Recommendations for the classification of steels for use in welded structures

The purpose of the following recommendations is an attempt to bring up to date and somewhat enlarge the scope of document IIS/IIW-22-59 (Recommendations for the choice and classification of steels for use in welded structures). They state the guiding principles on which to base a classification of steels for electric fusion welding with a maximum heat input of 85,000 J/cm. They cover only structural mild steels, carbon-manganese steels and micro-alloyed steels. Quenched and tempered steels are not included.

Preface

Document IIS/IIW-22-59, though very much discussed when it was published, has proved very useful.

Some years age, Commission IX "Behaviour of metals subjected to welding" appointed Sub-Commission IX-F, under the chairmanship of Mr. Bonhomme (Belgium), with the task of renewing, extending and bringing up to date the document mentioned above.

After many discussions, Sub-Commission IX-F has drafted this new document. The Sub-Commission is well aware that the modifications proposed to the initial document are not so extensive as many experts might desire, but it is of the opinion that a more profound modification could not meet general agreement i the present state of knowledge.

Sub-Commission IX-F hopes to be able, within a few years' time, to present a completely revised document which must, of necessity, be extended to cover higher strength materials. Sub-Commission IX-F believes, however, that the modifications here proposed, although not radical, will be most useful to many users.

1. Introduction

In 1949, Commission IX of the IIW agreed upon the following definition of weldability which was adopted by ISO/TC 44 "Welding" in 1953 and which, in 1967, was the subject of recommendation ISO R 581;

"A metallic substance is considered to be weldable to a stated degree by a given process and for a given pur pose, when metallic continuity can be obtained by welding using a suitable procedure, so that the joints comply with the requirements specified in regard to both their local properties and their influence on the construction of which they form part".

This definition admits a "degree" of weldability. A logical development of this concept is the idea of classifying steels in groups, which correspond to different degrees of weldability. The definition includes not only the metallurgical aspects, but also the streng and the ductility of the parent material which will be welded. The criteria considered have been selected with a view to preventing:

- the occurrence of cracks
- brittle fracture

1.1. Cracks

The question of cracks is extensively discussed in

Document IIS/IIW-367-71 (ex doc. IX-704-70) drawn up by Sub-Commission F "Study of recommendations relating to steels for welded constructions" of Commission IX "Behaviour of metals subjected to welding" of the IIW but not committing the IIW as a whole.

List of members of Sub-Commission IXF (IIW Assembly in Lausanne in July 1970): Mr. W. Bonhomme (Belgium)- Chairman, Messrs. P. Amiot (France), J. Degenkolbe (Germany), U. Guerrera (Italy), H. Hoffstedt (Sweden), T. Kanazawa (Japan). P.E. Lagasse (Belgium), J. Lessels (United Kingdom), R. Liston (United Kingdom), N.N. Prokhorov (USSR), R.V. Salkin (Belgium), M.J. Spanraft (Netherlands), Trudeau (Canada), J.H. Van der Veen (Netherlands), J. Vrbensky (Czechoslovakia), H. Wintermark (Norway).

and, thus, cannot be absolutely fixed. The special precautions mentioned above are e. g. welding with preheating and/or postheating, welding with local or complete subsequent heat treatment for stress-relieving, welding with filler metal having particular properties, welding sequence, etc...

In deciding whether special precautions should be taken, reference should be made to any type test data available on the steel quality which is to be used (see section 5.3). In certain cases it may also be necessary to carry out procedure tests.

2.5. Fabrication procedure

This term implies all operations for manufacture which are not included in the welding operation itself. Among these are to be considered cold-working during preparation and stress-relieving.

When cold-working is involved, a better quality of steel may be necessary, whereas effective stress relieving may allow the use of lower quality steels (see doc. IX-646-69 already cited and X-452-68 "Heat treatments for the relieving of welding residual stresses and their metallurgical influence".

