BRITISH PRACTICE IN WELDING OF STEEL STRUCTURAL WORK

L'APPLICATION PRATIQUE DE LA SOUDURE AUX CONSTRUCTIONS MÉTALLIQUES EN ANGLETERRE

ANWENDUNG DER SCHWEISSUNG IM STAHLBAU IN ENGLAND

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Welding by means of the Oxy-Acetylene Blowpipe has not met with much support in Great Britain for the assembly and the reinforcement of steel bridges but has been most extensively applied to the purpose of cutting shapes in new work and the removal of defective steel members.

Electric Welded Construction on the other hand has developed into general practice during recent years and therefore this report deals exclusively with the application of electric arc welding to steel structures.

In reviewing the present position of electric arc welding as applied to the fabrication and erection of structural steelwork it is of interest to recall the early steps in the development of the process and its application.

1. Historical Progress.

The carbon arc process was introduced in 1885, the arc being maintained through the medium of a carbon pencil and metal added by means of a filler rod. In 1890 carbon was replaced by a soft iron wire, thus eliminating the necessity for the filler rod and what is commonly known as "bare-wire welding" was introduced. The process is substantially the same today except for improvements in the welding equipment and the analysis of the wire.

In 1907 the first light coated electrode was introduced by covering the wire with a thin coating of paste in order to stabilize the arc. A close study was made at that time of the metallurgical side of the problem and in 1911 the first heavy coated electrode was produced in Great Britain.

As confidence in the process grew the welding of steel structures became a practical proposition. British welding engineers, faced with conservatism and unfavourable regulations in their own country, were forced to go further afield to introduce their ideas. The results and progress of their initial pioneering have been particularly marked in Europe[1]) and Australia, and their work throughout has been based on the application of the heavy coated electrode. In America welding engineers have progressed on parallel lines and to a more advanced degree in the quantity of welded steelwork erected, but the bulk of their work has been carried out with bare wire welding. The differentiation is important in view of the marked variation in characteristics of design and methods of fabrication produced by the two processes in their respective spheres.

[1]) Belgium and Switzerland.

The British welding engineer in pinning his faith to the heavy coated electrode, maintains that the production of a metallurgically sound weld under practical conditions should not depend entirely on the skill of the operator but as far as possible on the natural function of the electrode during fusion. In other words he considers that a suitable covering should be provided on the electrode to form an active slag that will

a) clean the surface of the parent plates from oxide during welding,

b) protect the weld metal whilst molten from atmospheric gases and therefore prevent oxide and nitride defects from forming in the metal and

c) melt at a low temperature and thereby not be trapped in the weld metal as slag inclusions. Considering the extensive practical experience of American engineers in the erection of steel structures with bare wire welding, the marked tendency apparent in the U. S. A. during the last 18 months to employ heavy coated electrodes provides some justification that the claims of European engineers are sound in this connection.

2. Design.

It is certain that success in welded construction depends very largely on the initiative shewn by the designer and his ability to break away from existing practice developed essentially for riveting.

Bare wire welded structures of the open truss type, with their general use of the simple lapped joint and rolled steel sections, do not appear to differ very largely in form from riveted structures. On the other hand in Europe there is a more advanced tendency to design welded structures on a monolithic basis with a general use of butt welded joints, even in main members.

A further characteristic of considerable importance and individual to structures welded with heavy coated electrodes, is the general application of light single run fillet welds. This practice, although of comparatively recent introduction, has been successfully developed to an advanced degree both in Switzerland and Australia. The linear strength of a fillet weld is approximately proportional to the square root of the linear volume of weld metal deposited, so that the economic advantages of the light single run fillet weld are paramount. A further asset is that welding contractional stresses are reduced to a minimum, but what may perhaps be regarded as the most important advantage, is the fact that the soundness of a weld can be judged by expert visual inspection, provided that correctly constituted heavy coated electrodes are applied. Thus the problem of control and inspection is solved in a simple, economical, and efficient manner.

