A Rational Approach to Standards for Welded Construction

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Part 2

Weld Metal

Weld metal, even if its chemical composition approaches that of the parent metal very closely, is a material inevitably very different in constitution and structure as a result of rapid solidification, reheating and the effects of plastic deformation during cooling which are totally unlike those imposed by rolling. Yet in our specifications we pretend that weld metal can or should have the same properties as the parent metal and that this is important in relation to the safety of the structure. The outward manifestation of this pretence is the weld metal tensile test. A more useless and more meaningless test is difficult to imagine.

The mechanism of deformation and fracture observed in the tensile test, i.e., the general extension followed by necking, and the cup and cone fracture, are peculiar to tests involving round specimens and are entirely a consequence of certain geometric parameters of the machined, round, specimen. What is observed in a tensile test is not readily related to deformation and fracture of a structure; not even a member is a structure subjected purely to tensile stress. The cup and cone type of fracture for instance is only observable in a tensile test with a cylindrical specimen. Welds are never stressed except through parent metal and the stress conditions, the deformation and eventual fracture of a weld are as much influenced by the stress and consequent deformation of the heat affected zone and the adjacent parent metal as by the mechanical properties of the weld itself. Moreover, those mechanical properties in a single pass weld or in a multiple weld when the inter-pass temperature would normally drop almost to room temperature will be quite different from these properties determined in an all weld metal test piece. It is well known that for most weld metals the percentage elongation, which for no sensible reason is expected to match that of the parent metal, is in fact very much lower unless very much higher interpass temperatures are used in making the specimen than would be used in practical welding or alternatively the specimen is heat treated before testing.

Weld metal does not have to perform except in conjunction with a parent material and it is difficult to see what information is obtained from an all weld metal test piece that is not much more realistically obtained in the transverse tensile test or cruciform test. Despite the stringent and quite unrealistic ductility requirements in the all weld metal test piece. recent work carried out at the British Welding Research Association has revealed that when a structure such as pressure vessel is subjected to long time creep conditions at higher temperatures, failures may eventually take place as the result of preferential cracking in the weld metal indicating that the parent metal can sustain much larger deformations than the weld metal at high temperatures. Figure 3 shows such a creep failure after 1200 hours and 6% creep strain at 450° C in a weld attaching a nozzle to a pressure vessel. Figure 4 shows similar cracks in a machined butt weld in an experimental spherical mild steel vessel after 1800 hours and 2.8% membrane strain also at 450°C.

There is no relation between percentage elongation at room temperature and creep ductility and it may well be that in striving for an unnecessarily high degree of room temperature ductility in weld metal, as demanded by the all weld metal test, we diminish the high temperature creep ductility that might be obtainable at some sacrifice of room temperature ductility by suitable alloying.

It is significant that this particular deficiency of weld metal was revealed in tests on actual pressure vessels, that is in weld metal : parent metal combinations. It is doubtful whether this same deficiency would be apparent in all weld metal tests.

For one thing it would be quite difficult to specify priorital the minimum creep ductility required at any given temperature of, as seems likely, it proved in any case impossible to match the creep ductility of the parent metal.

