WELDING CRACKS – SOME REMEDIAL MEASURES (FOR THE REFRESHERS)

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A welding Inspector immediately declares an welded component as unacceptable, if he detects a crack in weld or in heat affected zone or in parent metal, however small it may be in dimension and depth. In fact he works very hard in all possible ways (i.e. Magnaflux, dyepenetrant, x-ray test etc.) during weld inspection, moves to and fro with his magnifying lens and finally becomes happy when he detects a crack, even if it is of 'insignificant' dimension & depth. Vulnerability of a crack (due to its unacceptability) can be well judged by the fact that sometimes weldability of a combination of material/thermal severity (thickness) / welding technique/process/weld consumable/ heat treatment is declared as satisfactory if the HAZ is found free from any crack. Such aspects as cause/Prevention/effect on welds of crack – the king of weld defects - are discussed here at a practical level. Many learned welding technologists, it is acknowledged, must be well conversant with the contents of this paper.

To consider definitions :

Crack : It is a discontinuity produced either by tearing of the weld metal when it is in plastic stage and is solidifying from the molten state and is still above 550°C which is called **hot crack**, or by fracture when cold when it is termed as **cold crack**.

Crack which is visible on the surface is called a **surface crack** and a crack which can only be detected by radiography or fracturing, say by nick break test, is called **Internal crack**.

Cracks in fusion welded joints may occur either in weld metal or in parent metal, e.g. in HAZ. **Weld metal crack** can generally be classified as longitudinal, transverse, crater and "hairline" which are usually associated with slag inclusions. Sometimes longitudinal crack in a weld seam may emanate from crater cracks.

Parent metal crack usually means crack within the blackish HAZ, which may be longitudinal or transverse to the seam or sometimes just under the run. Transverse crack in Parent metal may also originate from crack in the weldmetal.

CAUSE AND PREVENTION

A) Weld Metal Cracks

1. Hot cracks in weld metal may form when usually :

a) Weld Metal has high Sulphur(S) content and there is not enough manganese (Mn) present to nullify the bad effect of 'S'. 'S' is usually kept below 0.03% in weld and it is preferable to keep Mn/S ratio greater than 18.

b) Weld metal contains carbon more than 0.15%.

c) Base metal has abnormally high 'S' content (more than 0.06%) and abnormally low 'Mn' content (less than 0.4%). When 'S' content is high, films of low melting point Iron Sulphide (FeS) inclusions form as interdendritic films between the grains. Consequently the deposit will be exposed to longer time of solidification or shrinkage stress and more will be the resultant strain producing cracks. Mn has greater affinity for 'S' than Fe and hence MnS forms preferentially to FeS. Further MnS does not dissolve in liquid steel & therefore MnS does not increase the Freezing range. In order to entirely eliminate hot cracking due to sulphur, a certain Manganese – Sulphur ratio is required to be maintained in the weld metal and this would vary depending upon the Carbon Content. In the range 0.06 – 0.11% Carbon, minimum Mn/S ratio should be around 22. Between 0.11 and 0.13, the Mn/S ratio should be 30 and for Carbon content from 0.13 to 1.15 a Mn/S ratio of 59 is desirable.

d) Very thin layer of weld deposit on a comparatively thick plate may produce hot cracks. These occur particularly in root runs as small weld has less capacity to resist the contractional stress. This also occurs when the joint is too stiff to allow any distortion. For the same reason, during welding in heavy sections of plates having high restraint, the size of individual runs must be large enough to withstand the shrinkage stresses and in case of fillet welds, minimum size of root run is stipulated in specification depending on the plate thickness being welded.

e) Rapid cooling of the weld metal by chilling agents (i.e. draughts, low temperature conditions) increases the tendency of such cracking.

2. As high localised stresses arising due to shrinkage of weld metal and resistance to the movement of the parts during welding give rise to weld metal cracks, it is necessary to carefully consider the joint conditions as well as the degree of restraint opposing such movements. The assembly, therefore shall be made in such an order so as to allow shrinkage to take place freely as far as practicable.

3. Parts fitted badly or joints incorrectly prepared may give rise to poor fusion or lack of penetration or slag inclusions on some areas and from these defects hair-line cracks may initiate progressing through the depth of weld.

