Guide for the welding and weldability of reinforcing steels for concrete structures

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1. Introduction

The aim of this document is to present the typical features of welding in the field of concrete reinforcing steels and to assist in the definition of weldable reinforcements.

In this connection, the applicable welding processes are reviewed and their possible effects on the steel properties are presented. The concept of weldability is discussed on this basis and as a function, among other things, of the requirements a welded connection should fulfil. Finally, the question of limitations on the chemical composition of the steel is approached and analysed.

2. The concrete reinforcements

The properties of the reinforcements are codified in specific standards.

Besides low yield stress (±200 MPa) plain reinforcements, which are still used as auxiliary armatures, such as stirrups, most of the steels presently produced are high strength bars or wires whose surface shows lugs or protusions (deformations) to improve the bond strength with concrete. Depending on the standard considered, the guaranteed yield stress mostly ranges between 400 and 500 MPa. In some cases, this range may extend down to 350 MPa or up to 600 MPa.

Generally, the steel grade is designated by the nominal yield stress.

The required yield stress level may be achieved through different fabrication processes such as :

hot rolling of a naturally hard steel (either high carbon steel or low carbon microalloyed steel) ;
hot rolling of low carbon steel followed by a quenching and self tempering treatment ;
cold working of low carbon steel (twisting, stretching or drawing).

3. Welding in reinforced concrete construction

Reinforced concrete construction plays an important part in civil engineering and building due to the fact that the combination of concrete and steel produces good properties in building materials.

However, while it is possible to form concrete into almost any shape during its state of workability, the reinforcement is supplied as bars, reels or mesh-type formations. For that reason, the reinforcement elements must be adjusted to the shape of the prefabricated parts. Therefore, processes are required which will provide the optimum methods of adapting the reinforcement to the shape of the prefabricated part and to the required strains. Moreover, the reinforcement is frequently fabricated at the bending plant rather than the building site. In these cases it is necessary to ensure that the reinforcement remains in the correct arrangement during transportation and laying, and that the individual elements are placed exactly in the planned position. This fact implies assemblies of reinforcements. Even if, for instance, tieing is a possible solution to join crossing bars, in many cases, however, welding may be a preferred technique since it provides an improved rigidity for a comparable operating time. Moreover, for other types of bonds, welding is the only solution.

This explains the increasing interest of many users for weldable high strength bars.

Welding of reinforcements involves several types of joints and processes. Among the most usual may be mentioned : butt, overlap and cruciform weld and, as regards processes, manual metal arc welding (MMAW), gas metal arc welding (GMAW), resistance welding, flash welding and gas pressure welding. Table 1 gives different possible combinations of geometries and processes, while Fig. 1 shows some typical types of welded connections.

Butt and overlap bonds are necessary to join end to end bars of insufficient length and cruciform welds are used for meshes.

Welded assemblies may also be classified in two types :

Load bearing welded assemblies, which can be taken into account for calculation purposes by assuming a certain resistance of the welded connection.
Non-load bearing assemblies (tack welded assemblies) : by tacking, the components of a reinforcing system are safeguarded against movement. The load-bearing capacity of such welded assemblies must not be taken into account for calculation purpose

Welding of reinforcement can be performed either on site or in specialized workshops. In the former case, rain, cold and other forms of bad weather are parameters which can be unfavourable but which it is difficult to avoid. As far as workshops are concerned, the problems are different. Quality control can be applied and welding operations can be performed in better conditions : on the other hand, the problems of productivity and economics must be considered.

Table 1

Combinations of types of joints and welding processes for reinforcements

Welding process	Type of joint		
	Butt weld	Overlap weld	Cruciform weld
Arc welding Manual	*	*	*
Gas shielded/MIG	*	*	*
Resistance welding			*
Flash welding	*		
Gas pressure welding	*		

Welding at high rates and under severe conditions requires the use of suitable steels for the applications in question.

4. Process used for the welding of reinforcements

4.1 Manual metal arc welding (MMAW) :

This process can be applied to the fabrication of both load bearing and non-load bearing joints for on-site as well as for limited series in workshops.

Electrodes with rutile or basic coatings are generally used. The type of electrode is selected according to the resistance of the deposited metal and to the strength required for the connection.

The diameter of the electrodes depends on the type of joint and on the diameter of the assembled reinforcements. The weld current is selected (AC- or DC-polarity) and adjusted according to the value specified by the fabricant.

4.2 Gas metal arc welding (GMAW) :

Because of the automatic feeding of the weld wire, this process is suited for long series of welds made in workshops. On site, it is advisable to ensure that wind does not impair the gaseous protection, mostly provided by carbon dioxide or by a mixed gas such as CO_2 Ar.

The weld generators supply a direct current under a constant voltage and the weld wire is connected to the positive pole.