The confusion between mechanical testing

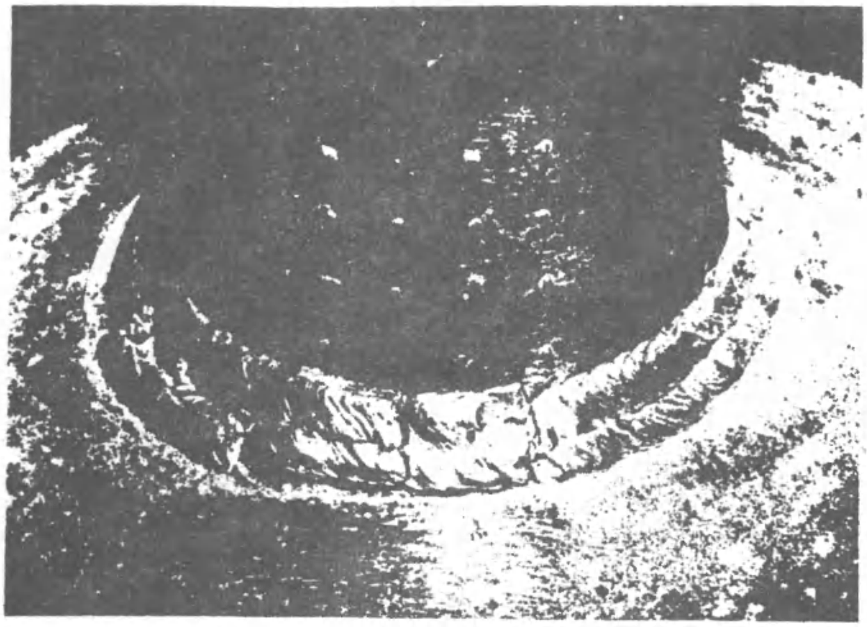

Fig. 3 Creep rupture failure in mild steel weld attaching nozzle to pressure vessel after 1200 hr at 450°C, under internal pressure producing creep strain of 6 %

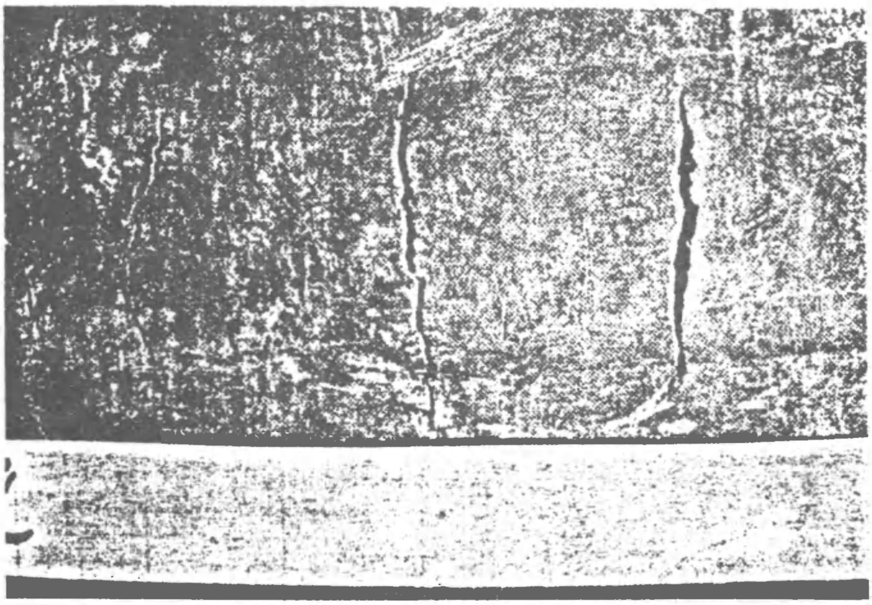

Fig. 4 Creep rupture failure in machined shell butt weld of experimental mild steel pressure vessel welded with mild steel electrode after 1800 hr at 450°C under pressure producing 2.8 % membrane creep strain.

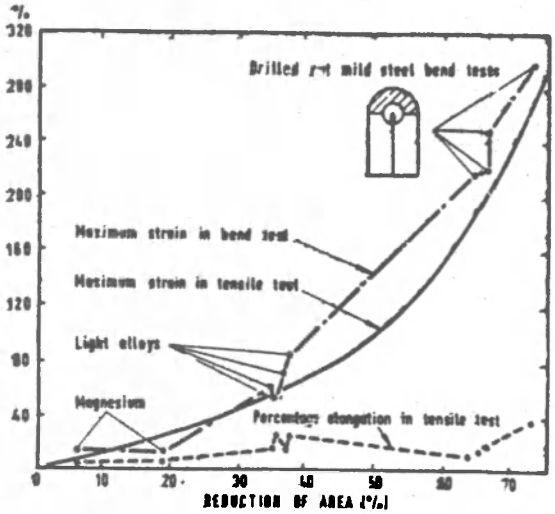

Fig. 5 Relation between percentage elongation, maximum strain in the tensile test, maximu strain in the bend test and reduction of area i the tensile test.