4. Longitudinal cracks in weld metal are more likely to occur in the first layer of a weld than elsewhere and if such crack is not gouged out and rewelded, it may spread through the subsequent layers of weld metal. Cracks of this nature frequently result from unsatisfactory shape or position of the deposit, thus it may be necessary to change the welding procedure & parameters.

   For example, during building up of worn-out flanges of railway wheels (which have high carbon content > 0.5%) by submerged arc process, longitudinal cracks of smaller lengths were found to form only on the 1st layer of deposit on the wheel material due to concave & thin profile of the weld run & deep penetration into the parent material due to which weld layer obtained high Carbon from the wheel material. By changing the various weld parameters like welding current, speed of travel, polarity & grain size/type of flux, it was possible to minimise such cracks by achieving convex profile of the run thus effecting less penetration. Even with the modified technique if a few small cracks are found to form sometimes on the 1st run, the 2nd run deposited at higher current (than that used in the first run) easily melts out these cracks of insignificant depth & dimension, as depth of penetration on the 2nd run is usually more than 1 mm. Finally, the macro etched full section of such welded wheels were found to be completely crack free. Therefore, during actual welding operation if the welding inspector finds a few small longitudinal cracks on the 1st weld layer & then stops further welding (as to him any crack is not permitted), it will definitely be a wrong step and the welding Engineer must convince him that these cracks will melt & vanish after deposition of the 2nd run due to high current of the submerged Arc process producing high penetration.

5. Transverse weld metal cracks generally form in joints with high degree of restraint and may extend into the parent plate, particularly in the HAZ, if it has been hardened.

6. In certain apzplications, it is desirable to use electrodes of special mild steel composition or of austenitic composition which deposit weld metal highly resistant to cracking.

7. The Sulphur content of most commercial mild steels does not normally affect the weldability of the material. Weld metal cracking may be encountered, however, if excess Sulphur is present in the parent plate or core wire of the electrode. Sulphur Printing of such materials can conveniently reveal the presence of undesirable quantity or segregation of Sulphur.

PARENT METAL CRACKING

1. Under certain conditions, Parent metal cracking may also occur in thick section of mild steel. Therefore in IS 226 specification for semikilled steels having 'C' content of 0.25 max & SP of 0.06 max, weldability test has been specified in case of thickness over 20 mm.

2. Usually parent metal cracking (which is also called underbead cracking or HAZ cracking) is associated with high tensile steels (i.e. medium Carbon or low alloy or high alloy steels) and normally situated within the heat affected zone which becomes easily hardend with undesirable microstructure namely martensite. Composition of the Parent plate (i.e. higher alloy content), associated cooling rate after welding, degree of restraint & joint configuration jointly play roles for formation of such HAZ/ underbead cracks. Cooling rate depends on factors like thickness of plates being welded, rate of heat input during welding, atmospheric temperature, preheating, post heating etc. and also joint configuration.

   Hardening of the HAZ results from the rapid cooling of the deposited metal and its hardness increases with the increase in thickness of the plate due to rapid dissipation of heat and consequently quenching action due to sudden cooling.