This process may be used for the fabrication of load bearing and non-load bearing weldments of different types. The achievement of cruciform welds may be facilitated by the use of a device controlling the weld time.

The diameter of the electrode wire is generally between 0.6 and 1.2 mm. Flux cored electrode wires may also be used.

Important setting parameters in this process are :

- weld voltage ;
- weld current, which is linked to the wire feed speed ;
- weld time ;
- shielding gas flow rate.

These parameters are selected according to the assembly to be welded (type of weld and diameters of the reinforcements) and possibly according to the environmental conditions (for instance, increase of the gas flow rate in case of a slight wind when welding on site).

4.3 Resistance welding :

This process is used for the fabrication of cruciform welds in workshops. The reinforcements to be joined are clamped between two electrodes in alloyed copper. The fusion of the metal is performed in Joule effect.

The main parameters of this process are :

- the electrode force, which has to be sufficient to minimize the contact resistance between the electrodes and the reinforcements and to prevent the projections of molten metal ;
- the sqeeze time, which allows an adequate positioning of the reinforcement before the current flow ;
- the weld current and the weld time, which condition the amount of heat generated ;
- the hold time during which the electrode force is held so as to compensate the shrinkage of the weld metal after the current flow.

The different settings of these parameters depend upon the diameters of the welded reinforcements.

Mention should be made of special welding machines which are suited to perform preheating or postheating treatments which can be necessary for the assembling of certain steels.

A practical means of quickly checking the results of the welding operation is to check the relative penetration of the assembled reinforcements which can be measured by the difference between the thickness of the crosspiece before and after welding (Fig. 2).

4.4 Flash welding :

This process is used for load bearing butt joints on bars of equal or nearly equal diameters only and is performed on stationary welding machines. The bars to be welded are clamped between copper electrodes. The clamping force must be sufficient to avoid sliding of the bars during the upset operation. The parameters of this welding process are :

- electrical capacity of the machine ;
- initial distance between the electrode ends ;
- flashing distance during which expulsion of molten metal occurs ;
- upset distance and upset force ;
- the welding time which is the time between switching on the welding current and the end of upset.

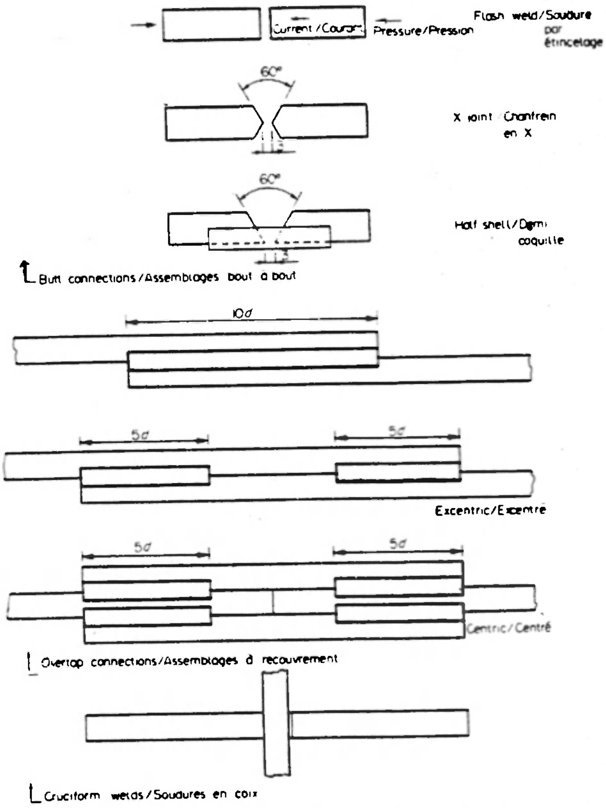

Fig.1 **Different types of welded joint**

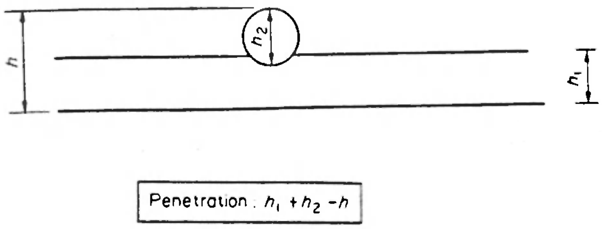

Fig. 2. Measurement of the penetration in cruciform welds

Depending on the steels to be assembled, the preheating treatment may be applied with the machine so as to decrease the cooling speed after welding.

4.5 Gas pressure welding :

Gas pressure welding is used for the fabrication of load bearing butt joints. Heating is by the combustion of a gas.

The setting up data are : the burner width, the pressure of fuel gas and oxygen, the separation of the bar ends prior to heating, the heating time, the upset force.

