the crack intensity at a strain of 0·0012. A standard scale has been placed alongside the specimens in order to assist the comparison. Above the strain of 0·0012 little or no change can be observed in the intensity of the cracks.

Fig. 8, Plate 2, is an illustration of a tensile specimen which has had a central hole drilled in it. It is observed that the crack formations near the hole are normal to the edges of the hole; which is as expected from general theory. Fig. 9, Plate 2 illustrates the result obtained when a tensile specimen, in which a V-notch has been cut, was subjected to a tensile strain.

In an attempt to provide a more practical illustration, a patent chain link was tested. The chain link is composed of two parts which interlock; one of which is illustrated in Fig. 10 and Fig. 11, Plate 2. This part was coated with the lacquer, heat treated and then subjected to a tensile test; the method of loading being indicated in Fig. 10. Shortly after applying the load, cracks were seen to form in the region of A, see Fig. 10, and then to spread on either side of it. On increasing the load further, the lacquer started to peel off the specimen in the region of A; this being indicated in Fig. 12, Plate 2,

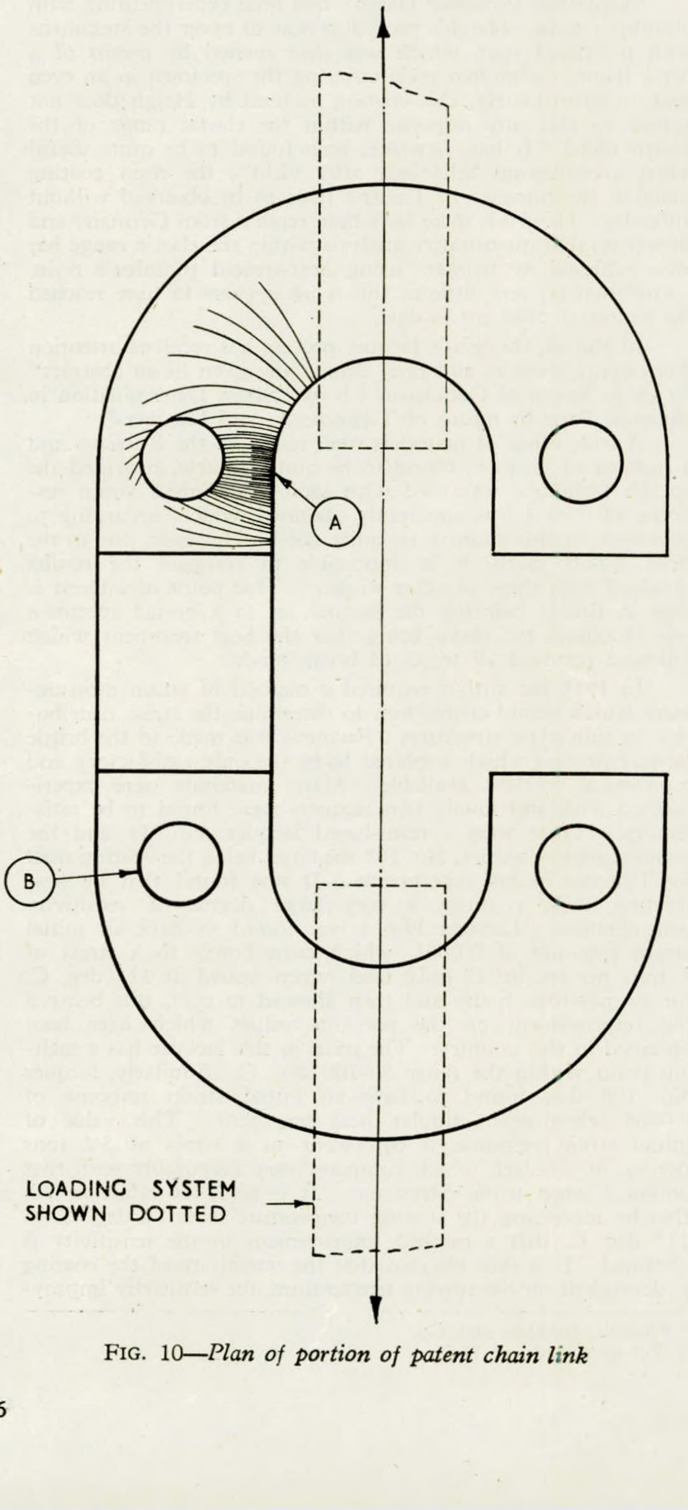

FIG. 10—*Plan of portion of patent chain link*

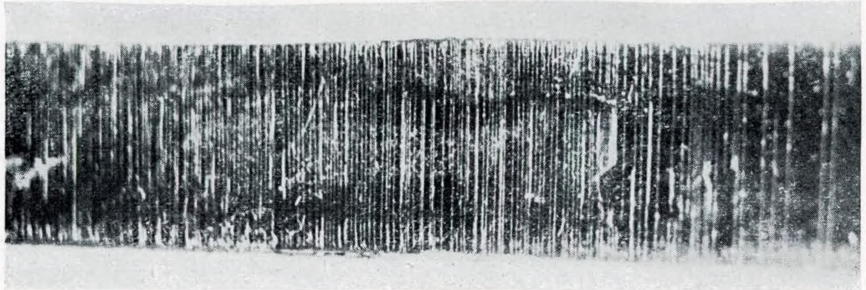