2.6. Effect of service life conditions

In some particular cases, the conditions of service of the construction must be considered, because it may lead to deterioration of the welded joints.

2.7. Acceptable risk in case of fracture

Consequences of a failure in terms of danger to human life, repair costs, etc., are not the same for all structures and affect the choice of the material.

2.8. Conclusions

The choice between the different qualities of steel depends not only on the intrinsic properties of the steel, but also, to a great extent, on design, thickness, on the nature and level of the stresses to which the structure is exposed, on the welding procedure, service life conditions and on the service temperature.

3. Limits of applications

The present document contains only recommendations to be applied to rolled products such as plates, sections and bars of C-, C-Mn- and C-Mn microalloyed steels (quenched and tempered steels being excluded) whose specified tensile strength ranges are within the limits from 370 to 700 N/mm2 (37 to 70 kgf/mm2) used for structures such as bridges, buildings and the like, ships, rolling stock and locomotives, storage tanks and machine frames for service temperatures between about -50 to +50° C (lowest and highest atmospheric temperatures).

The present document only gives the recommendations that, in the present state of knowledge, can reasonably be put forward. It should be understood that these recommendations pre-suppose that proper precautions are taken to ensure that good welding practice is followed.

The general principles may also apply to other kinds of structures, such as pressure vessels, boilers, penstocks and pipe-lines for water, gas or oil, though for such structures the limiting values or the referen criteria given in this document for assessing brittle fracture and weldability may require some adjustmen

4. Classification of steels for use in welded structures

4.1. Classification

Four steel classes are to be considered, namely:

B - C - D - E

4.2. Comments on this classification

B-steels are intended for use in welded structure or structural parts, not of excessive thickness, subjected to normal loading conditions.

The use of these steels is generally justified for structures or structural parts in which brittle fractu are not to be feared, either on account of the thickne sizes and shapes adopted, or because of the fabricati and/or service conditions.

C- and D- steels (improved notch-tough qualities are to be used for structures or structural parts who design, size and/or service- and service life-conditi necessitate the risk of brittle fracture being taken int account. These qualities differ from one another in their applicability at different service temperatures, for the same service temperature, in their notch-toughness.

C- steels are to be used in cases where, owing t thicknesses, loading conditions and the general desig of the structure, some resistance to brittle fracture necessary.

D-steels are to be used in cases where, owing to increased thicknesses, loading conditions and the gen design of the structure, a high resistance to brittle fr ture is necessary.

E-steels are to be used in cases where, owing to thicknesses, loading conditions and the general desig of the structures, or the particularly catastrophic co sequences of a fracture, a specially high resistance t brittle fracture is desirable.

Of course, this classification does not imply that the whole welded structure should be made of the qual required for those parts of the structure which are su jected to the more severe conditions. For the selecti of the steel quality to be used, account should be take of the points mentioned in section 2 of these recomme dations.

It is recalled that, for any structure, whatever steel quality is used, the choice of this quality depen not only on the risk of brittle fracture inherent in the service conditions but also on the welding and fabrica tion procedures.

Experience has shown that the use of a steel of a lower class can be considered for structures that are submitted to a full scale test on the finished structure adequately duplicating service conditions.

5. Classification tests for steels

5.1. Criteria for classification

Sub-Commission IX-F believe that the selection of steel should be based upon the properties of the produ as delivered by steel-maker.

document IX-646-69 "Guidance for welding and weldability of C-Mn and C-Mn micro alloyed steels". (+)

As a result of the local heating during welding and of the thermal conductivity of the metal, the heat-affected zones are subject to a rapid cooling, which may produce hard and low ductile constituents (even martensite). Those hardened zones are situated approximately in the same region as the maximum residual stresses and may be at the same time subject to a volume increase due to hardening, initiating supplementary residual stresses. These are particularly dangerous zones, in which may occur cold cracks, associated with the embrittlement due to hydrogen in the weld metal. This danger can be diminished by procedures described in Doc. IX-646-69.