4.6 Thermit welding (T.W.) :

With this process, the weld heat input is developed thanks to a highly exothermic chemical reaction between aluminium and iron oxide : $Fe_2O_3 + 2Al = 2Fe + Al_2O_3 + heat$.

This process is applied for the butt jointing of reinforcements. The extremities of the bars to be assembled are positioned according to a given spacing in a mould made of sand. The mould is fitted with a special orifice so as to allow preheating of the bar ends. Combustion of the aluminium powder-iron oxide mixture is initiated and the liquid iron performs the weld. This process involves a high heat input.

5. The welding procedures

The choice of the welding procedures to be applied is dependent on several factors such as the type of joint to be made and its function, the selected welding process, welding equipment and weld filler metal, the type of reinforcing steels to be welded and also the tests and criteria to evaluate the weld quality.

Wholly or partly, these factors may vary to a great extent from one country to another and give nevertheless satisfactory results because the recommended procedures laid down in each area of the world are the fruit of a well-proven experience.

It is therefore out of the scope of this document to state stringent rules concerning the welding of reinforcements. Some general recommendations will rather be proposed.

Only welders who have been trained in the welding of reinforcing steels should be employed. They should be tested for the particular welding process involved.

Welding reinforcing steels for concrete components implies the necessity of the use of adequate equipment and checking periodically that this equipment is working properly. The welding consumables have also to be stored under environmental conditions compatible with the indications recommended by the manufacturers.

Surfaces to be welded shall be free from defects which would adversely affect the quality of strength of the weld. They should also be free from loose or thick scale and rust that would prevent proper welding. Adherent mill scale or a thin layer of rust may generally remain. With regard to requiring a groove, the ends of the reinforcing steels must be shaped to the proper geometry, for instance by sawing or grinding. For flash butt and gas pressure weldings, the bars to be assembled may be cut off by means of a guillotine, a saw or a wheel. When using a guillotine, care should be taken to avoid bending distortion of the cut ends. Concentric alignment of the bar ends prior and during welding is necessary. As a rule for any welding process and any joint, the bars to be assembled should be properly positioned during welding. The quality of the welds should be checked by appropriate means periodically during fabrication.

6. The concept of weldability

A welding operation results in a change of the metal microstructure, the extent of which depends on the steel grade and the heat input. Generally, the parent metal properties are modified in a small area called the heat affected zone. Beyond this zone, an evolution of the properties can also be observed, due for example to a metallic grain refinement, to ageing phenomena or more simply to the relief of pre-existing stresses.

According to the joint geometry and the heat input, the weld thermal cycles can be completely different. In order to clarify the ideas, two types of assemblies will be considered in the first approach : cruciform welds and flash butt welds.

In cruciform joints, only a small amount of metal is melted. Welding time is generally very short : a few seconds for manual or gas welding, a fraction of a second for resistance welding. As a result heat flows very quickly and, in most cases, independently of the dimensions of the assembled bars. The steel near the weld is submitted to a pronounced quenching treatment. Cooling times between 800° and 500° are close to one second or less. In the conditions, brittle microstructures can appear.

The flash butt welding process is quite different. In these welds, a larger zone of metal is heated. Preheating can be performed before welding and the electrical current can be maintained during the upset phase. Heat is distributed over the whole section of the bars. The thermal gradients are less abrupt than in cruciform welding since operating times can reach ten or twenty seconds. Cooling times are consequently slower and brittle structures are generally avoided.

It can therefore be stated that the welding of reinforcements may be divided into "cold welding" which means a low heat input, and "hot welding" when the heat input is rather high This distinction may seem somewhat arbitrary because, for each welding process, it is as a rule possible to vary the welding parameters and thus to cross the border. However, this concept can help us to understand the problems liable to appear during welding.

On this basis, the production of "sound welds" can be envisaged in two ways :

- either with reference to the steel, which means that welding is performed under rather severe conditions but on a steel with a low sensitivity to these phenomena ;
- or with reference to the welding procedure, which means that joining is carried out under selected conditions specially chosen to minimize the effects of "cold welding" or "hot welding".

Consequently, weldability is a complicated matter which, depends simultaneously on the steel properties, on the welding process and procedures and on the requirements the welded joint is expected to satisfy.

The weldability is assessed on the basis of mechanical tests on welded joints. Thus, the first step is to choose the tests and the criteria. To do so, it is necessary :

to define which properties (and at what level) a reinforcement should display so as to ensure satisfactory behaviour during the preparation of the armature, during the erection of the reinforced concrete structure and during the life of the construction ;
to select among the properties those which can be influenced by the combined effects of the welding operation and of the steel quality ;
to adopt mechanical tests to evaluate these properties in an objective and realistic manner ;
to lay down acceptance criteria according to the level required for the properties considered and possibly of a safety factor.