FIG. 4—*Crack formation in calibration strip*

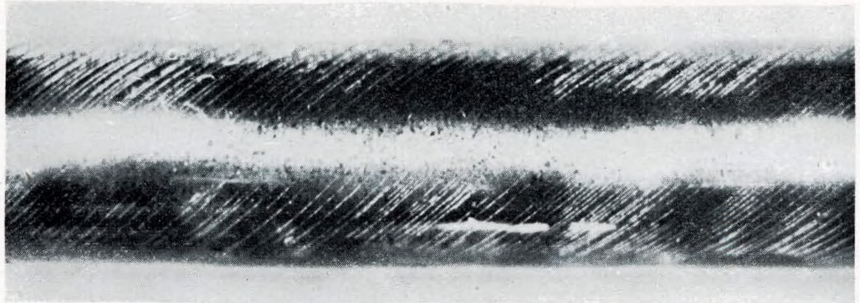

FIG. 5—*Crack formation in a torsion specimen*

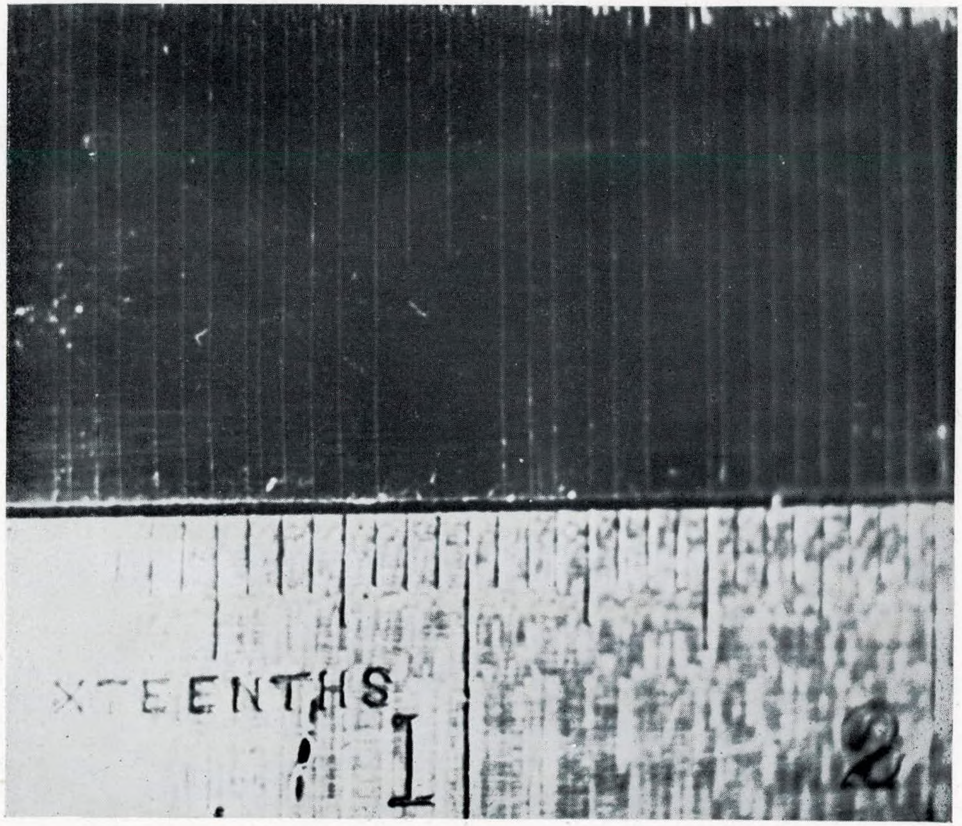

FIG. 6—*Crack formation due to uniform tensile strain of 0·0004*

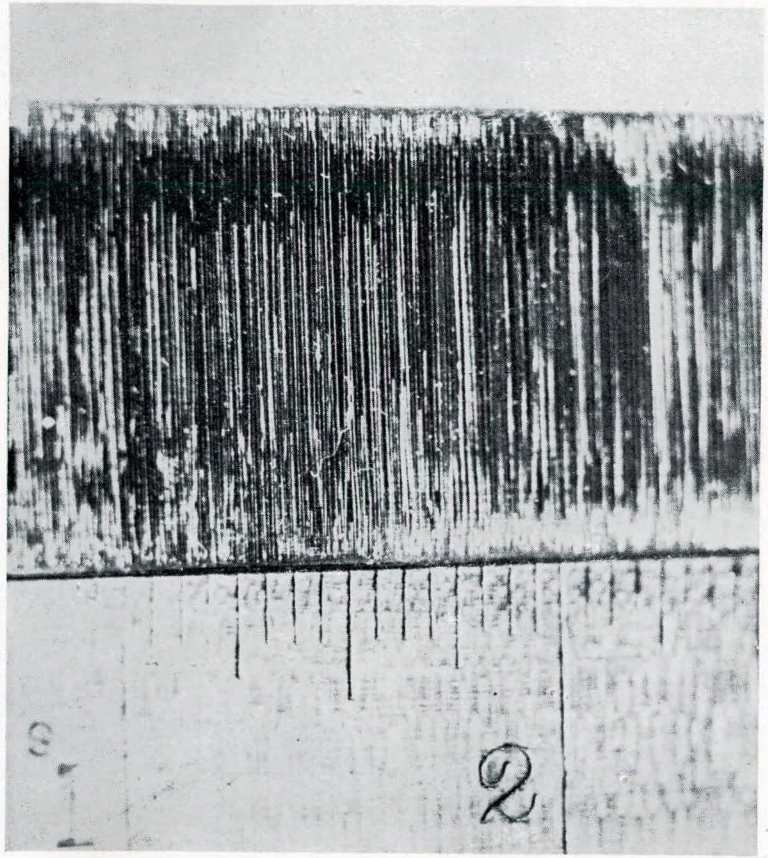

FIG. 7—*Crack formation due to uniform tensile strain of 0·0012*

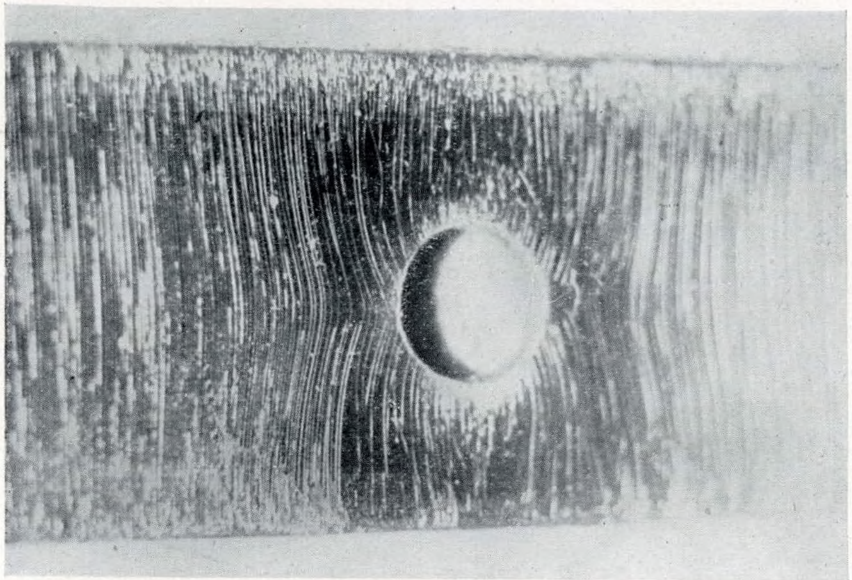

FIG. 8—*Crack formation around hole in tensile specimen*

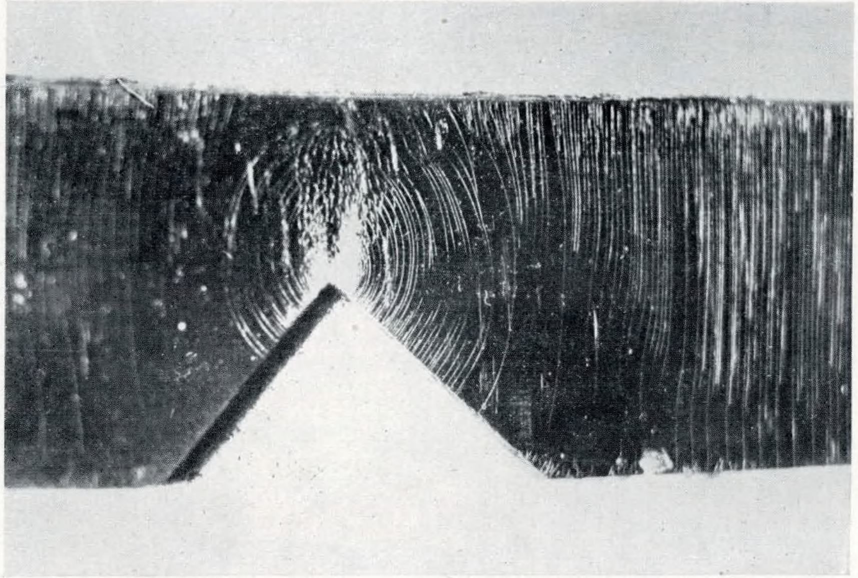

FIG. 9—*Crack formation around V-notch in tensile specimen*

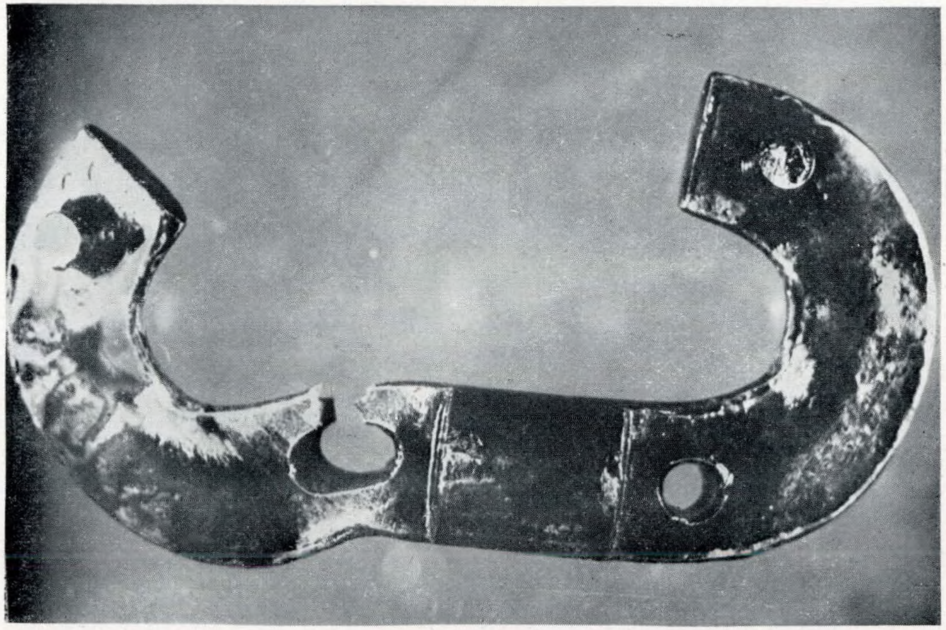

FIG. 11—*Portion of patent chain link after tested to destruction*

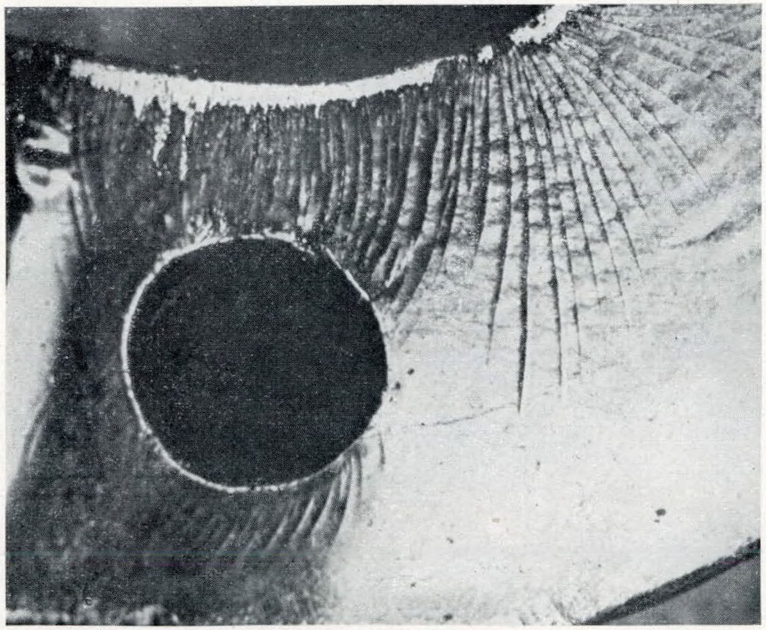

FIG. 12—*Crack formation in patent chain link*

which was taken after one test. The formation of the cracks can be seen in Fig. 12, Plate 2, and has been sketched on the upper half of Fig. 10. The lower half of the specimen in Fig. 10 has been left clear of cracks, but in actual tests, identical crack formations occurred in both halves simultaneously. Finally the specimen failed by the material tearing across the hole B, see Fig. 11, Plate 2. It will be observed that failure has occurred at the section where the crack formations were heaviest. In this particular case, it was quite evident where the failure would occur, and the tests were made purely as an illustration.