So-called hot cracks are due to another cause: they may appear at high temperature, mainly in the weld metal, as a consequence of the hot shortness of the structure resulting from the welding operation and of the stresses arising from this operation. Here again, the nature of the steel (chemical composition of weld and parent metal) and the welding conditions are simultaneously in question.

1.2. Brittle fracture

Brittle fractures are generally formed without local plastic deformation. The resistance of steel to this type of fracture should be considered as its capacity to resist initiation of such a fracture and/or its capacity to arrest such a crack which has initiated.

In the present state of knowledge, it has been found impossible to base a classification of steels on both of these types of behaviour, but it is hoped in the future to consider them when it becomes possible to introduce type testing (see section 5.3. below).

In the present document, the properties of the steels, as regards brittle fracture, have been considered as a principal factor for the classification of steels for welded constructions.

Some qualitative suggestions about the possibility of diminishing the danger of brittle fracture, taking into account the characteristics of the construction, are given in the following paragraphs.

2. Factors affecting the choice of steel

The risk of occurrence of cracks or brittle fractures depends on:

(a) the properties of the steel as supplied,

(b) the service temperatures to which the welded assembly is exposed,

(c) the complexity of design of the structure (geometrical factors, shape, thickness of material, etc..) and the level of the stresses,

(d) the welding procedure,

(e) the fabrication procedure,

(f) service life conditions(corrosion, fatigue, etc..)

As regards properties (a), the choice of steel, depends on (b), (c), (d) and (e). It also depends on the acceptable risk in case of fracture. From practical experience, it is also evident that where control over welding procedure is poor the risk of failure is greate and this may influence the choice of steel.

(+) This document will be published as a booklet in the near future.

2.1. Effect of the properties of steel as supplied

The properties of a steel are determined by its chemical composition, the metallographic structure, the manufacturing practice and the thermal or mecha cal treatment which it has undergone prior to welding Further, the properties of a steel may be modified locally, to a greater or less extent, by the welding o tion itself. Experience has shown, however, that a sification of steels could be made on the basis of a certain number of their properties and a classificati of this type, within the limits of applications defined chapter 3, is given below.

2.2. Service temperature

The danger of brittle fracture increases as the temperature of service of the structure falls. It is, however, well to bear in mind that the testing tempe tures given in section 5.2. below have no correlatic with service temperature.

2.3. Effect of the complexity of the structural design and the nature and level of the stre

Just as steels can be differentiated according to their resistance to brittle fracture, welded structu may be differentiated according to the complexity the design, with special reference to those factors which influence the tendency to brittle fracture: vi degree of restraint, stress concentration, etc... S tures may show different degrees of complexity of design, according to the magnitude of the followin factors: degree of restraint, grouping of welds, r ity, discontinuities in shape and thicknesses of ma ial used.

The degree of complexity of the structural des may have an influence on the nature and level of t stresses, particularly by introducing triaxiality a stresses, particularly by introducing triaxiality a increasing the level of the stresses in the welded and in its proximity.

2.4. Effect of welding procedure

Apart from the type of steel, the design of th ture and the nature and level of the stresses, the ing procedure has a considerable influence on th result. The thermal conditions depend on the m of welding, the thickness of the parts to be weld heat input and the temperature of the parts to be ded.

These thermal conditions are especially imp for steels over 500 N/mm2 (50 kgf/mm2) specif sile strength.

The compatibility of parent metal and filler and hence, the choice of steel, may also be infl by the welding process. The residual stresses risk of crack and fracture formation increase w increasing thickness of the material. Special p tions and/or a higher quality of steel are neces above certain thicknesses, the limits of which with the grade of steel and with the service cor

The main criterion used in classification is the notch toughness of the material. The chemical composition is considered as a criterion relating to welding precautions to be used.

The recommendations given below are based on the V-notch Charpy-test, which is widely known and has been extensively used.

