Geometrical Defects in Arc Welded Joints in Steel Materials— Classes of requirements

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1. INTRODUCTION

1.1 Scope

This recommendation defines three quality classes of requirements as regards geometrical defects in welded joints. The quality classes relate to number and sizes of geometrical defects in the welded joints and mainly reflect the quality of workmanship.

The recommendation is intended to be used for quality control of manual or mechanized arc welding of products in unalloyed or alloyed steels. It is applicable to butt welds as well as fillet welds.

The recommendation was prepared by Commission V "Testing, measurement and control of welds" of the International Institute of Welding with the intention of providing a unified, international basis for the evaluation of weld quality, primarily by non-destructive methods.

1.2 Limitations

1.2.1. The classes do not directly relate to the fitness-for-purpose of the welds. The document is not intended to be and should not be used as a "design code". However, those interested such as end users, designers, code committees, etc. should, in each particular case, specify a weld class or a mixture of weld class requirements (cf. appendix C) in order to obtain a sufficient assurance against potential failure caused by all relevant types of defect.

The requirements of the recommendation should not be used as absolute limits, but rather as limits which should not be exceeded by more than a defined probability. It should be noted that defects surpassing the size limits often may be present in a weld without imparing the fitness-for-purpose of the product. An inspection system using one of the quality classes as a basic requirement but permitting acceptance of larger defects in certain cases ("two level system") is recommended. Further guidelines are given in appendix C.

1.2.2. The recommendation should be supplemented by requirements for inspection, testing and examination. Even if the recommendation contains specifications regarding all possible types of defects, this does *not* imply that welded joints must be examined for all types of defects.

1.2.3. Metallurgical deviations in welds are not covered by this recommendation.

1.2.4. Standards for rolled sections, tubes and other rolled products define limits for the permissible deviations from the shapes and dimensions prescribed. Corresponding limits exist for wrought and cast products etc. The permissible deviations may be of such a magnitude that the requirements of this specification may be misleading. This applies in particular to defects of the misalignment type (No. 16) but also to other types of defects, for example No. 9. When significant deviations from the prescribed shapes and dimensions are present in the raw materials, it will be necessary to evaluate to what extent the requirements of the recommendation can be applied.

1.2.5. The recommendation pertains to welds having a thickness within the range from 3 to 50 mm.

1.2.6. According to ISO 2553, weld thickness is designated by the symbols "a" (fillet welds) and "s" (butt welds). It should be noted that weld thickness of a fillet weld is equal to the throat. Countries using leg length as a measure of fillet weld size may wish to reformulate the quality requirements so that the limits refer to leg length. Difficulties arise, however, for partial penetration fillet welds when the requirements are reformulated in leg length.

Doc. IIS/IIW-778-83 (ex doc. V-751-83) prepared by Commission V "Testing, measurement and control of welds" of the IIW, but not committing the IIW as a whole.

1.3 References

1. ISO 6520
Classification of defects in metallic fusion welds, with explanations.

2. ISO 2553
Welds—Symbolic representation on drawings.

3. Doc. IIS/IIW-636-80
Inspection of welds when fitness-for-purpose criteria are applied, preliminary recommendation.

4. Doc. IIS/IIW-369-71
Parameters characterising defects in metallic fusion welds.

2. EVALUATION OF WELDS

2.1 Evaluation for individual types of defects

A welded joint shall be evaluated separately for each individual type of defect except when stated otherwise.

2.2 Interfering defects

Two or more interfering defects shall be considered as one defect. Defects are considered to interfere if the distance between the defects, measured in the height and width directions of the welded joint, is smaller than the height or width, respectively, of the larger of the defects. Each cross section of the welded joint shall be evaluated separately. Only defects of the same type are to be considered.

All forms of porosity (Nos. 3, 4 and 5) are, however, to be considered collectively. The dimensions of interfering defects in the height and width directions shall be measured between the opposite extreme edges of the defects.

2.3 Local and continuous defects

A defect is considered local if the total length of defects (of the type in question) does not exceed 25 per cent of the length of the section of the weld examined. Only defects of the same general type are to be considered together. Two or more defects located at different distances from the centre line of the welded joint are to be assessed separately, unless they are interfering. Long welds have to be examined in sections, each section corresponding to the length covered by, for example, one radiograph. A section length approximately 20 times weld thickness, but not more than 500 mm, is recommended. It is recommended that each section be evaluated independently.