The above examples, whilst being severely limited in scope, do illustrate the usefulness of the brittle lacquer process as a method of stress analysis.

CONCLUSION

From the above investigation it is apparent that there are lacquers available which when applied to engineering components are sufficiently sensitive to elastic deformations to be classified as "brittle lacquers" and used as strain measuring instruments.

On comparing the advantages and disadvantages of the brittle lacquer process of stress analysis with other standard methods such as photo-elasticity and strain gauge techniques, a favourable result is obtained, and it would appear that this process deserves greater recognition and would justify its use in fields where at present it is not being applied.

ACKNOWLEDGMENTS

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Discussion

MR. C. H. YOUNG said he was very interested to hear that Mr. Rockey felt the brittle lacquer process was of value in the field of stress analysis. Before making a few observations, he would like to explain why he was taking part in the discussion. As Mr. Rockey had said, there appeared to have been a growing interest in the general technique of brittle lacquer for stress analysis for the past twenty years or so. As far as could be seen, however, the difficulty in this country had been that there was no lacquer or range of lacquers really suitable for the purpose, although such lacquers had been available in the United States of America. His company had been approached several times in the last few years as to the possibility of making a set of lacquers for stress analysis work. Some two years ago it was decided that an effort should be made to provide such a lacquer or set of lacquers and it had fallen to their lot to carry out this work.

One or two points had occurred to him when reading the paper. First, he would be interested to know what technique Mr. Rockey used for carrying out the tests. He himself felt that the technique of incremental loading practised by some was probably the best way of doing it, but Mr. Rockey seemed to advocate a crack matching technique. He would like to know what results had been obtained with that particular approach, because, having seen a large number of these calibration bars, he thought it would be very difficult to match the cracks at all accurately. The incremental loading technique whereby one loaded in increments and then examined and recorded the values obtained was probably preferable.

Secondly, the author's technique appeared to be to coat the specimen, then to raise the temperature to 100-110 deg. C., to sensitize the coating, and then to make the test. This would appear to create a considerable practical difficulty in the sense that if one wished to make an analysis of the pattern on a large complex structure, it would be difficult to obtain uniform heating over the whole of the test surface and the same heating characteristics for the calibration bar. To use this method quantitatively, one would need to have the film on the calibration bar in exactly the same condition as obtained on the specimen.

The author had mentioned the use of an aluminium primer underneath the coating lacquer. Such a primer was a valuable part of the technique in that it markedly improved the definition of the cracks and rendered them more easily visible. Had the lecturer tried his heating technique with and without the aluminium primer? If one raised the temperature to 100-110 deg. C. in the presence of an aluminium primer, would this affect the crack pattern subsequently obtained when the specimen was stressed?

As Mr. Rockey had said, there was sometimes a certain measure of spontaneous crazing in the coating after the specimen had been heated and subsequently cooled. Mr. Rockey felt, and others had said the same, that this spontaneous crazing, provided it was not too severe, did not affect the final sensitivity. He himself was rather ignorant about this but it seemed to him that if there was any spontaneous crazing it must mean that a certain degree of tension had been released in the top coating. He would have thought that any spontaneous crazing must have some effect on the final sensitivity in the sense that the coating was not in the same degree of tension as it would be in the absence of crazing.

He suspected that the author's next trouble would arise when the second batch of lacquer had to be prepared. It was by no means easy to prepare a further quantity of lacquer having the same sensitivity characteristics as the first batch.

One characteristic of this type of coating appeared to be that the sensitivity was a function of the loading time. In other words, if the specimens were stressed more or less instantaneously a definite value for sensitivity was obtained; with a slow loading technique, such as was often necessary in practice, the sensitivity dropped considerably. A creep correction curve was included with the instruction pamphlet issued with the lacquers supplied by his company, whereby the true sensitivity could be read from a graph giving sensitivity against time of loading.

Carbon disulphide was used in these lacquers, as was the case with the American material. It was a hazardous compound, being both highly poisonous and also extremely inflammable. Like all such materials, if used intelligently and cognisance taken of the precautions laid down by the manufacturer one was reasonably safe. Even with ordinary lacquer solvents, there was some hazard, and they needed to be used intelligently.

A temperature controlled room was highly desirable for stress analysis work, but he would not go so far as to say that it was essential. To his way of thinking, it amounted to this: that the technique of stress analysis by the brittle lacquer process was effective so long as the lacquer on the calibration bar went through the same cycle of conditions as the lacquer on the specimen, since one made a comparison with the lacquer on the bar. Even if the temperature did fluctuate a few degrees, the lacquer coating would still operate as long as there was no spontaneous crazing or conversely so long as the temperature had not risen so high that plastic recovery of the coating ensued. As far as he could see, it was possible to work within ± 4 or 5 deg. F., which was a fairly wide tolerance over a period of sixteen hours.

In conclusion, the American "Stresscoat" materials had, as Mr. Rockey had pointed out, a sensitivity of 0·0007 inch per inch strain. In devising their lacquers, his company had set out to increase that sensitivity and the order they were obtaining was about 0·0004 inch per inch of strain at the lower temperature limit for the particular lacquer. In other words, stresses of the order of a few tons per square inch for mild steel could be recorded by these brittle lacquers.

MR. T. W. BUNYAN (Member) said that, owing to the fact that the majority of the work, on which stress analyses under static and dynamic conditions had been carried out, was on large engine components, pressure vessels and the like, which had for reasons of their size and location made heat treatment of any lacquer impracticable, his comments would not include many useful remarks as to the use of brittle lacquers for quantitative strain measurement. Strain sensitive lacquers and plumber's resin had, however, been used on a large number of occasions with varying degrees of success for indicating local stress concentrations during loading up or hydrostatic pressure test and had been found to be a very useful adjunct to the electric resistance strain gauge which was, of course, used whenever possible in preference to strain sensitive lacquers. But there had been many instances where, owing to the small size of a shafting or weld fillet, the use of a reliable strain sensitive lacquer would have been invaluable as the use of strain gauges of the resistance type was precluded because of their gauge length.

The brittle lacquer technique provided a strain gauge of infinitely small gauge length, and in such cases where the stress field was widely varying over small distances was, where practicable in application, the case of Hobson's choice. Either one used this technique or made a wild guess from readings obtained from resistance strain gauges, or short gauge length mechanical extensometers. If, therefore, he appeared to be somewhat biased against quantitative analysis with brittle lacquer he hoped his reasons, based on practical application of this technique, would be understood; though he would agree that the vibration engineer and stressman in the aircraft industry had had considerable experience with brittle lacquers and judging from published data had gained a measure of confidence in its use as a strain indicator.

He took some exception to the statement on p. 44, which seemed likely to him to be very misleading, that "They are, therefore, only 100 per cent efficient when used in temperature controlled rooms". From what he knew and indeed, from what the author had said himself, it would seem, in any circumstances, impossible to conclude that this technique could be anything like 100 per cent efficient.

On p. 45, the excellent strain sensitivity of an indication at 0·0003 inch per inch was interesting; in the following paragraph an accuracy of ±15 per cent was mentioned. He took it that the ±15 per cent did not apply to the low strain values recorded.

He was most interested in the author's work on obtaining strain performance data of the various lacquers marketed. He concluded that the author would also deal with the corresponding effects of heat treatment, and would be glad if he could publish the data as a companion to the present paper.

He would like to know whether the author had, in fact, used the stroboscopic technique, as it appeared that the use of stroboscopic illumination for crack definition under dynamic conditions was expecting rather a lot from the stroboscope.

Mr. A. M. Kennedy observed that, unlike the last speaker, he had been advocating the use of brittle lacquer for about three-and-a-half years and had tried to persuade various people to use it for stress analysis work—or at least to try it. The difficulty until fairly recently had been that although a calibrated strain lacquer was available in America, it could not be obtained in this country. As Mr. Young had said, one was now available which people were beginning to try. Personally, he thought it would contribute very much to the understanding of the strains and criteria of failure if this technique were more widely employed.

He had carefully avoided the use of the word "stress" because brittle lacquer was essentially a strain measurement technique. If it was used merely to determine a strain concentration, this being then converted into stress by the use of Young's modulus and inserted into an empirical formula developed for pressure vessels and the like in various B.S. standards, it would be found that nearly all the plant which had been used for the last three or four decades or more would have a stress which was quite unacceptable, although the plant had been fully satisfactory in service. Brittle lacquer was a method of strain concentration measurement, and not much had been known about this until recently. Much had been learnt from strain gauges, and photo-elasticity had provided some information; but there had been little attempt to use maximum stress concentration, let alone maximum strain concentration, and the field was still almost untilled. He agreed with the author that the brittle lacquer technique was a very good tool for digging in that field. It should take its place with the various other tools, such as mathematical calculation, relaxation methods, extensometers, strain gauges, both acoustic and electrical resistance types, etc.