3. Building Regulations and Investigations.

One of the most important developments in welded structural steelwork in recent years is the movement on the part of public bodies to draft regulations for its control. Under the usual forms of building regulations, no methods may be used which are not definitely sanctioned with appropriate specifications and provisions for inspection. Therefore the essential first step is to get welding recognised, naturally with safeguards for its proper execution. Welding committees have been formed in many parts of the World and their research engineers are submitting welded construction to a more exacting scrutiny in many respects, than has ever been made of riveted construction in the past. It may be ventured that more is now known of the behaviour of welded joints than the behaviour of riveted joints. There have been cases of the failure of riveted joints which have passed the scrutiny of boiler insurance inspectors and hydraulic tests, traceable to the faulty manipulation of hydraulic riveters. Hence it is inaccurate to say that riveted joints can always be guaranteed after inspection by established methods.

In framing regulations one of the most important factors to be considered is the subject of "allowable stresses" or "Factor of Safety". Needless to say most public bodies are inclined to err on the side of safety by specifying low allowable stresses. Whilst this is quite justifiable within reason, it should be borne in mind that the specification of a too high Factor of Safety is quite sufficient in itself to prohibit or seriously limit the welding of structural steelwork on economic grounds.

The recent report of the Structural Steel Welding Committee of the American Bureau of Welding states that the average ultimate tensile strength they obtained on butt welds (bare wire) was 22.1 tons per sq. in. on which the proposed allowable working stress of 5.8 tons per sq. in. gives a factor of 3.81 which they assume to be satisfactory as it compares with their normal steelwork factor of $3\frac{1}{3}$.

The generally accepted purpose of a "Factor of Safety" is to keep the load stresses well below the yield point, to allow a margin for indeterminate stresses, and for practical variations in materials and workmanship. Provided suitable specifications are drawn up to control the ability of the operator, electrodes, design and preparation of materials, etc. there would appear little reason to anticipate greater variation in the quality and workmanship in welding than riveting. In other words it would not appear unreasonable to assume practically the same factor for welding as for riveting or the steel itself.

In Great Britain, for a 28/30 tons per sq. in. steel we have an allowable working stress in tension of 8.0 tons per sq. in. (i. e. a factor of 3.5). It is generally recognised, and has been proved by test, that owing to the unequal distribution of stress induced in tension members by riveted joints, the actual breaking strength is reduced by 20%, so that the effective factor of safety is 2.8 and not 3.5. In compression the allowable working stress is 6.5 tons per sq. in. which when compared with the yield strength of the steel 18.0 tons per sq. in. (the point of failure in compression) shows a factor of safety of 2.77, which is roughly the same as that for tension. These calculations assume that the shearing strength of the rivets bears a definite relation to the tensile strength of the parts joined; often it is assumed that the two are equal. This strength does not come into full play unless all the rivets are equally good fits in their holes. The 20 % reduction is meant to allow for possible departure from the condition; it may sometimes be insufficient. Under these circumstances a factor for welding equal to that for the steel, or at the most 4.0, would appear to be ample.

In published results of recent investigations it would appear that much importance is attached to the determination of the static strengths of welded joints. Such values are of secondary importance except for use in design. Factors that deserve more attention are the resistance of welded joints to dynamic stresses, corrosion, solidity and ductility in the weld metal and above all "consistency under practical conditions". The future of welded steelwork must depend to a very large extent on its consistency under practical working conditions, in other words on its reliability.

The main factors controlling economic and consistent welded production include intelligent design, sound organization and welding procedure, thoroughly trained operators and inspectors and the employment of correct welding equipment and electrodes.

These factors would appear to present much more fruitful fields for investigation and subsequent control than the physical properties of various types of welds, which are meaningless, unless they forecast with a reasonable degree of accuracy the results that one may expect to obtain in practice.

4. Strengthening of Steel Structures by Welding.

The application of electric welding to the strengthening of steel structures has offered a valuable solution to Railway and Municipal Engineers faced with the problem of coping with increased traffic loads and depreciation due to corrosion. Well over 100 bridges have been strengthened by welding on Australian Railways and quite a considerable amount of important work has been carried out in Great Britain. Similar operations are either in progress or contemplated in India, South Africa and certain of the Crown Colonies.