2.4 Other quality requirements

Drawings and design specifications may—directly or indirectly—prescribe quality requirements which in certain respects are more stringent than the requirements of the present recommendation. As an example may be mentioned butt joints required to be backgouged and welded from the back. When gouging and seal welding have been correctly performed, defects Nos. 9 and 15 cannot occur. On the other hand, defects Nos. 11 and 16 may be accepted within the limits of the quality class of the welded joint, also in the sealing run.

2.5 Detectable defects

Defects smaller than the limit of detectability of the non-destructive examination procedures applied are normally not detected during the examinations. This is also the case for continuous defects. Whenever the present recommendation specifies : "Detectable defects not permitted", this implies that defects smaller than the limits of detectability of the non-destructive examination procedures applied may be present. Documents defining suitable limits of detectability for non-destructive examinations are in preparation by Commission V.

3. CLASSES OF REQUIREMENTS

3.1 General

Table 1 states the limits of the numbers, sizes and locations of the weld defects, for the three classes.

For certain types of defect, different limits have been defined for local and continuous defects, respectively. In the evaluation, all defects *not* exceeding the limits for continuous defects may be disregarded. The remaining defects shall be local (cf. clause 2.3.) and they should not exceed the limits for local defects.

3.2 Limitations in total defect height

Unless more stringent requirements have been defined in Table 1, the total height of defects which diminish the cross section of the joint shall not exceed :

Moderate requirements : 30 per cent of the nominal weld thickness, but not more than 10 mm.

Medium requirements : 25 per cent of the nominal weld thickness, but not more than 10 mm.

Stringent requirements : 20 per cent of the nominal weld thickness, but not more than 10 mm.

The values apply to any cross section of the welded joint, for each as well as several types of defects.

Table 1

Defect Ref. No.	Type of defect	ISO 6520 Def. No.	Comments	Limits for: Moderate requirements	Medium requirements	Stringent requirements
1	Cracks	100		Detectable cracks not permitted	Detectable cracks not permitted	Detectable cracks not permitted
2	Crater cracks	104		A few crater cracks permitted but no systematic defects Defect height and length not to exceed 20 per cent of the weld thickness, or 5 mm, whichever is the more onerous. Systematic, detectable defects are not permitted	Detectable crater cracks not permitted	Detectable crater cracks not permitted
3	Uniformly distributed porosity	2011 2012 (2016)	Projection on a plane parallel to the surface of the joint over the length of weld examined. Evaluation should be carried out separately for each area affected by porosity	Porsosity not to exceed 4 per cent of the projected area. Dimension of any single cavity not to exceed 5 mm	Porosity not to exceed 2 per cent of the projected area. Extent of any single cavity not to exceed 4 mm	Porosity not to exceed 1 per cent of the projected area. Extent of any single cavity not to exceed 3 mm
4	Clustered porosity	2013 (2016)	Projection on a plane parallel to the surface of the joint The porous area shall be local, systematic defects are not permitted. The possibility of masking other defects may have to be taken into consideration for observed percentages above approximately 5%	Porosity not to exceed 16 per cent of the projected area. Dimension of any single cavity not to exceed 4 mm	Porosity not to exceed 8 per cent of the projected area. Dimension of any single cavity not to exceed 3 mm	Porosity not to exceed 4 per cent of the projected area. Dimension of any single cavity not to exceed 2 mm

Table 1—continued

Defect Ref. No.	Type of defect	ISO 6520 Def. No.	Comments	Limits for : Moderate requirements	Medium requirements	Stringent requirements
5	Elongated cavities, wormholes, crater pipes	2015 2016 2024	Only a few crater pipes permitted (no systematic defects)	Height and width of continuous defects not to exceed 2 mm Height and width of local defects not to exceed 4 mm	Detectable continuous defects not permitted. Height and width of local defects not to exceed 3 mm	Detectable continuous defects not permitted. Height and width of local defects not to exceed 2 mm
6	Solid inclusions	300		The same limits apply as for the defect types No. 5		
7	Lack of fusion	401		Detectable defects not permitted	Detectable defects not permitted	Detectable defects not permitted
8	Incomplete penetration	402	Applies to butt welds in butt, corner and T joints. If the weld thickness has been prescribed to be *smaller* than the plate thickness, the defect height is the difference between the nominal and actual weld thickness. If, for this type of welds, it is considered necessary to avoid actual weld thickness *exceeding* the prescribed values, supplementary requirements must be stipulated.	Detectable continuous defects not permitted. Local defects permitted if height does not exceed 2 mm, but not more than 20 per cent of the weld thickness	Detectable continuous defects not permitted. Local defects permitted if height does not exceed 1.5 mm, but not more than 10 per cent of the weld thickness	Detectable defects not permitted