The great advantage of brittle lacquer was that it gave a complete picture at a glance. A part could be tested and taken into the drawing office, and the strains could be seen "in the round". But this was not the complete answer: one had to consider what those strains meant, and this was quite complicated. So far there was a brittle lacquer which, when strained under the simple conditions of a bent beam in which one had a tensile strain in one direction and a Poisson's ratio strain in the other, gave cracking at a certain value of tensile strain. Was it true to say that the calibration was the same when instead of a Poisson's strain in the direction at right angles there was a complex strain? For example, on his torsion specimen Mr. Rockey had a compression strain at right angles to his tension strain. Did his calibration then agree with the strains which he obtained on the calibration beam which was bent under simple bending?

There were one or two puzzling points in the paper. He did not follow why so great an effort was being made to increase sensitivity. People were not really interested, in a machine part, in strains corresponding to a stress in mild steel of less than 5 tons per sq. in. What was wanted was a coating sufficiently sensitive to give a range so that a picture could be built up between the first cracking of the coating and the yield of the specimen. There did not seem to be any advantage in much greater sensitivity and it would soon lead to the measurement of strains which were of no interest whatsoever. In fact, one doubtful point was that machining strains in the specimens were sometimes shown up.

As far as temperature control was concerned, temperature variations meant changes in length. If trying to measure strains comparable to strains due to the co-efficient of linear expansion of the test material, one must obviously control the temperature. When one used electric wire strain gauges one had also to control the temperature; one used a compensated strain gauge and on top of that one lagged very carefully. If, on the other hand, one wanted measurements which were roughly right—to know whether there was a strain corresponding to a stress of 5 or 10 tons per sq. in.—the permitted variation in temperature was of a kind which no-one present would allow for comfort alone. If the temperature of the room were to drop by 10 deg., they would all have their overcoats on in no time. ±5 deg. F. was a wide range. The temperature of the room was at present about 65 deg., and a fall to 55 deg. would constitute a very big change.

What electrical heating elements did the author use? Did he make them specially for each specimen, or had he an oven? It was not clear from the paper. The easiest method would probably be to have a room with an electric fire in it with a simple thermostat. This would no doubt give temperature control of ±3 deg. F., provided no-one came in and left the door open.

He was doubtful about the oven treatment if quantitative results were required. All the author seemed to be doing was to pre-stress his resin or coatings: he was not sure about this but he deduced it from the paper. In other words, the author heated his component up so that it expanded, put on his coating while it would flow, stoved and hardened it, and then cooled slowly. If the co-efficient of expansion of the coating was greater than that of the specimen, he would get tension over his coating. Was the pre-stressing uniform over the specimen, if this was in the form of a complicated part, or was the author laying up trouble for himself?

Another factor which had to be controlled, as was said in American literature, was humidity. A great deal had been said about it in the American literature, and the Americans seemed, quite rightly, to fancy themselves for their instrumentation. The humidity side had, however, in his own view, been exaggerated. As far as he could see, the effect was entirely secondary and he would quote one application from American literature which seemed to support this view. The problem was to examine the strains in a centrifuge basket. The only way in which it could be loaded was with water. The stress coating was put on and allowed to harden for about sixteen hours or thereabouts. The centrifuge basket was then loaded with water on top of the lacquer, and provided the test readings were obtained within half-an-hour, they were accurate when compared with the calibration bar not under water at all. The only precaution taken was to ensure that the water was the same temperature as the machine; this was done by keeping the water in the room while the lacquer was hardening, so that both were roughly the same temperature.

This lacquer had not been tried on large pressure vessels, but he thought it would give good results if the vessels were filled with water because the temperature would not fluctuate quickly, and ± 3 deg. would probably be maintained easily. The essential point was that during the test heat should not be flowing from the test rig into the specimen or from the specimen into the test rig, and that the calibration bar was at the same temperature as the specimen. Obviously, if they had different water equivalents and the temperature was varying one would lag behind the other.

In conclusion, he repeated that this was an extremely useful tool but its application must be watched carefully. It was quite wrong to assume that with brittle lacquer and strain gauges one did not need to do sums or know one's theory of strength of materials. Was the object to find the causes of failure? There were seven theories—principal tensile strains, principal stresses, maximum strain energy, von Mises Hencky, and so on. One did not avoid having to choose the right one merely by measuring strains. The point was what use could be made of these extensive measurements; they had to be collated with the results of experience. It might be years before one could claim authoritatively that this strain was too much for that duty.

MR. A. F. EVANS (Member) asked whether the author considered there would be any value, in cases where the part to be examined was somewhat complex and manipulation would be difficult, to make a model in lead and stress it until the strain appeared and then take readings. The objective would be to find stress concentrations.

MR. B. HILDREW (Associate Member) remarked that there was a tendency for everyone to claim that his system, be it stress lacquer or photo-elasticity, was better than any other. Personally, he thought each had its own individual field which must be sought out.

There were two major disadvantages against brittle lacquer: (i) it had apparently to be stoved for twenty-four hours; and (ii) stoving automatically limited the size of the article to be examined. He had had some slight experience of brittle lacquers and of plumber's resin; and he thought plumber's resin gave a rapid and easily interpreted result. It could in addition be used on very large objects. The trouble with plumber's resin was that it became effective only near the yield point of steel. Also to put on a thin coating was very difficult. Even on a flat plate it was almost impossible to get a thin even coating, and with a pipe or vertical object the resin usually ran down and set unevenly.

The author stated that a very fierce flame was required to melt the plumber's resin. That depended on the size of the object and on how much heat it was going to absorb. He believed plumber's resin flowed at about 140 deg. C.

Obviously if one could not stove an article for twenty-four hours because of its size, one could make a model and use the brittle lacquer technique. Was the stress distribution and computation made on the model easy to develop up to a full-size article? He was not referring to the half-size model, on which it would be quite possible to work, but to a model which was one-tenth or one-fiftieth of the size, e.g., a model of a very large pressure vessel; here the scale effect might be large and loading to scale difficult. He himself was prejudiced against model work for stress computation except, possibly, for temperature stresses. What were the views and experience of the author on the use of models?

It would seem to be very useful to use lacquer in conjunction with the strain gauge. By putting the strain gauge on a comparatively unstrained portion of the specimen, one could read-off the gauge and compare the lacquer pattern in the vicinity. A direct comparison with the lacquer pattern at stress concentrations would give an instantaneous though approximate idea of what was happening to the specimen as the test proceeded.

The compression patterns obtained by the author in the buckled panels were also interesting. Compressive strain with plumber's resin (which was where he had seen it) had always seemed rather indeterminate to him because the resin used to flake off. Before it flaked off, if one held a light anywhere near it, one could see it was pinging off—springing in the air and dropping back on to the surface in very tiny little splinters. Perhaps this was because it was too thick. He would like to ask the author whether the brittle lacquer could be used in compression other than by applying the lacquer when the specimen was under load?

The most interesting point in the paper was that tests had been carried out in America using dynamic loading. It was probably in this field that stress lacquer would prove most useful. It could be used for shock loads. Indeed, he did not see how anything else could be used and it therefore had the field to itself, bearing in mind that only maximum strain was indicated for impact problems—a possible limitation. If he had seriously to develop the technique, he would look towards dynamic problems in conjunction with electric resistance strain gauges, and make a field for it there.

Photo-elasticity used in three-dimensional investigation would probably be more useful than in two-dimensional problems. There was one tool in mathematics, a tool that could be used widely in various fields. He referred to "relaxation". Relaxation was very simple. People might not think so, when they came to examine it, because it was unfortunately laborious. With this method both elastic and plastic strain could be computed. The difficulty was that the operator needed a lot of practice. He did not think anyone could give an opinion on its worth until he had had long experience. It required two or three months' practice to become really skilful in its application. It was more accurate in two-dimensional problems provided the working conditions were known. It was useful, for example, on flat plates, in torsion problems and in problems on incomplete tores.

Briefly to summarize, he thought that for the examples given in the paper relaxation methods would be superior. However, such experiments were necessary before one could launch into the dynamic field where, in his view, brittle lacquer would hold its own in association with electric resistance strain gauges. He could envisage problems in which it was impossible to apply anything else, apart from very complex mathematics. Again, the lacquers mentioned by the author certainly seemed to be an improvement on "Stresscoat". From what he had read himself about the latter, it consisted of a number of lacquers, the choice depending on the humidity. This was an added complication and militated against its use.

For large structures he could see no solution other than plumber's resin if one must use a lacquer. It must be possible to heat treat plumber's resin. When he had used it he had noticed occasionally that it had registered tensile strain long before the specimen under test had been anywhere near yield point. This might have been due to:—

(i) resin coating applied too thick; or
(ii) a critical temperature reached during the application of the resin.

COMMANDER J. I. T. GREEN (Associate Member) asked how there could be any useful scale of calibration between the number of cracks per inch and the stress or strain. It seemed to him that each new crack must on average appear half way between previous cracks as the strain was increased. Hence it did not seem that quantitative results could be obtained once the intensity of cracking reached a high value. Had the author any figures showing the scale of stress against intensity of cracks?

