Weldability

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Welding as a technique of joining has such advantages as lower construction cost, saving in weight and greater flexibility of design. Constructions technically impossible by other fabrication processes have been achieved by welding processes.

In the wake of large-scale use of welding as a fabrication method, the materials of construction have been required to possess the so called property of 'weldability'. 'Weldability', as defined by the American Welding Society[1], is the capacity of a metal or combination of metals to be welded under fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service. A material would be considered to possess 'ideal weldability' if it is capable of being joined by any desired welding process, without special precautions, to produce joints whose properties allow the full potential of the materials to be utilized. Most of the materials of construction are nowhere near ideality and a number of factors affect this property of weldability. Obviously, weldability is not an intrinsic property of materials.

As can be seen, weldability involves three principal aspects[2] :

(a) Practical weldability which studies technical conditions under which welding can be carried out, whether by fusion or any other process like forge welding.

(b) Metallurgical weldability which is concerned with the micro structural changes in the materials brought about by the welding operation.

(c) Technical weldability which aims at determining the overall qualities of weld design as it affects weldability.

Numerous and varied tests have been proposed to evaluate weldability.

The overall measure of weldability is done in terms of the following parameters.

(i) Susceptibility to cracking

(ii) Distortion

(iii) Strength of the joint. It includes static, dynamic and, in certain high temperature materials, creep strength

(iv) Fracture toughness
(v) Brittle transition temperature in case of low temperature applications.
(vi) Corrosion resistance. (It is not always necessary.)

If welds are to permit full potentials of materials of construction to be realized, the following specific conditions must be fulfilled :

(a) The strength of the joint must be at least as great as that of the parent material.

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(b) The fracture ductility of the weld and heat affected zone (HAZ) must be sufficient to ensure that brittle fracture properties of the structure in service are not limited by these factors alone.

(c) The fatigue and creep properties of the joint should not be impaired by the metallurgical condition of the weld or HAZ.

(d) No localised corrosion attack should be favoured by the weld or HAZ.

These specific conditions depend upon the previously mentioned three aspects of weldability. Over the last quarter of a century, many workers in the field of welding research have contributed to the study of these aspects. The present paper is in the form of a review of present day knowledge about metallurgical and technical aspects of weldability and also critical appreciation of various tests designed to evaluate weldability as far as the major problem of crack susceptibility is concerned.

Metallurgical Weldability

The metallurgical aspect of weldability mainly deals with the resultant microstructure of welding operation in the joint region. Microstructure is known to affect all the parameters of weldability measure.

Under microstructure, one studies the following features in general :

(a) Grain size and shape

(b) Morphology of grains

(c) Phases ; their morphology

(d) Impurities ; their type, shape, size and distribution

(e) Discontinuities ; their shape, size and distribution

Ideally speaking, there should be least disturbance of base metal structure during welding and, in case of fusion welding, a fine grained fusion zone should exist. However, as the process stands, it is not possible to obtain ideal structures. In all welding processes, parent materials are subjected to a thermal cycle which brings about structural changes near the welded area. It is known as 'heat-affected zone' or HAZ. In case of fusion welds we have an additional distinct zone called fusion zone.

Microstructural Features of Fusion Zone

Microstructural features of fusion zone may be considered as resulting from 'natural' or 'externally influenced' solidification events[3]. Discontinuities are the externally influenced events which can be controlled by controlling external factors (process, procedure and/or environmental effects). These discontinuities in structure may be in the form of micro or macro porosity, oxide inclusions or incipient cracks.

The natural solidification events and accompanying microstructural features can be described as follows: Solidification begins with epitaxial growth upon incompletely melted grains in the heat affected zone surrounding the molten metal pool[1]. This soon leads to the creation of a solid/liquid interface consisting of numerous protuberances.

A cellular structure results when many slight protuberances advance simultaneously to create an interface deviating only slightly from a smooth surface.

An entirely different mode of growth results when a protuberance shoots out as a small spike. Since the transverse growth rate of the spikes is less than the longitudinal growth rate, branching of central stalk occurs, leading to cellular-dendritic growth mode.

Segregation accompanies both cellular and dendritic growth modes. A cellular structure leads to minimization of segregation and the mean distance between solute-rich regions (Fig. 1).

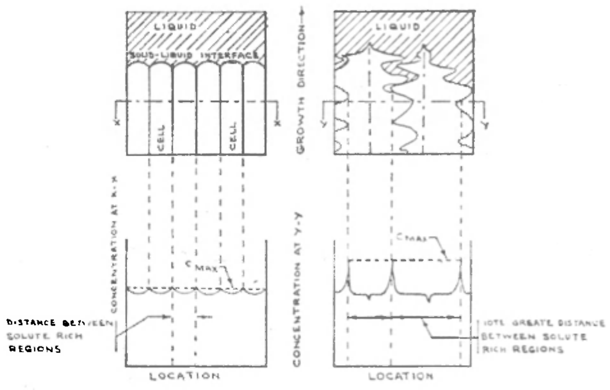


Fig. 1.