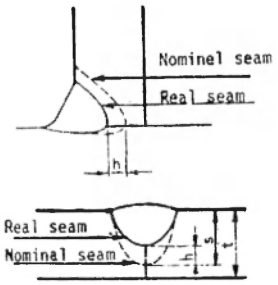
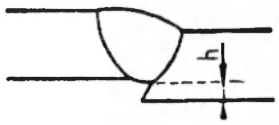
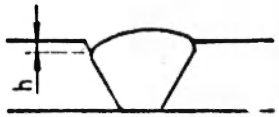
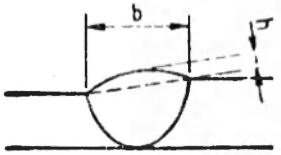
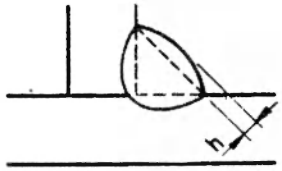
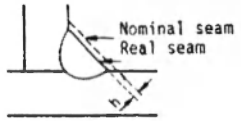


Table 1—continued

Defect Ref. No.	Type of defect	ISO 6520 Def. No.	Comments	Limits for: Moderate requirements	Medium requirements	Stringent requirements
9	Root notch			The height of the notch shall not exceed the limits stated for incomplete penetration (defect No. 8). See also defect No. 16. *Note : A notch at the root of butt welds welded from one side only. Related to linear misalignment.*		
10	Undercut	5011		The height of continuous defects shall not exceed 0.6 mm. The height of local defects shall not exceed 1.0 mm	The height of continuous defects shall not exceed 0.4 mm. The height of local defects shall not exceed 0.6 mm	The height of continuous defects shall not exceed 0.2 mm. The height of local defects shall not exceed 0.4 mm
11	Excessive convexity of weld surface, butt welds	502		The height of the reinforcement shall not exceed 10 mm but not more than 1 mm+25 per cent of the width of the weld reinforcement	The height of the reinforcement shall not exceed 7 mm, but not more than 1 mm+15 per cent of the width of the weld reinforcement	The height of the reinforcement shall not exceed 5 mm, but not more than 1 mm+10 per cent of the width of the weld reinforcement
12	Excessive convexity of weld surface, fillet welds*	503		Height shall not exceed 5 mm, but not more than 1 mm +20 per cent of the actual throat thickness (1 mm+10 per cent of the width of the weld reinforcement)	Height shall not exceed 4 mm, but not more than 1 mm+15 per cent of the actual throat thickness (1 mm+7.5 per cent of the width of the weld reinforcement)	Height shall not exceed 3 mm, but not more than 1 mm+10 per cent of the actual throat thickness (1 mm+5 per cent of the width of the weld reinforcement)
13	Fillet weld having a throat thickness smaller than the nominal value			The deviation only to occur locally and not to exceed 2 mm, but not more than 0.3 mm+5 per cent of the nominal throat thickness	The deviation only to occur locally and not to exceed 1 mm, but not more than 0.3 mm+5 per cent of the nominal throat thickness	No deviations permitted

* Similar requirements may be used as a guideline for the heights of individual runs in multirun welds, using the bead width instead of reinforcement width.