The main advantages claimed for the application of electric welding to the strenghening of bridges are briefly:

1. In some cases the only alternative to strengthening by welding is complete renewal.
2. Cost is invariably much less than when other methods of reinforcement are employed.
3. Delays to traffic passing over the bridges are avoided or greatly reduced.
4. In most cases underpinning or staging is unnecessary and on principle the existing structure is not weakened or disturbed by the replacement of members and rivets in the initial stages as is often the case with alternative methods.

The strengthening of structures by welding may be divided into three broad classes:

1. The reinforcement of riveting or riveted joints in which the welding and riveting act conjointly in carrying the stresses, as in the strengthening of lattice girder connections or plate girder flange angle and web splice riveting.
2. The reinforcement of existing members by welding on additional plates or sections.
3. The strengthening of girders by increasing their depth or by adding new members such as extra ties struts or cross girders, etc.

5. Combination of riveted and welded construction.

The question is sometimes raised as to how riveting and welding act in conjunction with each other or in other words ”What is the strength of a riveted and welded joint?“

It is quite possible for a riveted connection to be reinforced by welding and for the welding to bear the whole of the load and fracture before the riveting comes into play, due to the presence of ”slip“ in the rivets. In the case of an existing bridge, however, it must be borne in mind that the members are already bearing their dead load before the welding is applied and furthermore it would appear safe to assume that the initial slip in the riveted joints has already been taken up owing to the continual variation in the stresses transmitted and the natural vibration of the structure. It has been found that the strength of a combined welded and riveted joint may be estimated as the ultimate strength of the welding plus the yield point strength of the riveting.

In strengthening lattice girder joints it is necessary to ensure that the additional stresses carried by the welding are transmitted across the joint to the member of either side, that is to say, clear of the sections that are weakened by the existing rivet holes and this may entail the use of extra gusset plates.

Summary.

Welding by means of the Oxy-Acetylene Blowpipe has not met with much support in Great Britain for the assembly and the reinforcement of steel structures, but electric arc welding has developed into general practice. The results and progress of British pioneering have been particularly marked in Belgium, Switzerland and Australia, based on the application of the heavy coated electrode.

The production of a metalurgically sound weld under practical conditions should not depend entirely on the skill of the operator but in the natural function during fusion of the electrode. Success in welded construction depends on the initiative shown by the designer and his ability to break away from existing practice developed essentially for riveting. Attention is directed to the design of welded structures on a monolithic basis with a general use of butt welded joints, even in main members. With light single run fillet welds contractional stresses are reduced to a minimum and the soundness of the weld can be judged by expert visual inspection. More is now known of the behaviour of welded joints than of riveted joints. It is inaccurate to say that riveted joints can always be guaranteed after inspection by established methods.

In framing regulations one of the most important factors to be considered is "allowable stresses" or "Factor of Safety" which if too high is quite sufficient in itself to prohibit or seriously limit the welding of structural steelwork on economic grounds. The determination of the static strengths of welded joints is of secondary importance except for use in design. Factors that deserve more attention are the resistance of welded joints to dynamic stresses, corrosion, solidity and ductility in the weld metal and above all "consistency under practical conditions" to ensure reliability. The application of electric welding to the strengthening of steel bridges has solved the problem of increased traffic loads and depreciation due to corrosion.

Résumé.

L'emploi de la soudure au chalumeau oxy-acétylénique ne s'est pas répandu d'une manière très large, en Grande-Bretagne, pour l'assemblage et le renforcement des constructions métalliques; par contre la soudure à l'arc est devenue, dans ce pays, d'une pratique tout à fait générale. Les résultats et les progrès réalisés par la technique anglaise, particulièrement en ce qui concerne l'emploi des électrodes fortement enrobées, ont été mis en application, dans des conditions très marquées, en Belgique, en Suisse et en Australie.