Certain alloys which show a marked degree of constitutional supercooling result into dendritic and equiaxed grain regions.

Theoretical relationships governing the mode of solidification are shown in Fig. 2.

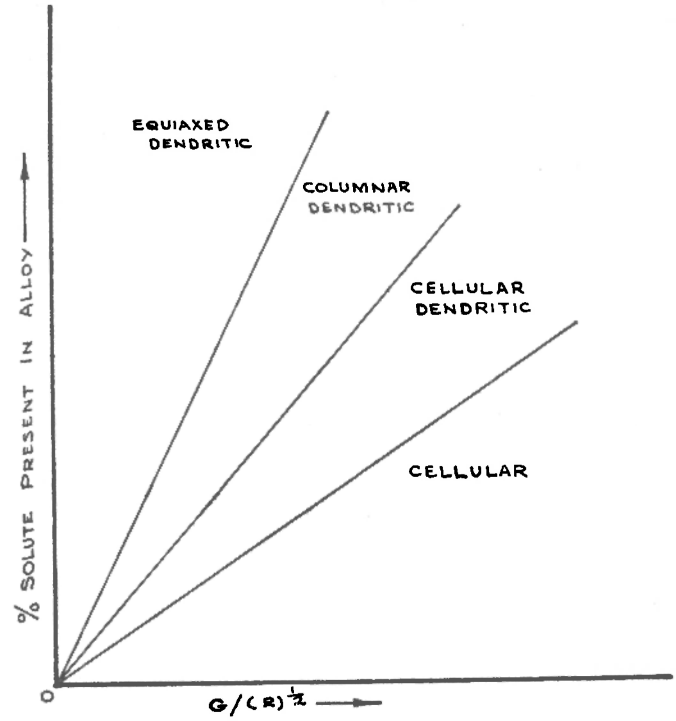


Fig. 2.

Microstructural Features of HAZ

The thermal cycles due to welding, set up at each point in the parent metal a stationary thermal condition which is defined by the maximum temperature attained (Qm) and the cooling rate (Vm) (Fig. 3)

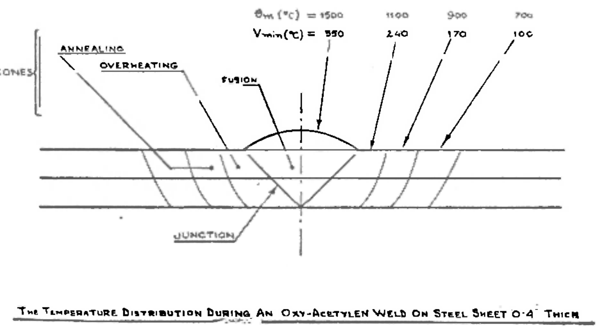


Fig. 3.

Microstructural features are a result of the changes introduced by the thermal cycle. These changes will depend on the two factors Qm and Vm. The following structural features are possible : (a) Grain boundary fusion if low melting phase is present near grain boundaries (b) Grain coarsening—a natural consequence of over heating (c) Redistribution of phases e.g. formation of grain boundary brittle phase (cementite) in steels, widmanstatten structure etc. (d) Recrystallization of cold worked grain (e) Allotropic Transformations e.g. martensite formation and (f) Precipitation of a new phase.

Consequence of Weld Region Microstructure

Burning in the overheated zone would lead to cracking. It is indicative of low ductility and poor fracture toughness.

Microsegregation would help stress corrosion cracking. Microporosity would lead to lower fatigue strength. Formation of such structures as martensite would introduce a lot of residual stresses which affect fatigue strength and distortion. Precipitation of phases would invariably weaken the joint area.

Technical Weldability

The third important aspect of weldability is the overall design of welded joints. The design of welded structure should be such that the distortion of the finished product is minimum, any arrangement that results in rigid joints should be avoided as much as possible ; full rigidity develops excessive restraint which can readily result in cracked welds during fabrication or later failure in service[5]. This can be achieved by proper positioning of the welding and minimizing of stresses. Overhead welding, as a rule, gives the least stress amongst the four positions viz flat, horizontal vertical, vertical and overhead.

The stresses can be minimised if proper care is taken of shrinkage, secondary bending and eccentricity of loading (Fig. 4.)

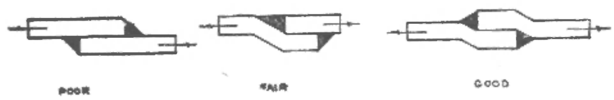


Fig. 4(a).

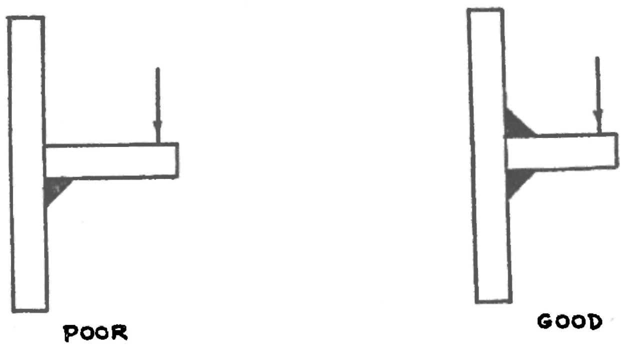
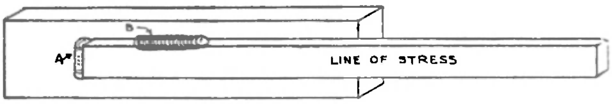


Fig. 4(b).