Table 1—continued

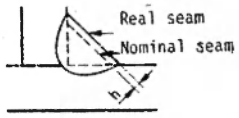
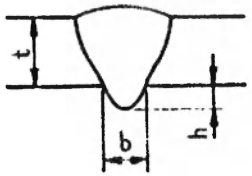
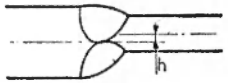
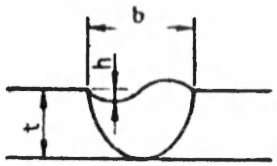
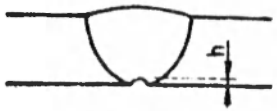
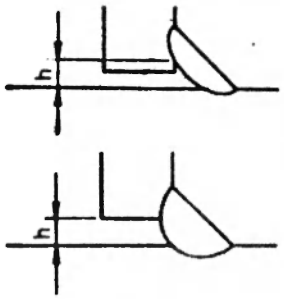
Defect Ref. No.	Type of defect	ISO 6520 Def. No.	Comments	Limits for: Moderate requirements	Medium requirements	Stringent requirements
14	Fillet weld having a throat thickness greater than the nominal value			The deviation not to exceed 5 mm, but not more than 1 mm+20 per cent of the nominal throat thickness	The deviation not to exceed 4 mm, but not more than 1 mm+15 per cent of the nominal throat thickness	The deviation not to exceed 3 mm but not more than 1 mm+10 per cent of the nominal throat thickness
15	Excessive penetration	504		The height of the penetration not to exceed 5 mm, but not more than 1 mm+120 per cent of the width of the penetration	The height of the penetration not to exceed 4 mm, but not more than 1 mm+60 per cent of the width of the penetration	The height of the penetration not to exceed 3 mm, but not more than 1 mm+30 per cent of the width of the penetration
16	Linear misalignment	507	The limits stated relate to deviations from correct position. What is understood by correct position depends on the circumstances. Unless otherwise specified, correct position for plates means that centrelines coincide Misalignments measured on the surface may be larger or smaller depending on variations in plate thickness, pipe diameter and wall thickness etc. See also clause 1.2.4 	Deviation not to exceed 4 mm, but not more than 25 per cent of the plate thickness	Deviation not to exceed 3 mm, but not more than 15 per cent of the plate thickness	Deviation not to exceed 2 mm, but not more than 10 per cent of the plate thickness

Table 1—continued

Defect Ref. No.	Type of defect	ISO 6520 Def. No.	Comments	Limits for: Moderate requirements	Medium requirements	Stringent requirements
17	Incompletely filled groove, butt welds	511	The values apply to smooth, rounded underfill. For sharp defects the values for the defect type: undercut, (No. 10), shall be used 	No continuous defects allowed. The depth of local defects not to exceed 1.5 mm, but not more than 20 per cent of the throat thickness	No continuous defects allowed. The depth of local defects not to exceed 1.0 mm, but not more than 10 per cent of the throat thickness	No continuous defects allowed. The depth of local defects not to exceed 0.5 mm, but not more than 5 per cent of the throat thickness
18	Asymmetric fillet weld	512	It is assumed that an asymmetric fillet weld has not been expressly prescribed	The difference between the leg lengths not to exceed 2 mm+20 per cent of the actual throat thickness	The difference between the leg lengths not to exceed 2 mm+15 per cent of the actual throat thickness	The difference between the leg lengths not to exceed 1.5 mm+15 per cent of the actual throat thickness
19	Root concavity	515		The same limits as for the defect type: incomplete penetration, (No. 8) If edges are melted, the limits stated for defect No. 10 may be used, as an alternative		
20	Bad fit up and incomplete penetration, fillet welds		A gap between the parts to be joined and incomplete penetration  Gaps exceeding the appropriate limit may in certain cases be compensated by a corresponding increase of the throat.	Defect height not to exceed 4 mm, but not more than 1 mm+30 per cent of the nominal throat thickness	Defect height not to exceed 3 mm, but not more than 0.5 mm+20 per cent of the nominal throat thickness	Defect height not to exceed 2 mm, but not more than 0.5 mm+10 per cent of the nominal throat thickness

The following notations have been used in the figures: b=width of weld reinforcement h=defect height s=nominal weld thickness t=plate thickness

APPENDIX A

This appendix is for information only, and does not form a part of the requirements.

General notes on quality and inspection requirements

A1 Fitness-for-purpose

Fitness-for-purpose of a product means that the product functions satisfactorily in service during the expected lifetime. Geometrical defects in welds may influence the strength of the welds ; large defects may lower the strength to an unacceptable level and render the product unfit.

