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NON-DESTRUCTIVE METHODS OF TESTING WELDS

MÉTHODES DE CONTRÔLE DES SOUDURES

PHYSIKALISCHE METHODEN ZUR PRÜFUNG VON SCHWEISSNÄHTEN

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I. Introduction.

Fusion welded joints in steel framed buildings and structures are now commonly used in many countries, but in Great Britain progress in this development of structural engineering has been slow, due in some measure to a lack of confidence in the reliability of welded joints as compared with rivetted joints. The strength of a correctly designed joint is dependent on the mechanical properties of the materials forming the joint, and in the case of rivetted steel structures, long experience has shown engineers that the materials in use are sufficiently uniform for the results of tests on small sample specimens to be regarded as reliable indications of the strength and properties of the materials in the finished joints. In making a fusion welded joint, the procedure is more complicated than for a rivetted joint, since local fusion and subsequent solidification of metal are involved in a process which is largely dependent for success on the skill and integrity of the individual workmen concerned. Accordingly, a satisfactory test result on a separate piece of welded work cannot always be regarded as a reliable indication that apparently similar welds in the actual structure are equally satisfactory, and in these circumstances the development and application of some form of test whereby an estimate of the quality of a weld can be obtained without any damage of the weld itself offers many attractions. If such a test could be found there is little doubt that the development of welding and its application to structures would be greatly accelerated. Many attempts have been made to develop tests of this character and it is the purpose of the present paper to summarize some of the work which has been carried out in this direction; such a summary may conveniently act as a basis of discussion, at the Congress, on an aspect of structural engineering which is of importance in view of the present and future use of welding in structures; the opinions expressed represent, of course, only the personal views of the writer.

In discussing non destructive tests it should be understood that the usual criterion in assessing the value of a weld is the ultimate tensile strength obtained in a test to destruction, combined with some measure of the ductility of the weld metal, obtained either from the elongation in the tensile test or in a separate test in which the behaviour of the weld is observed under some form of plastic bending or notched bar impact test. In a defective weld the combination of several factors may assist in lowering the tensile strength and ductility below values which can be considered satisfactory. The inherent properties of the weld metal itself such as intrinsic cohesion, grain size, etc., are of primary importance, but definite flaws or holes in the weld metal also have a very marked effect on the tensile strength. The more important of these defects appear to be lack of fusion between parent metal and weld metal, lack of penetration, and the presence of inclusions and blowholes, and the object of most non destructive tests is the detection of flaws of this nature. It is usual to assess the value of the tests by comparison with tensile test results on samples in which such flaws exist, although the comparison is not entirely satisfactory since a weld may possibly break in tension at a low stress because of intrinsically low cohesion of the weld metal without flaws of appreciable size being present. In the present stage of development, however, it appears that the detection of flaws, lack of adequate fusion etc., is the most important application of non destructive tests.

In applying a non destructive test to the examination of welded joints in steel buildings and structures it is essential that it should be satisfactory for fillet welds as well as for butt welds.

II. Consideration and Discussion of Existing Non Destructive Tests.

1. Magnetic Tests.

The essential features of a magnetic test of a weld are the production of a magnetic flux through the joint, and then the detection of regions of abnormally high reluctance (magnetic resistance). Two methods have been used in the detection of regions of high reluctance,

a) measurements of the magnetic potential drop, and

b) graphical methods similar to the use of iron filings in elementary magnetism experiments.

a) Methods in which measurements of the magnetic potential drop are made. The measurement of the magnetic potential drop across a weld as a measure of its quality appears to have been first developed by Spooner and Kinnard in 1922 (3) *), and their results, some of which are reproduced in Figs. 1 and 2, showed that the method possessed distinct possibilities. Somewhat similar tests were made at the National Physical Laboratory in 1925 (28), and quite recently further work has been carried out at the Brunswick Technische Hochschule (28). In making a magnetic test on a butt weld, the joint is placed across the poles of an electromagnet and the magnetic potential drop across the weld is observed in some convenient manner when the magnetising current is interrupted or reversed. The apparatus usually required for the magnetic observations is rather complicated for works or field use, and a useful advance in the technique of the method was made by Watts (27) in the production of a direct reading instrument which gives values proportional to the magnetic potential across the feet of the instrument when in position across a weld. An outline diagram of the arrangement used by Watts is given in Fig. 3, and some of his results are indicated in Fig. 4. In actual tests it has been found that faults in welds almost invariably increase the reluctance and hence the quality of a weld can be assessed from the ratio of the weld reading to similar readings on an unwelded plate.