5.2. Brittle fracture tests

For steels B (+), no brittle fracture tests are recommended.

For steels C, D and E, a brittle fracture test should be made. This test should be made with Charpy V-notch specimens, taken in the direction of rolling, with the notch perpendicular to the surface of the plate or product. The sampling will be taken at 1/4 of the thickness for thicknesses of more than 40 mm.

Steels C, D and E are characterized by an average V-notch Charpy impact value according to the following table:

Steels	Specified UTS range between 370 and 520 N/mm2		500 and 700 N/mm2	
	Energy J/cm2	Temp °C	Energy J/cm2	Temp. °C
C	35	0	35	-10
			50	0
D	35	-20	35	-30
			50	-20
E	35	-40	35	-50
			50	-40

For steels with specific UTS range between 500 and 700 N/mm2 (50 and 70 kgf/mm2), the choice of the energy value and of the corresponding temperature is left to agreement between the user and the manufacturer of the steel.

The number of tests to be made (minimum 3) is a matter for agreement between the parties.

These testing temperatures and energy levels were not selected as having particular significance with respect to service performance; they were selected only to classify steels according to their increasing resistance to brittle fracture.

5.3. Chemical analysis (++)

5.3.1. Steels with specified UTS range between 370 and 520 N/mm2 (37 and 52 kgf/mm2)

The following table gives the limits which should not be exceeded without special welding precautions.

Class of steel	C. max	Mn max.	Si max.	S max	P ma
B	0.24	1.50	-	0.05	0.0
C	0.24	1.50	0.50	0.05	0.0
D	0.24	1.50	0.40	0.05	0.0
E	0.22	1.50	0.40	0.04	0.0

If C $\leqslant$ 0.22% and if C eq $\leqslant$ 0.41(+) and if thicknes $\leqslant$ 37 mm, it will, in general, not be necessary to tak special welding precautions, concerning particularly t hydrogen content of weld metal, the preheating temper ture and the heat input conditions (++).

5.3.2. Steels with specified UTS range between 500 and 700 N/mm2 (50 and 70 kgf/mm2)

The following table gives the limits which should not be exceeded without need of special welding precautions:

Class of steel	C max.	Mn max	Si max.	S max.	P ma
B	0.22	1.60	0.55	0.05	0.0
C	0.22	1.60	0.55	0.04	0.0
D	0.20	1.60	0.55	0.04	0.0
E	0.20	1.60	0.55	0.04	0.0

If C $\leqslant$ 0.20 and C eq $\leqslant$ 0.45, and thickness $\leqslant$ 25m or
if C $\leqslant$ 0.20 and C eq $\leqslant$ 0.41 and thickness more than 25 mm and equal or less than 37 mm,
it will, in general, not be necessary to take special welding precautions as long as use is made of welding processes involving a low hydrogen content in the weld metal.

V and Nb should, in certain practical cases, be kep lower than: Nb : 0.05 V : 0.15

5.4. Special tests

It is recognised that the above classification makes use of acceptance tests, which, in some cases, will not directly relate to service behaviour e.g. C. eq for weldability and Charpy V-notch properties for resistan to brittle fracture. In the present state of things, it cannot be otherwise as regards classification.

Nevertheless, attention should be drawn to the inter est in and need for tests providing more direct informa tion on the behaviour of steels during welding and under service conditions. Such tests, the so called type-tests should, in the future, make it possible to adjust, according to the spirit of this document, the acceptance criteria to be applied. These tests might vary according to the type of application envisaged.

(+) For a few B-steels and for some applications, it may be useful to consider either notch-toughness requirements less severe than for C-steels or some limits to the nitrogen content.

(++) It should be noted that, for practical reasons, the limits of composition given below refer to ladle analysis.

(+) Carbon equivalent according to the IIW recommandation is:

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

(++) see document IX-646-69 of the IIW.