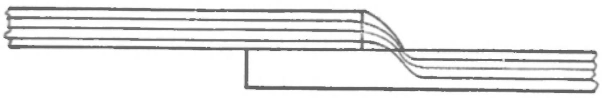
In many cases, the strength of the welded joint may be affected by the location of the welds in relation to the part joined. For instance, other factors being equal, welds having their linear dimensions transverse to the lines of stress are said to be able to carry a greater load than welds with linear dimensions parallel to lines of stress. (Fig. 5)



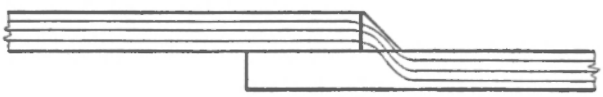
LOCATION OF WELDS IN RELATION TO LINE OF STRESS

Fig. 5.

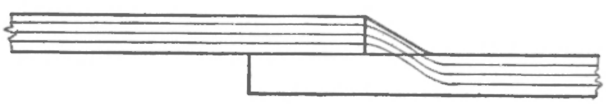
The distribution of stress through a welded joint must be carefully considered if proper results are to be obtained. An abrupt change in surface, such as a notch or saw cut in a square bar under tension increases local stress or causes stress concentration. The gradual change in section and omission of internal and external irregularities would ensure a uniformity of stress concentration. (Fig. 6)



(*a*) *Example of lap weld having poor distribution of stress through weld.*



(*b*) *Example of lap weld having a more even distribution of stress through weld.*



(*c*) *Example of lap weld in which there is a fairly uniform transfer of stress through the weld.*

Fig. 6.

In selection of the type of weld, two factors must be considered (a) intensity of loading and its characteristics and (b) effect of warping in cooling and ease of welding.

The commonly used groove welds have a number of typical characteristic properties such as : A single groove joint has good static strength but poor fatigue and impact strength. A double groove joint is capable of developing full strength both in static and dynamic conditions.

Thus we see there are many aspects of the weld design which need to be taken into account so that the material which is technically and metallurgically suitable does not fail due to design reasons.

Weldability Tests

There are several parameters to the final measure of weldability and thus there are several tests to determine weldability. For certain parameters, there are more than one test prescribed. Amongst such parameters, susceptibility to cracking is the most important one.

Technical literature[6] documents a series of well-known cracking tests. There exists no universal test, so that choice of a suitable test method depends to a great extent on the experience of an examiner. To understand the absence of any single universal cracking test one has to take a look at the variety of cracks that can be encountered in practice and explanations for their origin. Survey of literature[7] reveals that there are two types of cracks (a) hot and (b) cold. Their origin lies in one of the two regions of the welded joint, namely, HAZ and fusion zone.

In general, for a crack to appear, the first requirement is that strain must be applied to the affected material. In case of welding, that strain is invariably highly localised. The second requirement of cracking is poor ductility condition which would fail to accommodate the applied strain.

The strain in welding can occur due to (a) differential expansion and contraction arising from the application of an intense local source of heat to the joint (b) general deformation of the component : this may be produced either as a direct result of welding or in some other way. Critical strain could, for instance, be induced at the root of an unsealed butt weld as the result of deposition of several overlaying runs.

Poor ductility conditions in the joints may be due to (a) presence of thin liquid between solid metal grains (b) Presence of brittle films between comparatively more ductile metal regions (c) Drop in intrinsic ductility over a temperature range, due to phase transformation or other reasons and (d) Presence of certain gases introduced during welding.

Any laboratory test of cracking susceptibility should be able to reproduce the conditions of actual applications i.e. of restraints which introduce strains. In the light of the above comments one can examine four most widely used tests.

1. Controlled severity test[8] : This test can tell about base metal susceptibility under no external restraint but only under thermal cycle produced during welding conditions.

2. Key Hole Test[9] : This test involves conditions of mild self-restraint and thermal cycle restraint. This approximates a condition encountered in welding root passes.

3. NCFW Test[9] (NASL Circular Fillet Weldability Test) : The test employs relatively large self-restrained specimens by which heavy restraint, typical of that encountered in large constructions can be approximated. The test is capable of demonstrating delayed cracking also.

4. Varestraint Test[10] : The test employs varying degrees of restraint on the same sample. Thus it is more close to the actual strain situation in welded joint during the heat cycle. It cannot however predict any thing about cold cracking.

Conclusion

In the problem of evaluating materials for their joining capabilities, one has to take into consideration many factors, several of them being very complex in nature. For development of new alloys with respect to their weldability, one has to go through a systematic and often a time consuming programme of research to arrive at proper conditions of welding.

Acknowledgement

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