In considering the possible development of a test of this type for structural work the following remarks are submitted. The magnetic reluctance of

*) Bibliography of publications at the end of this paper.

a welded joint depends primarily on two factors, the dimensions of the continuous metal and the intrinsic properties of that metal. Accordingly, blow holes, inclusions, and similar defects will increase the reluctance of a weld by reducing the available metal through which the magnetic flux is passing; variations in the size of a weld will also affect the reluctance. While the inherent properties of weld metal appear to be such that the reluctance is always greater than that of normal mild steel, it should be understood that comparatively little definite information is available as to the relationships between magnetic and mechanical properties of steels, although it is known

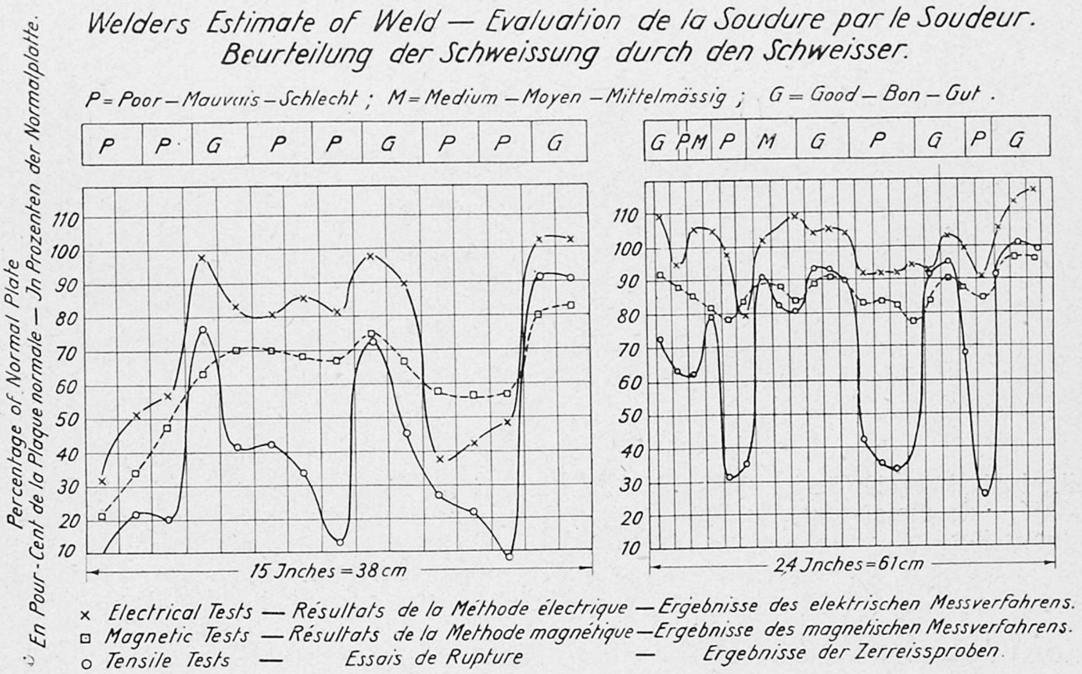

Fig. 1. Fig. 2.

Results of Magnetic Test obtained by SPOONER and KINNARD.
Résultats de la méthode magnétique de SPOONER et KINNARD.
Ergebnisse der magnetischen Prüfung nach SPOONER und KINNARD.

that comparatively small differences in composition and treatment and also internal stresses, may exert a marked effect on the magnetic properties. Deposited weld metal can be assumed to be more variable and more liable to internal stresses than a normal forged steel, and in the absence of definite knowledge of the magnetic properties of deposited weld metals the suggestion can be made that an investigation of such properties would be of use in the development of magnetic tests of welds. As stated by Watts, any particular magnetic test of welds can only be relative, and it is essential for any instrument readings to be compared with similar readings on a weld which is known to be good. Obviously, the maintenance of standard conditions for the examination of joints is a serious limitation of the method in regard to its application to structural work. Further, in attempting to apply the method to structures it must be remembered that the majority of the welds in such work are likely to be fillet welds, the examination of which is much more difficult than that of butt welds. In a butt joint the weld is in series in the magnetic circuit, but in the case of a fillet weld the plates are in contact at other places in addition to the weld, and it may be difficult to arrrange a suitable magnetic circuit of which the weld under examination is an essential part. Comparatively little work has been attempted in this direction, however, and although the outlook for eventual success is not promising, the advantages which might accrue are sufficient for the method to receive further critical experimental examination.