In the case of reinforcements it is generally admitted that two properties are important for welded connections : strength and ductility.

6.1 Mechanical tests on welded connections :

6.1.1 Shear test : A first test can be used in the particular case in order to measure the strength of the connection between the two bars. This test is known as the shear test (Fig. 3). One of the welded bars is clamped between grips and the load is applied to the other. This test induces shear stresses which are liable to occur in the weld during the handling of a cruciform welded armature or during service in a reinforced concrete construction. The fracture load is recorded and the result of this test may be expressed in terms of a shear coefficient, which is the percentage ratio between the fracture load and the load corresponding to the nominal yield stress in the thinner bar of the assembly. The

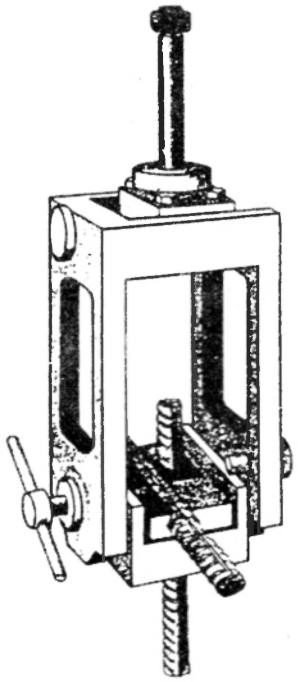

Fig. 3. Shear test

required minimum shear coefficient depends on the application considered. In cases where plain bars are welded to a cruciform joint, the shear resistance of the weld is necessary to ensure bond strength between the reinforcements and concrete. A shear coefficient value of 30% may then be requested (load bearing weld).

On the contrary, in case of deformed bars, the adhesion in concrete is given by the surface ribs. The role of the welded connection here is to maintain the proper geometry of the armature during the handling operations. A lower shear coefficient may consequent be accepted (non-load bearing weld).

6.1.2 Tensile test : The tensile test can be applied to any type of welded connection to determine the capacity of the reinforcement to transmit a load from one side of the weld to the other (Fig. 4). The tensile test comes naturally to mind when strength has to be evaluated.

To be representative of the tensile properties of the welded connection, the tensile test has to be carried out on as welded specimens, that is to say on specimens as they will be embedded in concrete. Consequently machining of the weld or of the reinforcement itself must be avoided.

The ultimate tensile strength of the welded assembly can easily be measured and compared either to the guaranteed tensile strength of the steel or to the actual tensile strength of the reinforcement in the non-welded condition. The effect of welding on the ultimate strength can thus be assessed.

The determination of the yield stress raise no special problem in the case of butt or cruciform welds : the local value of this characteristic in the weld area can be measured using an extensometer centred on the weld. For overlap joints, the cross section is much greater in the weld area than in the base metal. This means that until fracture, the main part of the overlap zone remains in the elastic field and that plastic deformations develop only at the extremities of this area. Important plastic straining occurs at these locations during tensile testing of single lap welds because the eccentricity of the two assembled reinforcements induces a flexion.* These considerations explain why the significance of yield stress on lap joints may be questioned and why the resistance of these joints is generally expressed only in terms of tensile strength.

The tensile test also makes it possible to evaluate the ductility of the welded connection. This parameter is specially important for cruciform welds, because the low heat input may embrittle some types of reinforcements (sensitivity to cold welding). Elongation is measured for this reason.

Figure 5 shows different types of elongation measurements which can be carried out on cross welds :

- elongation in the weld zone on a short base metal length (As) ;
- fracture elongation on a given base metal length (A5 or A10 for example) ;
- uniform elongation (Au : in this case measured on the broken specimen outside the necking area).

It is clear that the ductility of the joint is directly evaluated from the elongation in the weld zone on a short base metal-length (equal to twice the bar diameter, for example). The minimum elongation on such a basis may then be specified. The minimum value is set according to the necessary capacity for deformation which a reinforcement should display to ensure a proper behaviour in concrete, and also in relation to the initial ductility of the reinforcement in the non welded condition. For example, a minimum elongation of 4% on the 2d base