Correspondence

MR. J. H. LAMBLE, M.Eng., Ph.D., wrote that in the summer of 1936 he had the pleasure of listening to the late Professor B. P. Haigh describing the technique which he had developed of using plumber's resin for indicating yield in mild steel structures. Later with his students this technique was applied to a centrally loaded beam consisting of a 4 inch by 1 inch filler joist whose web had been reduced in thickness by planing in order that shear failure should occur. The joist was first washed with acetone and then laid over a gas burner with the web in the horizontal plane. A piece of resin was rubbed over the side of the web away from the flame until a relatively uniform coat was formed about 0·01 inch in thickness and the joist then cooled slowly to air temperature. As load was applied a series of cracks appeared in the resin coat. These cracks were about normal to the anticipated direction of the principal tensile strain and approximated closely to one of the two orthogonal systems drawn in a similar manner to that shown, e.g., by Morley, "Strength of Materials" 9th edition, Fig. 101, for uniformly distributed loading. Increase of loading led ultimately to yield patterns similar to those obtained by Haigh. A short piece of the same joist subjected to a compressive load applied to the flanges and in the plane of the web showed no cracks in the resin coat until the critical load of the web as a column was exceeded when three parallel yield areas appeared, one along the web axis and the others at the fillets.

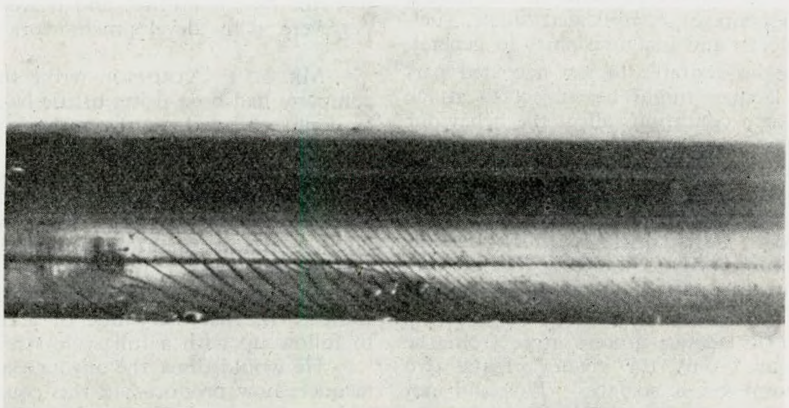

FIG. 11—*Cracked plumber's resin coat on ¾ inch × 20 s.w.g. brass tube subjected to torsion*

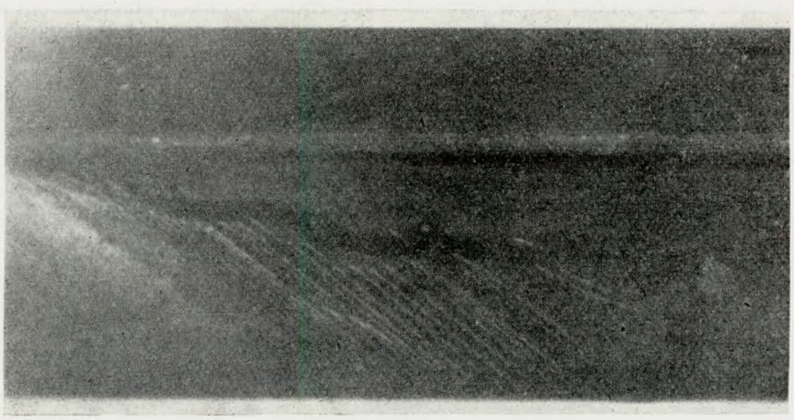

FIG. 12—*Cracked plumber's resin coat on 1¼ inch × ⅞ inch × 20 s.w.g. steel tube subjected to torsion*

For experiments on flat plates 24 inch by 16 inch subjected to hydrostatic pressure, the resin was applied in the form of a powder on to the horizontal surface of the material and then melted into a uniform coating 0·010 to 0·012 inch thick by radiant heat from an electric fire which was slowly withdrawn as the coating cooled. The plates were of elektron and duralumin, each $\frac{3}{16}$-inch thick, the crack patterns obtained were given in *Engineering* for 7th May 1948. A sheet of Perspex ⅜-inch thick was also coated with resin in the same manner—a rather finicky operation—and loaded centrally whilst being freely supported at its edges. An interesting crack pattern was obtained which had proved exceedingly difficult to photograph. "Stresscoat" dye did not appear to "wet" the plumber's resin and so was unsuitable for intensifying the crack pattern.

On p. 44 of the paper the author suggested that with "Stresscoat" under optimum conditions, quantitative values of the stresses might be obtained to an accuracy of ±15 per cent. (In view of this his later reference to 100 per cent efficiency was rather whimsical.) This was not surprising since with plumber's resin the actual shape of the specimen under examination affected the value of the strain at which the first cracks appeared and this was shown by changing the shape of the calibration specimen. If, on a calibration strip ½ inch by ⅛ inch in cross-section used as described in the paper, the strain at which the first cracks appeared was taken as the standard, then using a tube ¾ inch O.D. × 20 S.W.G. gave first cracking at a strain approximately 30 per cent greater, whilst if the specimen was a tube of rectangular section 1¼ inch × ⅞ inch × 20 S.W.G., the increase was found to be somewhat less and was dependent on which plane of bending was used. This was in conformity with what would be predicted from the theory of bending. Could the author say whether or not the same effect was seen with "Stresscoat" or with his heat-treated lacquer?

The sensitivity of plumber's resin was such that in their laboratory for a steel tube 1 inch O.D. × 20 S.W.G. stressed axially in tension, complete circumferential ring cracks in the resin coat had been observed for an applied stress of 800lb. per sq. in. A warning should be given that in using plumber's resin considerable patience was needed in order to obtain a uniform coating free from crazing and some "intelligent anticipation" of crack appearance was necessary since the initial cracks were so fine as to be easily missed on first appearance.

The two illustrations given were of tubes tested in torsion showing the early stages of cracking in the resin coat from the plugged ends of the tubes. It would be noticed that the cracks appeared first on the broader side of the rectangular section tube (sizes were as mentioned earlier).

Mr. A. J. Morton, B.Sc. (Graduate), wrote that the process as it stood should be of immediate value in the testing of a large variety of components of complicated shape, such as hooks, brackets, pulley blocks and machine parts in general.

In many cases it might be desirable to test a coated part *in situ,* in which case the lacquer might be subject to attack by oil or water. How did such conditions affect the behaviour of the coating? Further, was it practicable to examine a coated part over a period of weeks or months for the purpose of detecting strains which might develop very slowly in service? The author remarked that the intensity of cracking depended upon the thickness of the coat. What thickness did he recommend? It would also be interesting to know if the lacquers gave any indication of compressive strain when this reached a high value.

A limitation of the brittle lacquer process arose from the fact that it normally measured only the greater of the two principal strains at any point on a surface. This did not enable the principal stresses to be completely determined. For example, taking Poisson's ratio as 0·3, a transverse stress equal to half the longitudinal stress would reduce the indicated longitudinal strain by 15 per cent. As this strain was the only quantity measured, the estimated stress would be in error if the presence of the transverse stress was unsuspected. In some cases this error might be serious, especially if superimposed upon the additional 15 per cent which was stated by the author to be possible under normal conditions. It would therefore be seen that the process, although simple and convenient, did call for intelligence in the interpretation of results. With this reservation, however, its practical value was evident.

For many laboratory investigations, carried out with the object of evolving or checking a mathematical theory, the accuracy of the brittle lacquer process was as yet insufficient. In such cases the investigator must resort to electrical resistance strain gauges, with their great additional complication. These gauges enabled both principal strains to be measured simultaneously, so that the principal stresses could be calculated. Nevertheless, the practical advantages of the brittle lacquer process were such that if the 15 per cent error could be reduced to 5 per cent, and the initial strain response halved, the process would be preferable to strain gauges for much work of this type.

Although difficult, these objectives should not prove unattainable, in view of the very encouraging results already reported by the author, and it was to be hoped that he would persevere in his development work on the process.

Mr. L. F. Atkinson wrote that for several years now his company had been using brittle lacquers for stress analysis, and he could well endorse the author's conclusions that the process deserved greater recognition and a wider field of use.

He had never made much use of the resin-based lacquer No. 1, owing to the stoving difficulties and the tendency to craze on cooling, but "Stresscoat" was in constant use for both qualitative and quantitative work (under laboratory conditions and in the field). In many cases, as the author indicated, results from the lacquer investigations were quite sufficient to indicate the necessary line of action, and there was no need to follow up with a full scale strain gauge assembly.

He would draw the author's attention to a series of brittle lacquers now produced in this country which were very similar in behaviour to the Magnaflux "Stresscoat". These were available under the trade name of "Strainlac", and used an identical solvent (carbon disulphide). Although his own experience had been limited to one particular grade, results had been very good and equal to those obtained from the American lacquer. Further information might be obtained in the form of a technical bulletin.

Author's Reply

In reply to Mr. Young, the author said that he had always favoured the method of incremental loading, because although the initial strain response of the lacquers was insensitive to moderate variations in the thickness of the coating, the number of cracks per inch which were developed in the coating at a given strain varied with its thickness; the thicker the coating the fewer the number of cracks. He would therefore never attempt to match the intensity of cracks, since it was inevitable that the coating would be thicker in the neighbourhood of hollows and fillets. He had shown photographs of the cracks formations at various strains, so that anyone not conversant with the process could appreciate what happened in the brittle coating when the specimen was subjected to strain.