b) Magnetographic examination of welds. Magnetographic examination of welds was first developed by M. Roux (7, 15) and has since been used by Watts. The method is based on the well known principle that mobile iron filings in a magnetic field show the directions of the lines of force and mass themselves in positions of high reluctance. Thus in the appli-

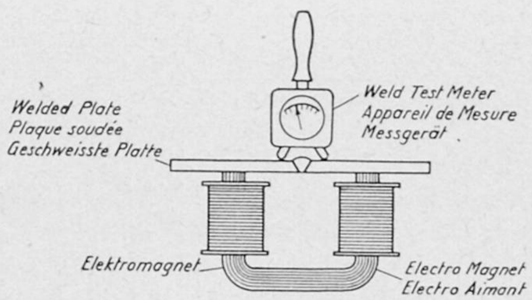

Fig. 3.
Method of Magnetic Test used by WATTS.
Méthode magnétique de WATTS.
Magnetisches Prüfverfahren nach WATTS.

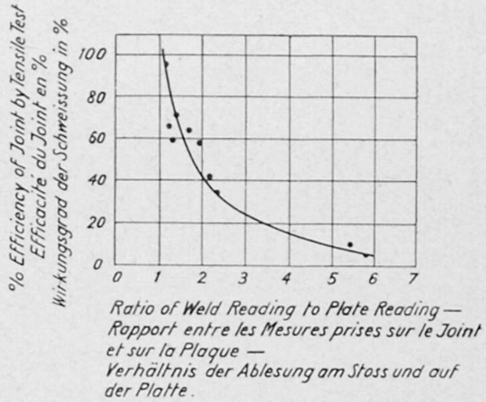

Fig. 4.
Comparison of Results of Tensile Tests and and Magnetic Tests obtained by WATTS.
Comparaison des résultats des essais de traction à ceux obtenus par essais magnétiques suivant la méthode de WATTS.

cation of Roux's method to the examination of a butt weld the plate is placed horizontally across the poles of an electro magnet with the weld between the poles, and a sheet of paper on the upper side of the plate is sprinkled with iron filings. Cracks, blow holes, poor fusion, etc., in the weld are indicated by massing of the filings over the faults; the filings are then fixed in position on the paper by spraying with a gum solution. Watts (27) has used fine iron powder instead of filings, and blue print or brown print paper; permanent records can then be obtained by holding a small portable arc lamp over the magnetograph and obtaining a shadow print of the iron powder on the sensitized paper. A horizontal position for the paper is preferable but not essential. No indication of the value of the method on fillet welds appears to have been recorded. In general, the method can hardly pretend to be very exact, and from its nature it seems somewhat unlikely that it can be developed as a general field test for welds in structures.

2. Electrical Tests.

a) The Sperry Test. Two or three years ago E. A. Sperry (11) stated that the electrical method he devised for the detection of flaws in rails has been adapted to the non-destructive testing of welds. Unfortunately, the statement was not supported by actual figures in regard to tests on welds, and accordingly it is not possible to discuss his results in detail.

The essentials of the Sperry method used in detecting flaws in rail heads and now applied to welds appear to be as follows. The whole apparatus is mounted on a railway car travelling along the rail track and a heavy direct current is made to traverse a length of the rail by means of contact brushes.

The current in the rail produces a magnetic field at right angles to the length of the rail with no longitudinal component. If, however, the current is deflected by a flaw in the rail a longitudinal component of the magnetic field is set up and links with a search coil carried by the moving car; the small E. M. F. induced in the coil is amplified and recorded graphically. The position of the flaw is known from the position of the car relative to the rail.

In regard to examination of welds in structures Sperry makes the following statement. "The application of this method of inspection to welded structural steel buildings or welded steel ships involves a small plant which, in point of size, is of the order of a 5 kw. welding set. This unit combined with a very compact amplifying and recording equipment is easily handled by a crane and can thus follow the progress of the welding, making an accurate ink record of the soundness of the work as it goes along, indicating any spots where the weld is defective. Welds in different structural shapes have been brought under the electrical inspection. It is found that some require special shapes of the inspection element, which is a light affair of about a pound's weight."