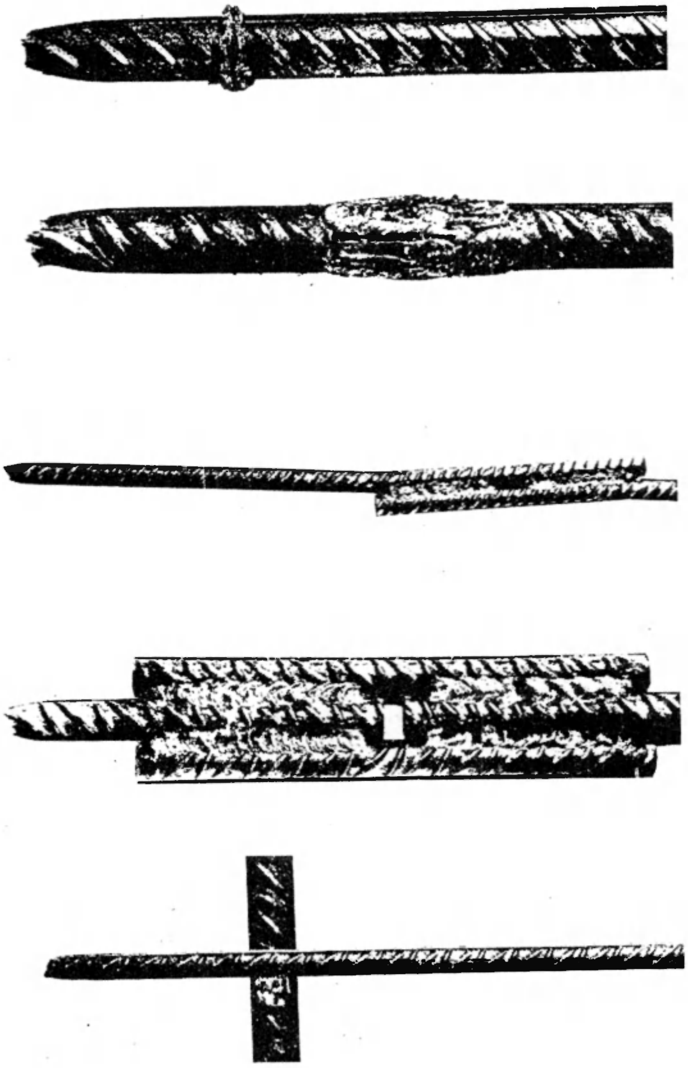

Fig. 4. Tensile test on welded connections

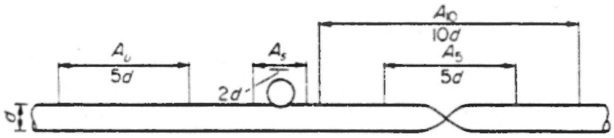

Fig. 5. Tensile test

length may be required when the base material has a high capacity for elongation, while a lower minimum elongation may be accepted in other cases.

Measurement on such a small base length cannot, however, be recommended as a general practice and has to be replaced by an equivalent method (and criterion) easier to carry out. It can be shown in this connection, that the elongation in the weld area is influenced by the uniform elongation of the base metal (Fig. 6).

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* It is to be noted, in this regard, that this flexion effect does not appear on such a weldment embedded in concrete.

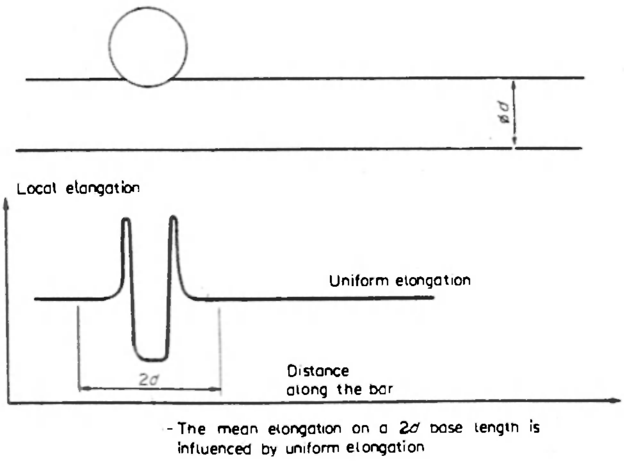

Fig. 6. Elongation in the weld and uniform elongation

Fig. 7. Tensile test. Fracture outside the weld

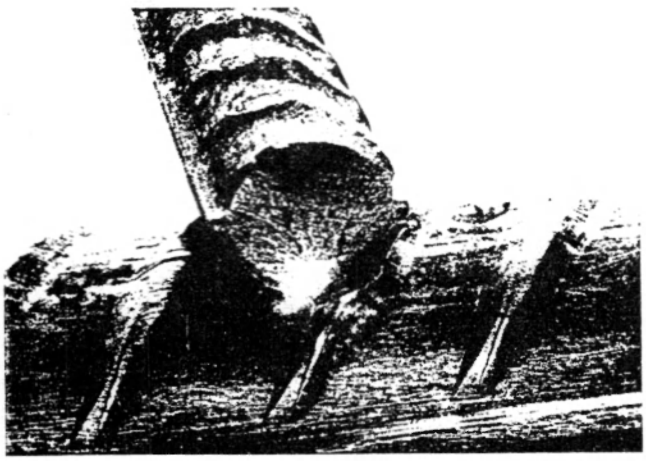

Fig. 8. Tensile test. Brittle fracture in the weld

Different fracture conditions may be considered :

Fracture near to the grip of the tensile machine :

In this case the trial should not be considered as valid and should be run again.