With regard to the necessity of having to heat the specimens up to 110 deg. C., in order to obtain a satisfactory degree of sensitivity, the author agreed that this presented considerable difficulties when the specimens were large. However, with the aid of suitable electrical radiating elements he had been able to heat treat specimens possessing a superficial area of 4 feet by 2 feet and obtain satisfactory results. It was essential, however, to ensure that all parts of the specimen reached the same temperature. The heat treatment which the present lacquer required was necessary to ensure that all of the solvent was driven off, leaving the coating in a brittle condition. It was hoped that by the use of a more volatile solvent, this heat treatment would be reduced or even rendered unnecessary.

Since he did not use an aluminium undercoating on his specimens he was unable to state what effect the heat treatment would have upon such a coating. However, he did not think it would have any serious effect upon the final sensitivity of the lacquer coating. He had found that providing the surface of the specimen was reasonably bright, the cracks in the lacquer were clearly visible and no undercoating was required.

With regard to the spontaneous crazing of the coating during the cooling process, no doubt a considerable amount would affect the final sensitivity, but providing the crazing was limited no change in the initial strain response of the coating could be detected. Nevertheless, the presence of craze lines was very undesirable since they prevented the formation of well-defined crack patterns; the cracks ending at the junction with a craze line.

With reference to the batching of materials he had not noticed any variation to date.

He was glad that Mr. Young had stated that providing both the specimen and the calibration bars went through the same cycle of heat treatment, whether in a heat controlled room or not, accurate results could be obtained since this was the view he had always held. One did not always obtain that impression from some of the American literature.

In reply to Mr. Bunyan, the author agreed that in many instances the brittle lacquer process was the only suitable method, especially when strains had to be measured in very inaccessible places. He was sorry that his comment on page 44 had been misinterpreted. What he had intended to imply was that the maximum accuracy of ± 15 per cent was quoted on the assumption that temperature control was available, but if this was not the case then this degree of accuracy would not be obtained and the percentage fluctuation of the recorded values about the true value would increase.

In reply to Mr. Bunyan's query on the application of the accuracy of ± 15 per cent to low strains, he had found that even at strains as low as 0·0003 this accuracy could be obtained providing great care was taken during the heating and cooling processes.

With regard to the use of the stroboscopic technique when investigating the strains set up in a rotating member, he had not any personal experience but was of the impression that it had been quite successful.

In reply to Mr. Kennedy, he agreed that more engineers ought to use the brittle lacquer process and one of the functions of this paper was to draw further attention to this very useful tool of the stress analyst.

With regard to the behaviour of the lacquer under a system of complex strain, he had found that it had behaved in a satisfactory manner, the comparisons between the strain values as recorded by the brittle lacquer and the actual strains in the member, being obtained by means of electrical resistance strain gauges. Moreover, a recent paper* had shown that providing the ratio of the principal compression strain to the principal tensile strain did not exceed $-3/1$ then the law of failure due to maximum tensile strain did apply.

In many complicated machine components it was quite possible that the strain at areas of high stress concentration would be several times that of the mean or average strain in the component. Therefore if one was content to use a coating with an initial strain response of 0·0007, it would mean that when this coating began to record the strain in those areas of the member, which at working loads were subjected to relatively low strain, e.g., say, a strain of magnitude 0·0003, then the material in the region of the stress concentrations would be in the plastic stage and a re-distribution of strain would be taking place. It was to avoid this occurrence that attempts had been made to increase the sensitivity of the lacquer to strain. However, the present initial strain response of 0·0003 of the heat treated lacquer was quite satisfactory and the author agreed with Mr. Kennedy that no great advantage would be achieved by obtaining any further increase in the degree of sensitivity.

He had used a number of the woven grid type of heating elements and by using these it was possible to ensure that the heat treatment was equally distributed over the whole of quite large specimens.

He agreed with Mr. Kennedy that humidity had little effect on the behaviour of the coating.

He was glad that Mr. Kennedy had emphasized that this was essentially a strain measuring instrument and he wished to endorse those remarks.

In reply to Mr. Evans, he imagined that little would be gained by using a lead specimen. There would be early creep in the lead, and this would lead to a re-distribution of the stress systems. He thought that more benefit would be obtained by coating the actual specimen with a brittle lacquer and observing the crack formations.

In reply to Mr. Hildrew, he again agreed that the heat treatment was a disadvantage but that he was hoping that future research would lead to an improvement in this respect.

He had been testing model girders and panels for several years and it had been his experience that quite reliable results could be obtained from such work. However, it was essential to ensure that all the dimensions of the model were in correct proportion to the actual specimen. However, the effects of

* Durelli, A. J. and de Wolf, T. Experimental Stress Analysis, Vol. 62, "Law of Elastic Failure".

welding, riveting, etc., would be greater in the model than in an actual member.

He thought that Mr. Hildrew's suggestion of using a strain gauge to tell what was happening in the brittle lacquer, whilst useful, would be the wrong approach. It would be better to coat the specimen, note where the greatest strains occurred, and then use the strain gauges to determine the strains at these chosen positions.

The lacquers could not measure compressive strains until the specimen was plastically strained, then it was apparent that a high compression strain would cause the lacquer to flake off from the surface. The same thing would occur at lower strains if the lacquer coating was too thick, but providing the coating was approximately 0·005 inch thick this would not occur until the specimen had been strained well into the plastic range. This flaking would only be a rough guide and could not lead to any quantitative measurement. However, it was possible to obtain details of the compression strains in a specimen by coating the specimen and then very very slowly loading the specimen up to a desired load, maintaining the specimen at that load for some considerable time, say half-a-hour, and then quickly reducing the load. During the gradual loading operation the lacquer crept with the specimen and consequently few or no cracks occurred in the coating but on release of the load a series of crack formations would be formed which would be orthogonal to those obtained during a normal loading test. He had successfully used this process during an investigation into the stress distribution in thin rectangular panels subjected to end compression.

With regard to Mr. Hildrew's claim that relaxation methods were superior to experimental methods, there was considerable evidence that in many problems, especially those associated with the behaviour of thin plate structures, the theoretical results do not match with experimental evidence, but surely the best method was to use both processes, if time permitted.

In reply to Commander Green, he again stated that due to the fact that the number of cracks per inch developed at a given strain varied with the thickness of the coating, little reliance could be placed upon results obtained from matching the intensity of crack formations. However, the method of matching the intensity of the cracks was useful when no other method could be used. One could, however, obtain the relative values of the stresses in a member by observing the position and growth of the isoenstatics.

He was very interested in the results obtained by Dr. Lamble while using plumbers' resin, since he himself had achieved little success with that method. It was quite possible, however, that he had not used the correct heat treatment. With reference to Dr. Lamble's question regarding the shape of the specimen altering the value of the initial strain response, he thought that with Stresscoat no such phenomena had been observed. During his own investigations on stiffened and unstiffened rectangular panels and the normal calibration and tensile specimens, he had not noticed any similar phenomena with his heat treated lacquer. He had found that the Stresscoat dye was not very effective on the heat treated lacquer.

In reply to Mr. Morton, he had not had any experience of using his lacquers under water, but Greer Ellis had stated that Stresscoat would operate quite efficiently after it had been immersed in water for an hour. It was essential, however, to ensure that the specimen was of approximately the same temperature as the water.

Brittle lacquers were not suitable for determining the strains which had been gradually developed in a specimen over a period of weeks since the lacquer would creep with the specimen. However, one advantage that the brittle lacquers possessed was that the cracks once developed would remain open for months afterwards, thus the crack patterns could be examined at leisure any time after the tests. It was generally agreed that the best thickness of coating was 0·005 inch.

The heat treated lacquer indicated high compression strains, since these would cause the coating to flake, but this did not occur until the material was in the plastic state and, moreover, no quantitative results could be obtained from this action.

The brittle coatings enabled the principal stresses to be obtained, when the compression crack formations could be determined by the process of relaxing a tensile strain. Unfortunately this was not always a practical proposition and then, as Mr. Morton had rightly suggested, the investigator must resort to another form of extensometer, such as electrical resistance strain gauges.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Institute on Tuesday, 9th January 1951

An ordinary meeting was held at the Institute on Tuesday, 9th January 1951, at 5.30 p.m. Mr. J. Turnbull (Vice-Chairman of Council) was in the Chair. A paper entitled "Stress Analysis Using the Brittle Lacquer Process" by K. C. Rockey, M.Sc.(Eng.), A.M.I.Mech.E. (Associate), was read and discussed. Thirty-one members and visitors were present and six speakers took part in the discussion.

Mr. I. S. B. Wilson (Member) proposed the vote of thanks to the author which was accorded with acclamation.

The meeting terminated at 7.15 p.m.

Barrow Meeting

A meeting under the auspices of the Institute was held at the Technical College, Barrow-in-Furness, on Friday, 2nd February, under the Chairmanship of Mr. F. P. Laurens, O.B.E., when Mr. Denis O'Neill delivered his paper on "Safety at Sea 1850-1950", which was originally presented to a meeting of the Institute on the 12th December 1950.