L'obtention d'un cordon de soudure métallurgiquement sain ne doit pas être conditionnée entièrement, dans la pratique courante, par l'habileté du soudeur, mais elle doit résulter normalement de la manière dont se comporte l'électrode pendant la fusion. Le succès, en construction métallique soudée, est lié à l'initiative du constructeur et à son aptitude à rompre avec la pratique actuelle des assemblages, qui est basée sur l'emploi du rivet. L'attention est actuellement dirigée vers la construction de structure monolithique, basée sur l'emploi généralisé des assemblages soudés bout à bout, même pour les membrures principales. Lorsque l'on emploie des soudures d'angle en congé déposées en une seule couche, les efforts de contraction dus au retrait sont

réduits au minimum et l'examen des cordons à l'œil nu permet d'apprécier la qualité de la soudure. On sait mieux, maintenant, ce que l'on peut attendre d'un assemblage par soudure que d'un assemblage par rivetage; il n'est en effet pas exact de dire que l'on peut garantir un assemblage rivé après examen suivant les méthodes antérieurement employées. L'un des facteurs les plus importants pour l'établissement des Règlements est la considération des „efforts admissibles", qui découle de celle du „coéfficient de sécurité"; si d'ailleurs ce coéfficient de sécurité est trop élevé, il entravera plus ou moins complètement l'emploi, dans des conditions économiques normales, de la construction soudée. La détermination de la résistance statique des assemblages soudés n'est que d'importance secondaire en dehors du calcul du projet; les facteurs pratiques les plus importants sont la résistance aux efforts dynamiques, à la corrosion, les qualités de ténacité et de ductilité du métal d'apport et surtout le „comportement" en service normal. L'application de la soudure électrique au renforcement des ponts métalliques a permis de résoudre les problèmes posés par l'augmentation du trafic et par leur usure par corrosion.

Zusammenfassung.

Die Acetylenschweißung hat in Großbritannien für die Konstruktion und die Verstärkung von Stahlbauten keinen großen Anklang gefunden, dagegen hat sich die Lichtbogenschweißung allgemein durchgesetzt. Diese bahnbrechenden englischen Leistungen haben besonders in Belgien, in der Schweiz und in Australien Beachtung gefunden; sie beruhen auf der Anwendung der stark ummantelten Elektrode.

Die Gewähr für eine metallurgisch einwandfreie Schweißung sollte nicht einzig im Geschick des Arbeiters, sondern schon im natürlichen Ablauf des Schweißprozesses begründet sein. Erfolge bei geschweißten Bauten hängen davon ab, ob der Konstrukteur genügend Initiative besitzt und sich nicht scheut, von den üblichen, für die genieteten Konstruktionen entwickelten Grundsätzen abzuweichen. Der Verfasser macht aufmerksam auf die Konstruktion geschweißter Bauten auf monolithischer Grundlage mit allgemeiner Anwendung von Stumpfstößen, auch für Hauptglieder. Bei leichten einfachen Kehlnähten werden die Schrumpfspannungen auf ein Minimum reduziert und die Güte der Schweißung kann durch äußerliche Untersuchung vom Fachmann geprüft werden. Das Verhalten von geschweißten Verbindungen ist heute besser bekannt, als dasjenige von Nietverbindungen. Es ist nicht richtig, zu behaupten, daß man sich auf genietete Verbindungen verlassen kann, wenn sie nach der üblichen Methode geprüft worden sind.

Was die Vorschriften betrifft, so muß besonders eines berücksichtigt werden: Sind die „zulässigen Spannungen", bezw. der „Sicherheitsfaktor", zu hoch angesetzt, so wird das Schweißen im Stahlbau aus wirtschaftlichen Gründen verhindert oder doch ernstlich erschwert. Mehr Bedeutung als die Bestimmung der statischen Beanspruchung in geschweißten Verbindungen ist die Berücksichtigung der Widerstandsfähigkeit von geschweißten Verbindungen gegenüber dynamischen Beanspruchungen, Rostgefahr, Festigkeit und Dehnbarkeit des Schweißgutes und vor allem die „Bewährung in der Praxis". Der Anwendung der elektrischen Schweißung auf die Verstärkung von stählernen Brücken ist es zu verdanken, daß das Problem der gesteigerten Verkehrslasten und der Korrosionsschäden gelöst werden konnte.