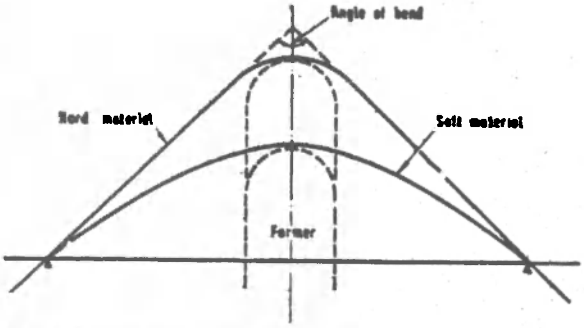

Fig. 6 Hard and soft materials sustain different amounts of maximum fibre strain when bent to the same angle.

purely as a method of quality control in production and the significance of the properties determined in mechanical tests for the safe design of a structure becomes particularly obvious in the attempts - pathetic sometimes - to make other welding processes conform with requirements established for manual arc welding of mild steel.

Most specifications for weld metal require a transverse bend test on a butt weld. For plain plate the bend test has no other significance than to check whether the material can be flanged by cold deformation without cracking. There is, however, a clear relation given by the full curve in Fig. 5 due to Kuntze between the reduction of area in the tensile test and the maximum strain to fracture in the bend test. This relation holds reasonably well for all metals and it will be observed incidentally that percentage elongation gives no indication at all of the ultimate ductility of a metal when subjected to severe non-uniform straining as it is in the bend test or in the region of high strain concentration in a structure. Aluminium alloys with a percentage elongation of not much less and sometimes more than mild steel nevertheless show smaller reductions in area and consequently require a much larger diameter former in the bend test than mild steel if they are to stand bending 180° without cracking. All this means is that aluminium alloy plate is more difficult to flange than mild steel, but it also means that aluminium alloys in general are less ductile than mild steel in accommodating very high strains in local regions of stress concentration without cracking. This, however, has not in any way diminished the attractiveness of aluminium alloys for high duty structures such as aircraft or low temperature pressure vessels made to perfectly satisfactory standards of safety.

For the same bend angle a hard material will sustain much higher extreme fibre strain than a soft material as is illustrated in Fig. 6. If a harder material cracks at a smaller bend angle than a softer material it does not necessarily mean that the harder material is less ductile; it may in fact have sustained much higher plastic strains before cracking than the soft material which did not crack at all.

If one applies all this to the interpretation of the results of bend tests on butt welds which consists of a sequence of hard and soft zones a bend test failure does not necessarily indicate a bad or unacceptable weld; it may merely indicate that at any given bend angle one zone has been strained much more than another. If the weld metal has a higher yield point and a different stress strain curve from the parent metal it will clearly deform less in the bend test than the thermally softened zones on either side of it. If a premature rupture should occur this may merely mean that the deformation in the bend test has not been absorbed uniformally and that consequently the softened zones have been strained to rupture at a smaller bend angle than they would have been had the total deformation been more uniformally distributed over the weld and heat affected zone.

The bend test requirements are particularly difficult to meet with welded aluminium alloys. The welding speed in particular has a strong influence on the width of the softened zone; a very wide softened zone is clearly undesirable and yet the wider it is the easier it will be to satisfy the requirements of the bend test. The result of this is that welded joints made at high welding speed with narrow softened zones may be condemned whereas inherently soft and weak joints may pass.

Nobody in fact is quite sure what the transverse bend test is trying to establish. The ASME code says that the bend test is carried out 'to check the degree of soundness and ductility of groove weld joints'. It clearly does neither; sponge, perhaps the best example of unsoundness, bends readily without rupture. If a bend test fails as the result of a large slag inclusion or as the result of lack of side wall fusion is one to conclude that the weld metal is bad or is one to condemn a whole pressure vessel in which radiography and ultrasonic testing fail to find another slag inclusion or any lack of side wall fusion?

The soundness of weld, if it is important, can be established much better by radiography, ultrasonics and other means of non-destructive testing. At the best the bend test cannot supply information that is not already available from non-destructive examination or from the tensile test. Like the all-weld metal test piece it is totally irrelevant in relation to design and safety and totally inadequte as an indication of either weld quality or weld soundness.

Whatever tests are used for quality control of any given combination of parent metal and welding process the requirements should be appropriate to the particular metal and welding process and not be derived from requirements applicable to a different material or a different welding process. What can be achieved in the way of say low temperature impact properties in multipass manual arc welding may not be achievable in electroslag welding or even in submerged arc welding.