The meeting was well attended, and at the conclusion of the reading of the paper a vigorous discussion took place in which Mr. Kelly, Captain Roberts, Commander Hughes, Mr. Melville, Mr. Wharton, Mr. Frayn and the Chairman, participated. The lecturer fully dealt with all points brought forward at the conclusion of each speaker's remarks.

The lecturer was thanked by acclamation on the conclusion of proceedings on a resolution moved by Com'r(E) J. J. Hughes, R.N. (Member), seconded by Mr. L. R. Horne. Mr. Sandham, the Principal of the College, was thanked by the Chairman for the loan of the lecture hall.

Local Section

Swansea

A film lecture, in technicolor, entitled "Hard Metal" was given at the Y.M.C.A. Building, Swansea, on Wednesday, 24th January 1951.

Mr. Cloudsdale (Member) took the Chair and having made a few introductory remarks concerning the subject of cemented tungsten carbide, handed over to Mr. Bolsover and Mr. Porter, technical representatives of the manufacturers. For the next hour an audience of sixty-seven were entertained to a most interesting and instructive film and commentary dealing with the manufacture, physical characteristics and uses of cemented tungsten carbide.

At the conclusion of the film, Mr. Bolsover and Mr. Porter dealt with the many questions and also placed on view an array of samples of the raw materials and finished products. The audience warmly responded to the vote of thanks proposed to the lecturers and the meeting terminated at 9.20 p.m.

Junior Section

Lecture at Falmouth

On Friday, 19th January, Mr. R. S. Hogg (Member) gave a lecture on "Launching of Ships" to over seventy members of the Institute of Marine Engineers and students of the Technical Institute, Falmouth. The lecturer, who has had a wide experience of ship construction in H.M. Dockyards at Chatham and Portsmouth, dealt with the construction of slipways, the details of preparation for a launching and the construction of the necessary timber structures involved.

Mr. Hogg's easy style, coupled with the numerous pictures on the screen and a fund of examples gathered during his long practical experience, fixed the launching details in the minds of his audience. The concluding part of the lecture dealt in some detail with the practice, now fairly common in America, of broadside launching.

After a number of questions had been dealt with, Mr. P. Ewing (Member), of the British Tanker Co., moved a vote of thanks in sparkling style and this was ably seconded by Mr. C. Moffatt (Member) of Lloyd's Register.

The Falmouth Vice-President, Mr. D. Dunn, general manager of Silley Cox and Co., Ltd., was present, with over a dozen senior members of the Institute and it was gratifying to see a number of the local shipwrights in the audience. The chair was taken by the Principal of the Technical Institute, Mr. C. J. Tirrell (Member).

Lecture at Liverpool

Seventy-one members, students and visitors attended the lecture by Lt.Com'r(E) A. P. Monk, D.S.C., R.N.(ret.) (Member), on "The Construction of Marine Boilers" given at the College of Technology, Liverpool, on Tuesday, 13th February 1951. Mr. L. Baker (Member of Council) was in the Chair and introduced the lecturer.

The lecture covered the construction of modern water-tube boilers in considerable detail and was greatly appreciated by the audience. Twenty-two persons present took part in the discussion which lasted longer than the lecture itself. Mr. Serjeant of the College of Technology proposed the vote of thanks to Commander Monk and this received hearty support from those present.

Lecture at Belfast

On Thursday, 15th February 1951, in the Central Hall of the Municipal College of Technology, Belfast, Lt.Com'r(E) A. P. Monk, D.S.C., R.N.(ret.) (Member), repeated his lecture entitled: "The Construction of Marine Boilers". The Chairman of the meeting was Mr. D. H. Alexander, M.Sc. (Member), Principal of the College.

The meeting was well attended. In addition to engineering students of the College and junior engineers from the various industrial establishments of the city, there was a leavening of Members and Associate Members of the Institute and representatives of local technical institutions.

At the close of the lecture many points were raised by members of the audience, and the discussion continued considerably beyond the normal time. Mr. W. E. McConnell, a former Vice-President, proposed the vote of thanks in a very appropriate speech.

The Institute was represented by the Vice-President for the Belfast area, Mr. C. C. Pounder, who, before the meeting began, outlined the scope of the Institute's activities, and referred especially to its interest in all young men who are engaged in marine engineering and allied occupations.

MEMBERSHIP ELECTIONS

Elected 5th March 1951

MEMBERS
Carl Raymond Brandt, Com'r, U.S.N.
Hugh Cassidy
Stanley Charles Dibley
Robert Dixon, M.B.E.
Arthur Vernon Franklin
Cecil George Hutton
William Johnston, Lt.-Com'r(E), R.N.R.
Francis Philip Laurens
Noel Levy
Cecil Rhodes Scott Lewis, B.E.M.
Gustave Henri Lor
Alan William Munns, D.S.C., Lieut.(E), R.N.
John Henry Pelham
Cecil Tudor Phillips, Capt.(E), O.B.E., R.D., R.N.R.
Robert Charles Pringle
William James Robertson
William Reid Greig Smith
Braham Swaroop Sood
Raymond Stockdale
Edgar John Taylor
Alwyn George Thomas
Edward Collier Thomson
George Wood

ASSOCIATE MEMBER
Douglas Walter Jaques, B.Sc.

ASSOCIATES
Minoo Dhunuishaw Aibara
Thomas Richard Armstrong
Colin Layton Bailey, B.Sc.
Alan Batey
John Collingwood Burton
Patrick Doherty
Secondo Follo
Alan Leslie Geary
Thomas John Bertram Griffiths
William Heppell
Archibald MacIntyre Hodgson
George Muir
Robert Henry Murray
Ronald Harold Jesse Peacock
George Ratchford
Leslie Robertson
Norman William Robinson
Mahadeo Bhikaji Sawant
Derek Sharp
Francis Colin Smith
William Marshall Suttie
Charles Tye
Robert William Wallace
Robert Baden White

TRANSFER FROM ASSOCIATE TO MEMBER
Frederick William John Crook, Lieut.(E), R.N.
Desmond Albert Richard Crowley

TRANSFER FROM STUDENT TO ASSOCIATE
Robert Leslie Bailey

GRADUATES
Mohmed Hassan Said Ahmed
Thomas Steele Allan, Lieut.(E), R.C.N.
Alvin Dexter Barnett, B.Eng.
Om Prakash Sindhwani, Lieut.(E), I.N.

STUDENT
David William Robins

PROBATIONER STUDENT
David Theobald

OBITUARY

DONALD BLAIR (Member 3070) was born in 1868 and served his apprenticeship with Muir and Caldwell and Co., steering gear engineers, Glasgow. He saw sea service with the Cunard Steamship Co. before joining the service of G. and I. Burns, Ltd., in 1888. He was also Chief Engineer of the first Lord Inverclyde's yacht *Capercailzie* for a time. In 1912 he was appointed Superintendent Engineer of G. and I. Burns, Ltd., and in 1922 when that company was amalgamated with Laird Lines, he was appointed Superintendent Engineer of the merged company, which appointment he held until his retirement in 1933.

Mr. Blair was elected a Member in 1916. He died in November 1950 at the age of eighty-two years.

LIEUTENANT(E) EDWIN CHARLES BUCKNALL, R.N. (Member 12616), was born in 1900 and educated at Manchester Grammar School. He served his apprenticeship from 1915 to 1919 on board H.M.S. *Indus*. He continued in the service of the Royal Navy being promoted successively to Warrant Engineer (1928), Commissioned Engineer Officer (1938) and Lieutenant(E) in 1943. Amongst ships in which he served were H.M.S. *Revenge, Courageous* and *Hood*. In 1946 he was appointed Engineer Officer in charge of machinery in H.M.S. *Tumult, Termagent* and *Loch Tarbert*, Reserve Fleet, Portsmouth.

He was elected a Member in 1949. He died on the 14th January 1951.

ROBERT STANLEY CAMPBELL (Member 3277) was born in 1884 and served his apprenticeship with Clarke, Chapman and Co., Ltd., Gateshead-on-Tyne, and was at sea from 1906 to 1910 with Ropner and Co., Ltd., West Hartlepool, obtaining his Extra First Class Board of Trade Certificate.

Mr. Campbell started in the drawing offices of the Parsons Marine Steam Turbine Co., Ltd., Turbinia Works, Wallsend, in 1910. Subsequently he was employed as works engineer assisting the works manager. He left the Parsons Marine Steam Tubine Co., Ltd., in 1922, having been selected by the late Sir Charles Parsons to assist him in the management of the Derby Crown Glass Co. which he had taken over in July 1921, and which became the Parsons Optical Glass Co.

After Sir Charles Parsons died in 1931 the works of the

Parsons Optical Glass Co. were sold and for a time Mr. Campbell was employed in the Heaton Works of C. A. Parsons and Co., Ltd., Newcastle-on-Tyne, subsequently returning to the Turbinia Works of the Parsons Marine Steam Turbine Co. in December 1933 as deputy works manager, and on 1st January 1938 he was appointed works manager, continuing in that position until his death which occurred on 1st January 1951. He was elected a Member in 1917.