Fracture in the parent metal :

When the fracture occurs outside the weld area (Fig. 7), it is clear that the welding operation has not impaired the tensile behaviour of the steel with regard to the non-welded condition. Thus a sufficient elongation is obtained in the weld area under the condition that the elongation of the base metal itself is satisfactory. In other terms, the reinforcement in the non-welded condition must fulfil the requirements specified for the considered steel grade.

For the fracture to be considered as occurring outside the weld, it has to occur at a sufficient distance from the nearest fusion line, for example, the following values may be quoted :

10 mm minimum for reinforcements with $\phi \leq 10$ mm

25 mm minimum for reinforcements with $10 < \phi \leq 20$ mm

40 mm minimum for reinforcements with $\phi > 20$ mm

Fracture in the weld :

When the rupture occurs in the weld, two types of fracture modes have to be examined :

Brittle fracture (Fig. 8) which takes place suddenly at a given load with no more subsequent elongation (Fig. 9). Generally, such a fracture corresponds to a low elongation of the base metal and thus of the weld, and is a sign of low ductility.

The ductile fracture (Fig. 10) which has a bevel edged appearance. This type of fracture starts when the tensile resistance has reached its maximum value (Fig. 11) and develops with further localized plastic deformation. Such a fracture is generally accompanied by an important deformation of the base metal and thus indicates a good ductility of the weld.

Briefly, it can be stated that the ductility of the weld zone is satisfactory when the fracture in tensile test occurs in the parent metal or in the weld butt with a bevel edged appearance.

Consequently, to appraise the ductility of the weld, a very simple criterion can be the aspect of the fracture. Nevertheless, the measurement of an elongation may be deemed necessary. Uniform elongation of the base metal may then be measured and compared to the value required for the reinforcement. Fracture elongation can also be used with a proper criterion because, as shown in Table 2, uniform elongation can be estimated from fracture elongation. The minimum fracture elongation could be :

the guaranteed value of the steel grade in the case of fracture in parent metal ;

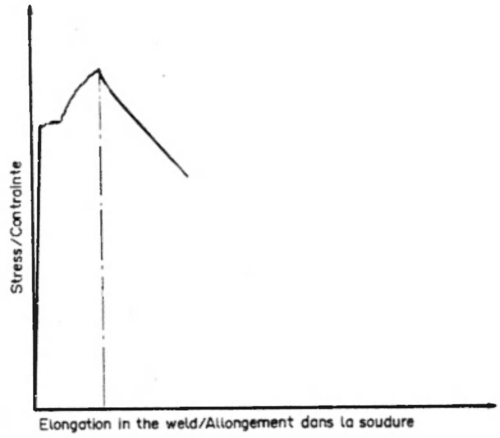

Fig. 9. Brittle fracture in the weld.

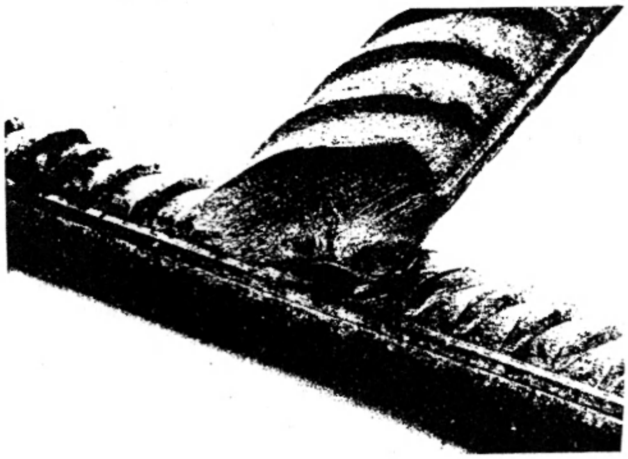

Fig. 10 Tensile test. Ductile fracture in the weld

75% of this guaranteed value in the case of fracture in the weld (the reduction of 25% takes account of the lower necking phenomenon due to the proximity of the weld).

With regard to other types of welded joints, similar criteria to those used on cruciform welds can be used to evaluate the ductility.

6.1.3 Bend test : The bend test around a mandrel of a given diameter may also be used to evaluate the ductility of the weld.