It is difficult to see, however, how the Sperry test as outlined above can be successfully applied to a fillet weld. In the case of rails, the uniformity of cross section, and the type of defect usually encountered, namely, a transverse fissure of appreciable size in the head of the rail, readily lend themselves to a method which is dependent on a change in direction of current flow. In the case of fillet welds in steel structures, the shapes of the parts and the welds, and the types of defects to be expected, are very different from those in rail heads, and successful use of the method on rails is not necessarily an indication that it will also be successful in structural welds. The claims put forward for the method therefore appear to require independent confirmation.

b) Resistance Tests. Spooner and Kinnard (3) have also made direct measurements of electrical potential drop across butt welds in an investigation of the possibilities of non destructive tests. The potential drop was compared with the corresponding drop over an equal portion of unwelded plate and the results of the tests, some of which are shown in Figs. 1 and 2 showed that there were distinct possibilities in the method as far as butt welds were concerned. These workers were of the opinion, however, that measurements of magnetic potential drop were more likely to be of use than the direct electrical method in a commercial non destructive test of butt welds. Sperry has also used direct measurements of electrical potential drop in detecting flaws in rails, but it is not clear from the published statements whether his method has been adapted for examination of welds.

The obvious difficulty in regard to the electrical potential drop method of test lies in the variable contact which is likely to occur when the current is led into a plate at rough surfaces. The method does not seem to have been investigated for fillet welds; the same difficulties arise as in magnetic tests, namely the provision of a suitable circuit of which the weld is an essential part, but in view of the greater flexibility of the electrical circuit compared with the magnetic circuit it is suggested that work on electrical resistance tests of fillet welds might be worthy of consideration.

3. Examination by X-Rays.

The value of radiographic examination of welds and welded joints is now well established; it is used by German Railways and by Swiss Railways, and has recently been suggested for Class I unfired pressure vessels in the 1930 Boiler code issued by the American Society of Mechanical Engineers. In the present instance the discussion of such tests will be largely confined to their possible practical use in the examination of welded structures, but it may be recalled that X-ray photographs are shadow-graphs produced by the differential absorptions of the rays in passing through the metal under examination. It may be noted that actual photographic film is not now essential, but that specially made sensitised paper can be used for the shadow-graphs. Positive defects are indicated in a shadow-graph, but no indication of the inherent properties of the weld metal is obtained.

In considering the possible use of radiographs as field tests for welds in structures the following points are relevant.

The thicknesses of the plates in the structures vary with different designs, but plates at least $\frac{1}{2}$ inch thick would be encountered in most cases, involving probably $^{3}/_{8}$ inch or $\frac{1}{2}$ inch fillet welds. For the examination of such welds in parallel plates the power of the X-ray beam must be sufficient for adequate penetration of 1 inch of steel. This would necessitate an electrical pressure from 150,000 to 200,000 volts, and an immediate practical difficulty would occur in the provision of this voltage at all parts of a building or structure during the course of erection; the cable required would be heavy and expensive, in addition to the cost of X-ray apparatus. It is of interest to consider the remarks of V. E. Pullin (21), Director of Radiological Research, Woolwich Arsenal, in connection with the use of X-rays in the examination of welds, since his views are based on a wide experience, not confined to the laboratory, but extending also to special portable X-ray equipment used in the examination of an airship, and operated at remote parts of the structure at heights of 60 and 80 feet from the ground. He states "X-rays may be used to examine welds in order to detect bad metallic union, blow holes etc., but their use in this capacity will necessarily be restricted to comparatively small specimens. It is at present out of the question to consider, for example, the use of X-rays in the examination of a long welded pipe line. On the other hand, the question of the X-ray examination of welds in specific instances is well worth consideration if the importance of the work justifies the special examination."

Another point in connection with X-ray examination of structural welds also arises. It has already been stated that the majority of welds in structures are likely to be fillet welds, and the writer is not familiar with any work in which it has been shown that the X-ray method can be successfully applied to the examination of a fillet weld in a direction parallel to the main plate. The difficulty is that the width (or length) of the plate lies in the same plane as the axis of the X-ray beam; examination along the junction of the weld metal and the plate in this plane is necessary in order to determine whether proper fusion has been obtained. In the case of a *T* joint made by means of fillet welds, adequate X-ray examination appears to be extremely difficult, and unlikely to be at all satisfactory. It appears that complete radiographic examination of all welds in structures is hardly likely to become general practice in the near future on account of the high cost of the process and the difficulties of application to fillet welds.

In addition to X-ray photographs it has been shown by Mehl, Doan and Barrett (17) that the gamma rays from radium emanation can be used to examine welds for internal defects. Such rays are somewhat similar to X-rays, but have a greater penetrating power, and the radium tube is much more portable than X-ray equipment. The questions of expense and adequate examination of fillet welds, however, also arise in regard to this method of examination.