ENGINEER REAR-ADMIRAL FREDERICK GEORGE HADDY, M.V.O. (Member 9877), was born in 1875. He was educated privately and at the Royal Naval Engineering College, Keyham. From 1905 to 1911 he served as an engineer lieutenant in the Royal yacht *Victoria and Albert,* and was appointed M.V.O. on the occasion of the visit of King George V and Queen Mary to Dublin after the Coronation. During the 1914-18 war he was engineer officer of the light cruiser *Sappho*; from August 1915 of the armoured cruiser *Sutlej*; and from July 1918 of the depot ship *Sandhurst* and the destroyers attached to her. From April 1919 to May 1921 he was engineer officer of the battleship *Queen Elizabeth,* the Fleet Flagship.

After a period on the staff of the Inspecting Captain of Mechanical Training Establishments he was, in 1928, appointed Engineer Overseer for the Admiralty in the London District. Two years later he retired with the rank of engineer rear-admiral.

In 1931 he became a Director of Peter Brotherhood's, Peterborough. He was elected a Member in 1944.

He died on the 31st December 1950 at the age of seventy-five years.

ROBERT HUNTER (Member 2642) was born in 1876. He served his apprenticeship with A. Douglas, Stranraer, and D. and W. Henderson and Co., Glasgow, from 1892 to 1898, then joining the Indo-China Steam Navigation Co., Ltd., serving at sea with that company until 1905. In that year he went ashore at Hongkong as surveyor with Mr. D. Macdonald, later becoming a partner in the firm Macdonald and Hunter, who were surveyors to the British Corporation, Bureau Veritas, the Registro Italiano, the Imperial Japanese Marine Corporation and the Germanischer Lloyd (Machinery). Mr. Macdonald retired after the 1914-18 war but Mr. Hunter remained in Hongkong until his retirement in 1930. He was elected a Member in 1912 and was also an Associate Member of the Institution of Naval Architects.

He died on 31st December 1950.

THOMAS KENNEDY (Member 9597) was born in 1893. He served his apprenticeship with J. P. Rennoldson and Sons, South Shields, who were famed for their production of engines for paddle tugs, etc. He went to sea in 1914 with Ropner and Co., Ltd., transferring to the Eagle Oil Transport Co. in 1915. He served on various ships of the company until torpedoed in the *San Zeferino* in 1917. As a result of this, Mr. Kennedy had to apply for extended leave on medical grounds from the company, and during his time ashore he became shipyard engineer for Eltringham and Co., Willington Quay. In 1919 he joined the staff of Renwick and Dagleas, Hebburn, and laid down the equipment in their new shipyard until the yard was ready for ship building. Unfortunately the slump came and this yard did not even build one ship. Subsequently he superintended the dismantling of all machinery which he had installed and the yard was sold off. He re-joined the Eagle Oil and Shipping Co. in 1921 as third engineer. He continued his service with the company in their various ships until December 1926 when he was promoted to Chief Engineer of the *San Gerardo.* Except for a few months in 1932 as Engineer in the Refinery at Aruba, Mr. Kennedy continued as Chief Engineer in the Eagle Oil Fleet until 1938, when he was appointed to supervise the building of new tonnage on the North East Coast. Following his appointment he was promoted to Assistant Superintendent Engineer, which position he held until the date of his death, 17th November 1950.

He was elected a Member in 1943.

RICHARD HALFORD SMITH (Member 7435) was born in 1882 and was educated at Allan Glen's High School and Royal Technical College, Glasgow. He served his apprenticeship with the Fairfield Shipbuilding and Engineering Co., Govan. He first went to sea in 1904, serving with the Worrock Line and then the Donaldson Line. At the end of 1913 he joined Elders and Fyffes, Ltd., attaining the rank of Chief Engineer in 1914. He sailed throughout the 1914-18 war, being torpedoed and spending four days in a lifeboat in 1918. He remained at sea and in 1933 was appointed Chief Engineer of the s.s. *Mopan* in which vessel he was serving when it was torpedoed on 9th September 1939. It was due to his efforts in maintaining a speed of 16 knots in a vessel of a nominal speed of 13½ knots that Mr. Smith was officially commended in the *London Gazette.* On 5th November 1939, however, the s.s. *Mopan* was sunk by the pocket battleship *Admiral von Sheer* and Mr. Smith was taken prisoner with all the other members of the crew. He remained a prisoner of war until 1945 and it was the privations and hardships he endured which were primarily responsible for his death.

He was elected a Member in 1933. He was connected with experimental work in regard to mechanical stokers and was the inventor of "Dix" firebars for which he took out a patent.

He died on 23rd December 1950.

WILLIAM ARTHUR TREVOR TAYLOR (Member 9360) was born in 1884. He studied at Edinburgh University and served his apprenticeship from 1902 to 1905 with W. H. Allen, Sons and Co., Ltd., Bedford. In 1912 he set up on his own account as a Consulting Engineer at Westminster. During the 1914-18 war he was a Technical Officer in the Ministry of Munitions of War, transferring to the Control Secretariat, Advisory Committee on Steel Sheet Industry. In 1919 he was Chief Technical Officer for design, etc., of four Government instructional factories in Wales, being awarded the M.B.E. for his services during the war. Since 1921 he had been associated with a number of well-known marine engineering firms, as well as being in business as mechanical and marine engineer. He was also chairman of the Simplex Rudder and Turbulo Auxiliaries, Ltd.

Mr. Taylor was elected a Member in 1942. He was also a Member of the Institution of Mechanical Engineers.

He died on the 5th January 1951.

OSWALD WANS (Member 5585) was born in 1879, and received his early education at Banff Academy. Subsequently, he attended Dulwich College for five years, leaving in 1897 to start his apprenticeship with Bryan Donkin and Company. He spent three years with them before going into the drawing office of the Sturtevant Engineering Company, where he remained for a year. His next post was with the Simms Manufacturing Company, of Kilburn, whom he left two years later, to go to India as a draughtsman with Burns and Company, Howrah, Calcutta. Eventually he became chief assistant in their mechanical engineering department, being employed mainly on the design and erection of steam engines, hydraulic presses, and other jute-milling plant. He returned to London at the end of 1905 and, soon afterwards, was engaged as leading draughtsman in the oil-engine department of J. I. Thornycroft and Company, where he was concerned principally with experimental work on oil engines for industrial purposes and for the propulsion of submarines.

Mr. Wans remained with Thornycroft and Company until the end of 1909, leaving to become head of the oil-engine department of Ruston, Proctor and Company, at Lincoln. Almost at once he concentrated on the development of cold-starting engines with airless injection—in direct descent from the design covered by the original Akroyd Stuart patents—and the adoption of higher compression; it may be noted that the term "cold-starting" was coined by him to emphasize this notable characteristic of the type that he evolved. A keen advocate of systematic research, he established a permanent experimental department at Lincoln so long ago as 1912. There he carried out exhaustive tests with an engine of 9½ in. bore and 16 in. stroke, using a compression pressure of about 420lb. per square inch and designed to permit of either side or end injection of the fuel. The power developed was 25 h.p. and the fuel consumption was 0.48lb. per brake horse-power per hour.

The innovations in oil-engine design for which Mr. Wans was responsible were numerous, and many of them have become standard practice. In 1918, he developed a duplex oil pump and an atomiser for dealing with tar oils. In the following year he brought out his first vertical oil engine, a unit of 400 brake horse-power, running at 250 r.p.m., which led to considerable developments in electric power generation; it was in 1922 that he first installed (at Maidenhead) a vertical high-compression airless-injection engine for this purpose. His next advance was the production of vertical oil engines for the propulsion of fishing craft, in which they were adopted extensively; and he had visions of their use, in multiple installations, in vessels of larger size, though he did not succeed in reaching his goal of 9,000 brake horse-power through a single propeller shaft. He did, however, fit four 250-h.p. engines, running at 300 r.p.m., in the motor-ship *Dunster Grange* in 1926. In the following year, he turned his attention to pressure charging, the first Ruston engine of this type being set to work in 1928 in his firm's works power station. Chain drive for camshafts, and oil-operated reverse gear, were also introduced by him at about this time. Some three or four years later, he pioneered in a new field, developing oil-engined locomotives for shunting and for mine haulage—now an important branch of the activities of Messrs. Ruston and Hornsby (as the company had by then become). Finally, he caused a gas-turbine research unit to be set up at Lincoln, and was closely engaged on the study of this new prime mover, especially in the industrial aspects, down to his retirement at the end of September 1949.

Mr. Wans was a member of the Institution of Mechanical Engineers, which he had joined as a graduate in 1898; of the Institution of Civil Engineers, of which he became an associate member in 1907 and a member in 1924; and of the Institute of Marine Engineers, to which he was elected in 1926. He was also a member of the Diesel Engine Users' Association, and a past President of the Lincoln Engineering Society. His first executive appointment in the firm of Ruston and Hornsby was that of technical manager, in 1918, from which he was promoted to be chief engineer in 1930 and technical director in 1937. He was the author of a number of important papers, read before the Institution of Mechanical Engineers, the Diesel Engine Users' Association, and other technical societies; and, in 1931, he delivered the third Akroyd Stuart Lecture at Nottingham University, on "The Development of Heavy Oil Engines". His keen interest in research was maintained to the end of his life, and probably his last office, before his retirement, was that of chairman of the British Internal Combustion Engine Research Association, which he held for its first three years, from 1945 to 1948.

He died on 2nd February 1951.