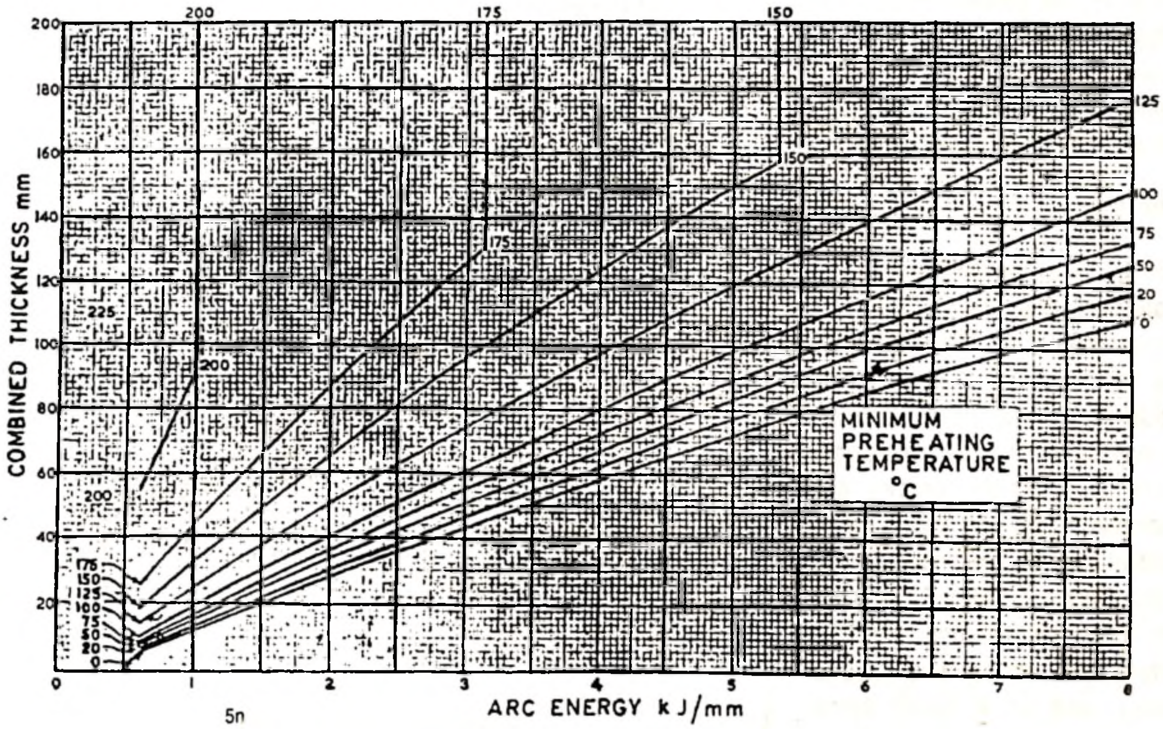
3. With higher Carbon Equivalent (CE) steels, the hardenability of HAZ increases, more so in case of heavier section and the cracking tendency increases. This is further aggravated by the presence of low melting point constituent like Fe_2S (Iron Sulphide) which could be neutralised by Mn to S ratio of 15 : 1. "Cold cracking" takes place when atomic hydrogen dissolved in weld metal (austenitic stage) diffuses into the neighbouring HAZ when austenitic structure changes and gets locked up in this zone with cooling. In time locked up Hydrogen forms molecules which meet the resistance of fast cooling metal, & build up high pressure and are finally relieved by formation of cracks in the HAZ.

   With higher CE & higher thickness of Section and at the critical cooling rate, usually a hard microstructure known as "martensite" (sharp needle shaped) forms in HAZ which is dark on macro/micro etching. This is the hardest, brittle and least ductile constituent and naturally Hydrogen gas forming pressure in such a brittle HAZ easily gives rise to crack.

   Use of hydrogen controlled electrodes, and adoption of preheating and postheating to reduce the cooling rate, overcomes this phenomenon, as the hydrogen then gets more freedom to diffuse out into the atmosphere and the low residual hydrogen, if any, also gets harmlessly dispersed.

Welding Procedure For Avoiding Hydrogen Cracking

Welding conditions for avoiding hydrogen cracking in C-Mn & alloy steels have been drawn up in graphical form in IS 9595 - 1980. 13 graphs (From Fig 5a to 5n) show the Arc energy and minimum preheat temperature required to get crack free weld for different combined thicknesses and steels of different Carbon Equivalents. One such graph for steels of C.E. between 0.55 to 0.59 is shown in Fig. 1. For getting the desired arc energy, welding speed (i.e. run length) has to be altered. Three tables (Table 6A, 6B & 6C) have been given in IS 9595 which gives run length from 410 mm of a 450 mm long electrode of



	Scale (see E-3.2)		
	A	B	C
To be used for carbon equivalent not exceding	0.55	0.57	0.59

Fig. 1 : Condition for Welding Steel of Stated Carbon Equivalent

varying sizes (2.5 to 10 mm) and Iron powder content in the covering so as to achieve the desired arc energy (from 0.6 to 8.0 Kj/mm).

Tables 2, 3, 4 & 5 in IS 9595 show the simplified conditions for fillet welds in steels of different compositions. Min. Preheat temperature has been recommended in these tables against Electrode classification & Hydrogen potential of the electrode (weld metal), specified min. leg length, min arc energy (for individual run) and combined thickness of the joint (This is the sum of the plate thicknesses averaged over a distance of 75 mm from the weld line).