The mean level of deformation applied to the metal in this test, depends on the mandrel diameter. When this diameter is expressed in terms of the bar diameter (mandrel diameter : kd, d : bar diameter), the elongation in the external fibres of the tested reinforcement is :

$$E\ (\%) = \frac{100}{1 + k}$$

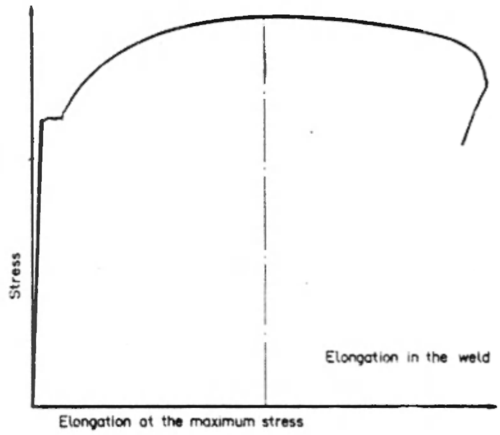

Fig. 11. Ductile fracture in the weld.

The result of this test is evaluated in accordance with the external aspect of the bent reinforcement (presence of cracks, rupture). The question may arise, whether it is advisable to carry out two different tests (tensile and bend tests) to assess the same property (ductility). In this connection, it should be pointed out that the bend test can easily be carried out on site but the main drawbacks of this test come from the fact that an objective criterion is difficult to set, and from the scatter of the results in many cases (specially on cruciform welds).

In order to clarify things, a more complete analysis of the local deformations taking place in the reinforcement either in tensile test or in bend test can be made.

In the tensile test, the way of stressing the metal is such that a distribution of the local strains is possible, the poor elongation of a locally less ductile metal being balanced by a higher elongation of an adjacent zone.

In the bend test, each section of the bar is submitted to the same strain, which is imposed by the curve of the mandrel. The metal cannot distribute the deformation.

Consequently the difference between the two types of test leads to an important question concerning the choice of procedures for testing the material : is it necessary for each elementary part of a bar to be submitted to the same deformation (for example, each small cylinder having the section of the bar as basis and a height of a few millimetres) or on the contrary, is it sufficient for the elongation of the weld zone as a whole (that is to say a cylinder with a height of about twice the bar diameter) to attain a given value ?

One main characteric of the steel lies in its capacity to distribute the local strains and this explains its properties related to ductility.

When the testing conditions do not allow this phenomenon to take place, an important advantage of the steel may not be taken into account.

It is, however, clear that a bend test may be necessary, for instance if the welded reinforcements were intended to be shaped during the fabrication of the armature at the location of the weld.

Table 2

Considering in Fig. 5 the base metal on which A10 is measured the length after tensile testing is :

$$10d(1 + A10)$$

This is also equal to :

$$5d(1 + A5) + 5d(1 + Au)$$

The first term of the above expression, is the length of the central part where necking occurs ; the second term is the length of the two 2,5d neighbouring zones on which no necking is recorded, the elongation of those two zones is to be considered as "uniform".

Comparison of the two expression gives :

$$Au = 2A10 - A5$$

This means that the uniform elongation can be estimated to be of the value of 2A10 A.

6.1.4 Definition of weldability : The considerations developed in the preceding sections give guidelines to help with the selection of the mechanical tests and criteria.

In this connection Table 3 summarizes the different tests characteristics which may be considered in these tests. It is clear that several possibilities exist.

Thus, the final choice is left to the Authorities concerned in each country. Mention can be made of a given test, easy to be carried out, which may be applied for investigation, liable to be confirmed, in case of doubt, by another test which will be then considered as determining ; for instance bend test as screening test and tensile test as determining test.

The second point is to define the welding procedure. Two alternatives can be pointed out in this connection :

either, weldability is evaluated in each case encountered in practice and thus according to the welding procedure adopted in a given situation ;
or weldability is evaluated in a more general way by selecting standard welding procedures which will be mainly used in a given area for present and future welding work.

A similar concept can be adopted for steels :

either weldability is systematically checked on every batch of reinforcements to be welded ;
or weldability is assessed once and for all on steel specimens representative of given grade and quality, and not for each production batch.

The latter possibility means that other methods must be defined to ensure that the steels delivered are weldable (chemical requirements for instance, as discussed in section 7).

These considerations lead to the major concept of weldable reinforcing steels and their definition.

7. Weldable reinforcements

As stated above the concept of weldable reinforcement is complex.

It should be first pointed out that, as a rule, all types of reinforcements are weldable provided an adequate welding procedure is adopted. This statement is confirmed in the actual practice. For instance, satisfactory welds can be obtained in steels sensitive to embrittlement if suitable preheating or postheating runs are applied even in the case of cruciform welds. The success of such a joining operation implies obviously an efficient control at each step (control of preheating, welding and postheating).

In many cases, however, welding cannot be carried out under sophisticated conditions. This means that it may not be possible to apply preheating runs and that manual metal arc welding is carried out using covered rutile electrodes. Welding has therefore to be performed on reinforcing steels whose sensitivity to embrittlement is sufficiently low as to be compatible with rather difficult joining conditions. From this come possible limitations on the chemical composition of the steels.