Fitness-for-purpose quality requirements are, as a general rule, defined as the most severe defect configuration which may be present in the welds, without imparing the fitness-for-purpose of the product. In many cases defect height is the essential parameter and fitness-for-purpose quality requirements state limits for defect height. Defect length usually is less important for elongated defects. However, defect type is also important ; planar defects (cracks, lack of fusion, lack of penetration, undercut etc.) are considered more dangerous than volumetric defects (porosity, for example) of the same height.

A2 Quality control

Any workshop should have some quality requirements applicable for the quality control of the welding production. The main purpose of the workshop quality control is to identify malfunctioning equipment, faulty procedures, and welders not performing satisfactorily for one reason or another within the production system, thereby permitting corrective actions to be taken. Quite naturally, *quality control quality requirements* relate to "levels of good workmanship".

A3 The performance of inspection systems

Inspection of welds is a common safeguard against the acceptance of products which are unfit for the purpose. The inspection system includes various non-destructive examinations. Each examination procedure includes a set of acceptance criteria, which are intended to be closely correlated to defect size and configuration as defined by the appropriate quality requirements.

A plot of the results of the examination of daily (or some other suitable interval) production shows the fluctuations in the quality of the welding (fig. A3).

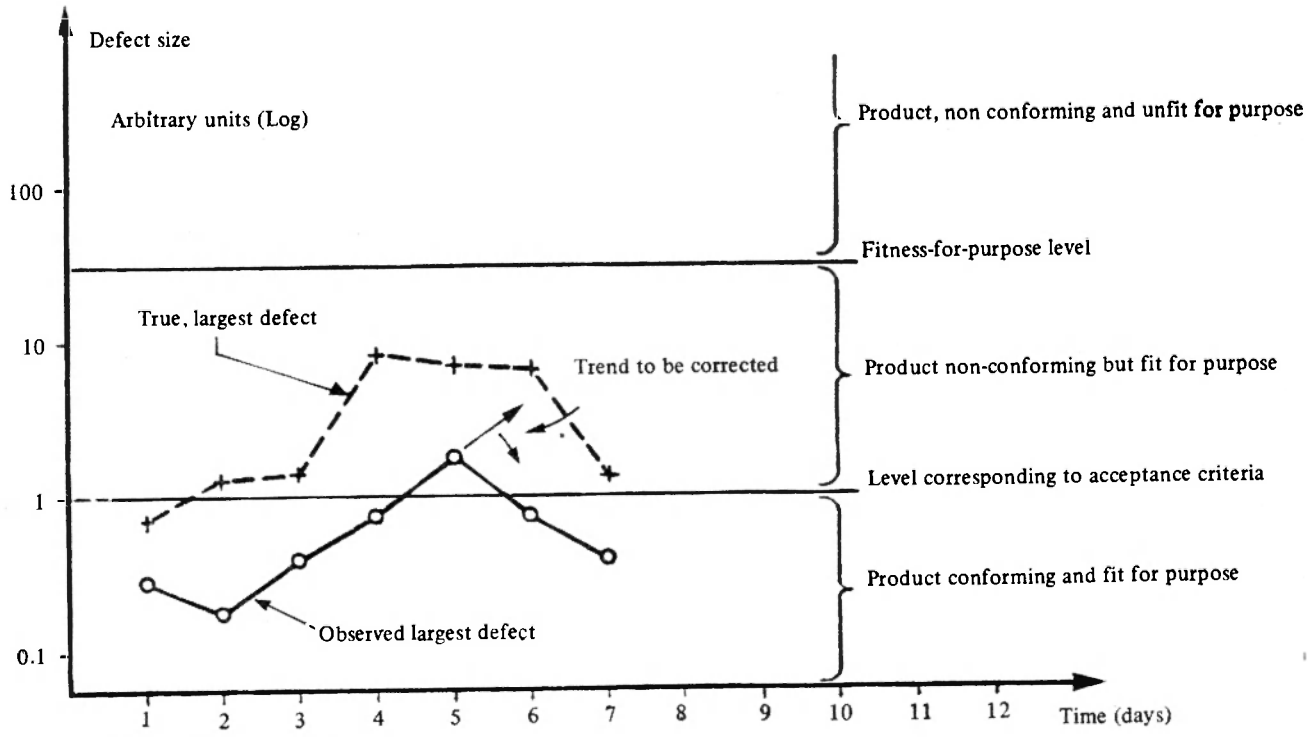


Fig. A3, Plot of examination results.