Objective criteria of requirements should be established strictly on the basis of what is required for safety - and this can clearly be done only by proper scientific investigations of the problem in the laboratory. In the context of any new welding process the requirements established for a more traditional process may be totally irrelevant and may, in fact, have been quite unrelated to the question of real safety in the past. Some of the newer welding processes such as CO_2 welding or electroslag welding may give much more defect-free and hydrogen-free deposits so that risk of cracking is much smaller and consequently a lower impact value may be perfectly acceptable without any sacrifice in overall safety.

The relative importance of low temperature notch toughness of weld metal in the whole complex picture of the brittle fracture problem is in any case by no means firmly established. There are no indications from the examination of brittle fractures that have occurred in service that the notch ductility of the weld metal is a critical factor. There has been one brittle failure of a welded gas-holder (during construction) in which the fractures initiated as longitudinal cracks along butt welds which had not been chipped back and rewelded from the reverse side so that there was a continuous, extremely long, pre-existing crack present pointing right at the centre line of the weld. The notch toughness of the weld metal was 33 ft. lb at the temperature of fracture.

WELD DEFECTS

Methods of non-destructive testing have been developed and gradually improved with the result that smaller and smaller defects in welds have become detectable and the problem of establishing acceptable levels of unsoundness has become increasing economic importance. Eventually this problem will disappear because there is every indication from present trends in the development of welding processes that processes such as manual arc welding with their inherent liability to produce defective welds will gradually be replaced by other processes with perhaps built-in quality control which will make it virtually impossible to produce defective welds. We would not today put up with machine tools incapable of achieving close tolerances and we may not have to put up for ever with welding processes producing defective welds.

For the time being, however, defective welds are with us and this raises the important question of whether any defects can be tolerated in welds and if so what is tolerable level of defectiveness. Some authorities - in the API-ASME Code for instance - have produced porosity charts and rules for permissible sizes of other defects which in the complete absence of any factual or experimental basis, must have been the result of divine inspiration of the code makers - though it does not say anywhere in the code whether the inspiration was the result of protracted fasting or not so that they began to see spots in front of their eyes.

For the sake of perfectionism - if notfoı the sake of economy or safety - completely defect-free welds could be justified. some people will have nothing but the best and they derive more aesthetic joy from a clean X-ray than from the most beautiful picture in the National Gallery. This is quite in order as long as it is they and not some sone else who has to pay for it. Lesser mortals may have to be satisfied with what is good enough for the job cannot be established by divine inspiration but only by patient experimental research. Such researches have amply demonstrated that for many jobs far less than absolute perfection is adequate.

Whether a given defect is permissible or not depends on the extent to which the defect increases the risk of failure of the structure. It is quite clear that this will vary with the type of structure, its service conditions and the material from which it is constructed. More specifically the following factors have to be considered:

1. The nature of the loading conditions whether static impact, fatigue or creep.

2. The stress level at the point where the defect is located.

3. The lowest temperature to which the structure is subjected in service (or during a pressure or overload test preceding service).

4. The notch toughness of the material in which the defect is located at the lowest service or test temperature and its notch sensitivity under conditions of fatigue loading.

DEFECTS AND STATIC STRENGTH

Under purely static conditions and at temperatures where the material in which the defect is located is above the transition temperature so that there is, a priorital, no risk off brittle fracture, defects can only lower the strength in proportion to the area of cross section they occupy. In some materials - mild steel is the most typical - the strength of weld metal will be higher than the parent metal so that even extensive areas of defectiveness will not reduce the strength of the joint to a value smaller than that of the parent metal. This is amply borne out by static tensile tests on butt welds in mild steel when even gross defects have been shown to produce no reduction in strength.