Table 3

Mechanical tests on welded connections and characteristics derived from the tests

	Test	Characteristics
1.	Shear test (for cruciform welds)	Shear coefficient
2.	Tensile test	Ultimate tensile strength Yield stress (in so far as it can be determined) Fracture appearance (ductile or brittle) Uniform elongation Fracture elongation (on a given base length).
3.	Bend test	External appearance of the specimen (no crack, presence of cracks, rupture).

These limitations concern the contents in elements liable to induce embrittlement. Carbon is the first element to be considered, for the simple reason that in "cold" welding martensite is formed in the heat affected zone. In order to ensure that this martensite is sufficiently ductile, carbon content should be limited. The influence of other hardening elements can be taken into account with the carbon equivalent. Different formulate have been proposed for the carbon equivalent ; the definition adopted by the IIW is mentioned below :

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cu + Ni}{15} + \frac{Cr + Mo + V}{5}$$

The maximum values for the carbon and carbon equivalent contents may be set in two ways.

First possibility :

Those maximum admissible contents are considered as necessary in order to ensure weldability. This concept is expressed in other terms as follows :

The limits are set in such a way that the steels whose chemical composition does not fulfil these limits are not weldable under the simple joining conditions which are imposed. These steels cannot therefore succeed in the weldability tests. Thus, there is no reason to carry out these tests and these steels are consequently rejected.

Therefore; the steels which fulfil those limitations on the chemical composition are liable to be welded. Therefore, weldability tests have to be carried out in order to assess whether a given steel is really weldable.

Using such a concept, the maximum admissible contents in carbon or in carbon equivalent may be fixed at rather "high" values. The limits represent in fact the upper border above which a steel is no longer weldable, and they of course depend on the selection of welding processes, welding parameters and types of joints and on the requirements of the welded connections. These limits are defined on the basis of specific studies carried out on a representative population for reinforcing steels.

Second possibility :

The maximum admissible contents in hardening elements are considered as sufficient requirements to ensure weldability. This means that the limitations on the chemical composition are fixed at very safe levels under which a reinforcing steel, that has been properly produced, is safely weldable under simple conditions. Such a steel must fulfil the conditions on the chemical composition and display satisfactory mechanical properties in the non-welded condition. This concept implies the adoption of low maximum values of carbon, cabron equivalent and if necessary other elements.

These values are fixed on the basis of a preliminary investigation performed on several steel samples representative of the reinforcements encountered in practice. Should a new type of steel come onto the market, this investigation should be repeated on this new quality so as to check whether the limits adopted are still valid.

In such a case the mechanical tests on welded connections are no longer necessary to verify the weldability of a well-proven steel. They may be used to check the aptitude of the operator or the correct observance of the permissible welding conditions. In this regard, it may be advisable that the producers of a given type of reinforcing steel publish a welding brochure indicating the main guidelines for the achievement of sound welds.

8. Limit values on the chemical composition of reinforcing steels

From the observations developed in the preceding section, it is clear that, according to the concept adopted for the definition of weldable steels, several possibilities are offered with regard to the chemical composition and its possible limitations on it. This idea is confirmed by the facts which show the great diversity of the requirements in national codes or standards.

Thus, it is out of the scope of this document to specify stringent conditions on the chemical composition ; those recommendations could not therefore reflect the actual conception of weldability adopted in each area of the world.

Nevertheless, ranges of limit values on the carbon and the carbon equivalent contents may be presented for information. It is found from the literature that, in most cases, the limitations lie within the following ranges :

maximum carbon content : value chosen between 0.20 and 0.30%

maximum carbon equivalent content : value chosen between 0.45 and 0.55%

9. Cold cracking of welds made in reinforcements

The danger of cold cracking in welding depends upon the simultaneous occurrence of several factors which can be schematically presented as follows :

the presence of hydrogen in the welds ;
a microstructure in the metal sensitive to hydrogen (generally a high amount of martensite) ;
a high level of stresses.

In the case of bars, this phenomenon is not likely to occur even when rutile electrodes are used, for the following reasons :

welds performed with low heat inputs, such as cruciform welds, do not induce important residual stresses ;
other types of welds, the higher heat inputs do not generally induce the formation of brittle microstructures.

It is only in the case of high carbon contents (above 0.27%) and low heat inputs that the use of rutile covered electrodes could involve hydrogen induced cracking.

10. Conclusions

This document has presented the main features of welding in reinforced concrete construction and of the weldability of reinforcements.

Welding and weldability can be approached in different ways, which have been reviewed and analysed. It is thus hoped that a useful background is provided so as to help the different authorities in charge of this question to adopt rational rules as a function of the specific national context.

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