As a general rule, the acceptance criteria level corresponds to a defect size (defect severity) smaller than the fitness-for-purpose level. The two levels may be separated by a large factor on defect size in certain applications. This factor functions as a safety factor on defect size, which compensates inspection uncertainties. It is known that non-destructive examination procedures are able to give only an uncertain estimate of the true defect size and configuration. The true, largest defect may be much larger than the observed (estimated) largest defect. This is in particular (but not exclusively) the case when only a sample of all welds is examined. Observed (estimated) defects larger than the acceptance level signifies that the welding production is drifting towards low quality. This trend should be corrected. The product examined is non-conforming, but not necessarily unfit for the purpose.

Repair may often be avoided, provided a better estimate of the true largest defect is obtained (by more extensive and/or more efficient examination) and no defect is estimated to exceed the fitness-for-purpose level.

APPENDIX B

This appendix is for information only, and does not form a part of the requirements.

Inspection uncertainties

B1 Categories of uncertainties

Inspection uncertainties are presently being studied by Sub-Commission VF of Commision V ; pending the preparation of more comprehensive documents, appendix B gives a very brief introduction to a rather complicated subject.

There are three main categories on inspection uncertainties :

Uncertainties related to sampling
Uncertainties related to examination procedures
Uncertainties related to inspection system deficiencies

Sampling is a common way of reducing examination expenses. However, when only a sample (a part) of all welds in a product is examined, the quality of the unexamined welds is unknown. The size of the largest defect may be estimated, but the estimate is uncertain. The magnitude of this uncertainty depends on relative sample size ; the uncertainty may be reduced by using larger samples. In principle this uncertainty is nil when all welds are examined.

Uncertainties related to examination procedures may be due to one of several factors. Non-destructive examination of welds usually involves human operators, often working under adverse conditions. Deviations and errors may occur. The common non-destructive procedures are in themselves far from perfect. Not all defects are found and sizing of defects is notoriously difficult.

The inspection system as such may malfunction, thereby adding further uncertainties. Examples of system malfunctioning are : Use of wrong specificationst incompetent inspectors and operators, lack of an efficien, maintenance system for examination equipment. Efficient quality assurance of the inspection system and all inspection activities is the preferred remedy against malfunctioning of the inspection system.

B2 The performance of procedures for non-destructive examination

Visual examination is a common and efficient method for evaluation of surface defects. Reproducibility and repeatability are supposedly of the order 0.5 mm. Larger deviations are frequent, however, because defect height (e.g. depth of undercut, deviation of fillet weld throat from design throat, height of reinforcement) varies along the weld ; measured height depends on the position of measurement.

The width of surface cracks often is smaller than the limit of resolution for the human eye (approximately 0.05 mm). Unaided, visual examination is unreliable as regards detection of surface cracks. Methods such as *magnetic particle examination and penetrant examination* give indications much wider than the true crack width. Visual examination aided by one of these methods (properly performed) is considered fairly reliable as regards detection of surface cracks. Still, as a manual method, inspector performance is critical for the reliability.

The height of surface cracks may be measured by special, non-destructive methods. These methods require specially trained operators and the uncertainty is of the same order as the uncertainty for examination of buried defects.

Radiography and ultrasonic examination are (with very few exceptions) the only methods available for detection and evaluation of defects buried in the weld metal.

Radiography is most sensitive to three dimensional discontinuties such as (wide) lack-of-penetration, slag inclusion and porosity. Other discontinuities such as

cracks and lack-of-fusion are less reliably detected, especially when oriented a few degrees askew of the radiation beam. In order to be readily discernible on the film, the thickness of the discontinuity parallel to the radiation beam must be of the order of two per cent of the weld thickness. As the thickness of the weld increases, the quality of the discontinuity image decreases due to radiation scattering within the weld.

Determination of defect height by radiography is difficult, if not impossible. However, special radiographic methods permit the evaluation of defect height in certain cases, but the methods are non-standard and special equipment and specially trained operators are needed.