In connection with X-ray examination of welds it may perhaps be mentioned that spectrometric or diffraction examination of welds by means of X-rays is essentially different from the radiographic method. Spectrometric examination of welds can give valuable indications of atomic structures, grain size, etc., and thus can be applied in non destructive tests of the inherent properties of the weld metal. This method of test is likely to prove of considerable value in future laboratory investigations of the properties of the metal, in welds, but since the actual mass of metal involved in each examination is small, the method is hardly suitable for development as a general field test of quality.

4. The Stethoscope Test.

It has been claimed by A. B. KINZEL (9) and others of the Union Carbide Research Laboratories, U. S. A., that a qualitative test of the strength of a weld can be obtained by means of stethoscope tests. The principle of the test is that adopted by a workman when he strikes a piece of metal with a hammer in order to determine whether it "rings true". In applying the method to a weld, however, it is refined by using an ordinary medical stethoscope with a rubber cap over the searching end, which should be of the cone shaped type. In making a test the operator presses the rubber-capped end of the cone against the metal which is to be tested, and the weld under examination is tapped with a hammer. J. R. DAWSON (23) states that when the weld is free from defects, the natural period note of the part or structure is heard, but when a portion of the weld containing a discontinuity is examined a high pitched reedy sound is noticeable in the early part of the sound caused by the hammer blow. He also suggests that the damping effect of a defect in a weld can be noticed in the subsequent sound waves. It is stated that the method is being used successfully for commercial testing of welded structural steel in buildings, and that it is easier to test a joint built into a large structure than a comparatively small test plate. It is also stated by Dawson that the method has discovered defects which reduced the strength of welds (as determined by subsequent tests) by only 5 to 10 per cent. It is further stated that frequency analyses of the sound waves have shown that the above interpretations of the sounds are correct, and that work is in progress towards the development of automatic apparatus which will record the sounds in such a way as to permit location of defects in the welds.

The writer has made one or two trials of the method on plates containing lap welds of known quality; the sounds obtained werevery complex and the results inconclusive, but the method is clearly one in which fair experience is necessary before positive results can be expected. The impression was obtained that definite analysis of the sound waves was hardly likely to add greatly to the efficacy of the method, but that it may be of value as a practical inspection test in the hands of an experienced observer. The simplicity of the test is attractive and should make it fairly easy for further practical experience to be obtained.

Conclusion.

From the foregoing discussion it can be stated that no practicable method of non destructive testing is immediately available, whereby it is possible to obtain a positive indication of the quality of the majority of the welds which may be present in a welded steel structure. Certain methods of non destructive testing are undoubtedly of value in particular cases, but the difficulties arising in the general application of such tests to welded structures are much greater than in most other uses of fusion welding. The difficulties, however, may not be insuperable and it is to be hoped that investigators will continue their work in the development of such tests. While a satisfactory non destructive test is not essential to the future development of welding in steel structures, it would undoubtedly increase very materially the rate at which such developments can be introduced.

Acknowledgment.

The writer desires to acknowledge the permission of the American Society for Testing Materials to reproduce Figs. 1 and 2. He is also indebted to Dr. H. J. Gough, Superintendent of the Engineering Dept. of the National Physical Laboratory, at whose suggestion the paper has been written, for helpful criticism and advice in the preparation of the paper.

Summary.

Welded seams may be tested physically by:

a) Generating and measuring magnetic or electric fields in the neighbourhood of the welds;

b) Examining the welds by X-rays;

c) Hammering to test the purity of sound of the welds.

These methods are investigated with respect to their applicability and the reliability of the results obtained. All the methods which have been introduced need further improvement, but the difficulties still existing are not insuperable.

Résumé.

L'examen physique des joints soudés peut s'effectuer:

a) par production et mesure de champs magnétiques ou électriques dans la zone des soudures;

b) par pénétration des soudures au moyen des rayons X;

c) par essai au son de la partie soudée.

L'auteur examine les procédés susindiqués au point-de-vue de leur possibilité d'emploi et de leur sûreté. Toutes ces méthodes ont besoin de perfectionnement; néanmoins, les difficultés qui subsistent encore ne sont pas insurmontables.

Zusammenfassung.

Die physikalische Prüfung von Schweißnähten kann erfolgen durch:

a) Erzeugung und Messung magnetischer oder elektrischer Felder im Bereiche der Schweißnähte;

b) Durchleuchtung der Schweißnähte mittels X-Strahlen;

c) Prüfung der Klangreinheit der Schweißverbindungen.

Die genannten Verfahren werden in Bezug auf ihre Anwendungsmöglichkeit und Zuverlässigkeit der Meßergebnisse hin untersucht. Alle angeführten Methoden bedürfen der weiteren Vervollkommnung, doch sind die noch bestehenden Schwierigkeiten nicht unüberwindlich.

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