In aluminium alloys defects may reduce static strength if the weld metal strength only just matches parent metal strength where, therefore, the transverse tensile test piece would be expected to fall in any case in the weld and not in the parent metal. If, on the other hand, there is fairly wide softened zone on either side of the weld failure may not take place in the weld but in the softened zone even if the weld is defective. There are not at present sufficient experimental data available on which reliable acceptance criteria for defects in aluminium alloys could be established. However the possible strength-reducing effect of any possible defects in the weld has to be seen in relation to other factors which may reduce the strength of a structure. It does not seem very sensible for instance to worry about some fairly scattered porosity and yet permit the inclusion of a weld contour the so-called 'reinforcement' better called 'overfill') which forms a fairly acute angle with the plate surface and introduces a stress concentration which may lower joint strength much more than porosity. More will have to be said about this in the context of fatigue.

Standards & Codes

New and revised Indian Standards and Amendments published during the preceeding month of September, 1986

IS : 822-1970 : Codes of procedure for inspection of welds.

IS : 226-1975 : Structural Steels (Standard Quality) (fifth revision)

IS : 806-1968 : Code of practice for use of Steel Tubes in general building construction (first revision)

IS : 814(Part 2)-1974 : Covered electrodes for metal arc welding of structural steel : Part 2 for Welding Sheets (fourth revision).

IS : 2041-1982 : Steel plates for pressure vessels.used at moderate and low temperature (first revision).

IS : 3589-1981 : Electrically welded steel pipes for water, gas and sewage (150 to 2000 mm nominal size) (first revision)

IS : 6286-1971 : Seamless and welded steel pipe for subzero temperature service.

IS : Buyers' Guide, Part 16 : Structural and Metals - Metal products.

IS : Buyers' Guide, Part 17 : Structural and Metals-Structural Steel.

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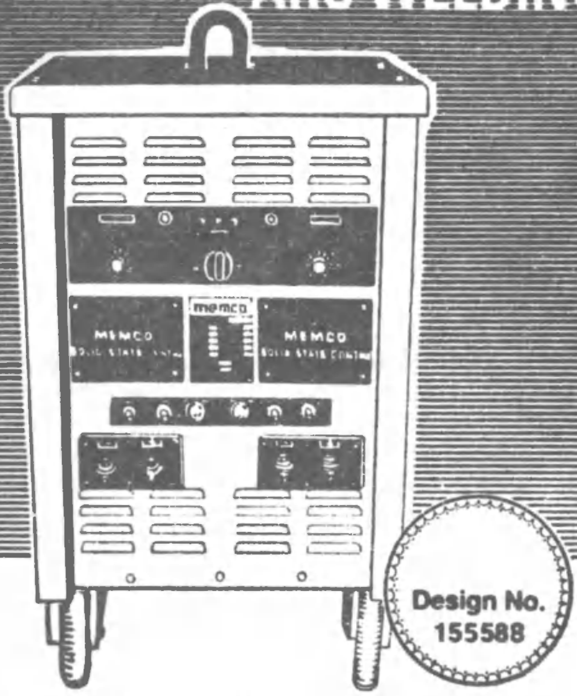

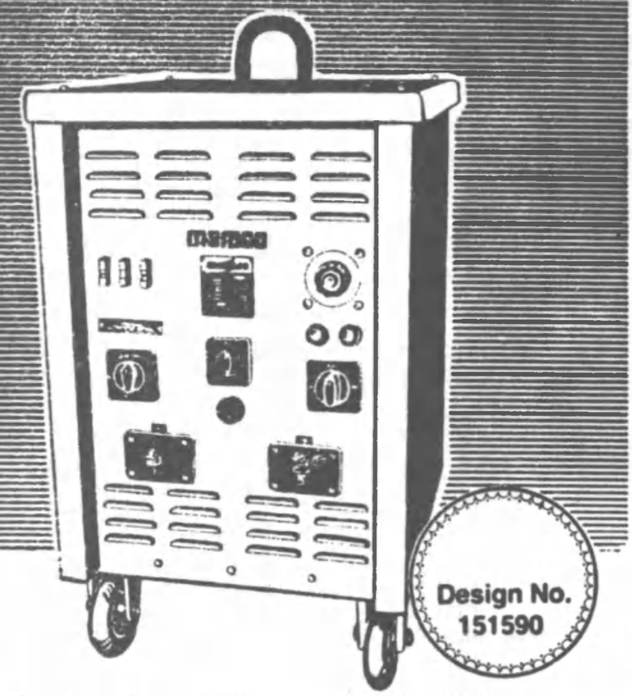

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