In contrast to radiography, the *ultrasonic* technique is highly sensitive to two dimensional discontinuities and less sensitive to three dimensional ones. Ultrasonic examination explores the reflection or refraction of an ultrasonic beam by a defect. The ultrasonic beam must be reflected straight back into the transducer from a defect ; if not, the defect is not detected (a similar restriction exists when two or more transducers are used). Planar defects may easily be overlooked if unfavourably oriented in relation to the direction of the ultrasonic beam used during the examination. Ultrasonic methods may provide an evaluation of defect height but use of a beam angle corresponding to defect orientation is very important a significant source of uncertainty).

APPENDIX C

This appendix is for information only, and does not form a part of the requirements.

Recommendations for the application of the document

In consideration of the present situation with respect to methods for non-destructive examination, inspection systems, welding technology, design codes and methods for the determination of critical defect sizes, Commission V recommends the following guidelines for the application of the document :

1. Production of arc welded products should be carried out within an efficient quality control system in the workshop and on site. A part of this system is comprehensive quality requirements for the welds. It is recommended to use this document as a basis for definition of such quality requirements (quality control levels). Preferably a single class (moderate, medium or stringent) should be applied for each batch of welds, if possible a single class for all welds in a given product or even for the total production. As an alternative individual requirements may be prescribed for each type of defect (e.g. stringent requirements for slag inclusions, medium for reinforcement, moderate for lack of penetration etc.) This is a more flexible, but also more complicated approach, and it has to be taken into consideration that determination of defect type is notoriously difficult for buried defects. For certain applications, the requirements for one or more defects may have to be modified and/or supplemented. In order to avoid confusion during production, such deviations should be kept at a minimum, if not avoided.

2. Customers* should use quality control requirements as initial requirements when acceptability of a product is evaluated.

   The choice of the class of requirement needed depends on stress level and the nature of the welded product. Customers should, in addition, ask for a conventional inspection system including a reasonable amount of non-destructive examinations, visual inspection, welding inspection, procedure testing etc.

3. The acceptance criteria for each non-destructive examination should be derived from the (geometrical) defect sizes in the class prescribed. The uncertainties inherent to each examination procedure should be compensated by a careful and conservative calibration. This, incidentally may permit the acceptance of marginally non-conforming welds by reexamination using a more precise and accurate examination procedure than used during the original examination.

4. Experience has shown that products conforming to the above mentioned requirements are fit-for-purpose, as a general rule. However, a substantial safety factor on defect size is inherent, for many applications. Even non-conforming products may, therefore, be fit-for-purpose.

5. When non-conforming welds are detected, the following precautions are recommended :

   (a) The quality control requirements should be considered a warning level. The workshop should take immediate and efficient action, correcting the welding production in such a way that future welds conform to the requirements.

*End users, designers, code committees, etc.

(b) The nature and the extent of non-conformity should be determined. This may involve, for example, further non-destructive examinations. All welds in the batch of nonconforming welds should be identified.

6. All welds in their entire length in a non-conforming batch may be repaired or even scrapped. This is a solution which is recommended only in special cases :

— when systematic, grave defects occur, such as extensive cracking

— when repair is easy and without harmful effects, which may be the case, for instance, for certain surface defects. An insufficient throat of a fillet weld may be repaired by welding one or more additional runs on top, etc.

7. As an alternative to (6), only the defective parts of the welds in the non-conforming batch may be repaired. One of the following solutions may be used :

7.1 The defective parts are defined as parts where defects surpassing the fitness-for-purpose quality requirements exist. Only these parts are repaired. This solution minimizes or even eliminates repair. However, the fitness-for-purpose quality requirements have to be determined which may involve complicated calculations, not found in conventional design codes. Further, the welds have to be thoroughly examined using non-standard methods. For further information see document IIS/IIW-636-80 (ref. 3).

7.2. The defective parts are defined as parts where defects surpassing the quality control requirements exist. These parts are repaired. This solution involves repair which may be both extensive and unnecessary. The advantages are: no special calculations are required and all examinations may be of a conventional nature.

The Sub-Commission holds the opinion that solution 7.1. represents the ideal, long term solution, but also that practical difficulties and the present level of fracture mechanics methods and examination technology often cause solution 7.2 to be the only one feasible. In any case the difficulties involved in repair should be taken into consideration. Harmful effects, such as excessive residual stresses or metallurgical deterioration may result from repair welding.