Lamellar Tearing

In certain types of joint involving welding of fairly large, highly restrained structure, lamellar tearing is likely to be formed when welding on susceptible plate material. Plates having non-metallic inclusions, distributed parallel to surface, are susceptible to such tearing effect. Hence such tears (Cracks) occur in parent plate & HAZ and run generally parallel to the plate

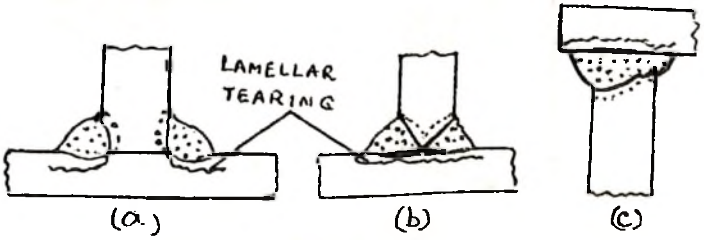


Fig. 2(a,b,c) : 'T' joint with fillet weld (a), 'T' joint with compound butt & fillet welds (b), Corner joint with butt weld (c) showing lamellar tearing (while fabricating large structures involving high degree of restraint surface. A few typical locations of such lamellar tearing are shown in Fig. 2a, b & c. Lamellar tearings frequently initiate from other defects such as hydrogen cracks.

Brittle fracture

Brittle fracture could occur by the passage of a crack through the material without visible ductility. It does not occur across a complete section instantaneously, although this may be the visible impression. Fast running brittle cracks are common in metals and alloys, where individual crystals can cleave as well as slip. Ductile failure on the other hand occurs by deformation of the crystals and slip relative to one another, and as a result some degree of visible yielding of the material adjacent to the fracture zone occurs. By analogy then brittle fracture occurs by cleavage across individual crystals and the fracture clearly reveals granular macro-structure with little or no visible yielding.

CONDITIONS FOR BRITTLE FRACTURE

Temperature

Each steel has its Ductile transition temperature (DTT) depending on its composition, at which the mode of failure changes from ductile to brittle. The lower the DTT, the better is the resistance to brittle fracture. Carbon content is an important factor affecting notch toughness of Steel and it raises the DTT by about 2^0 to 4^0F for each 0.01% increase in Carbon content. DTT is not a change

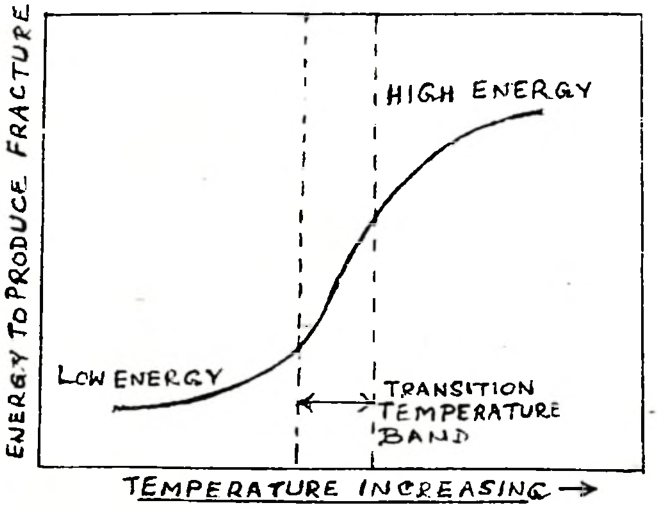


Fig. 3a : Temperature energy curve for fracture

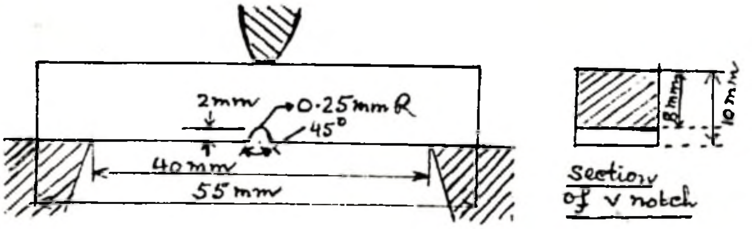


Fig. 3b : Details of charpy 'V' notch Impact test specimen

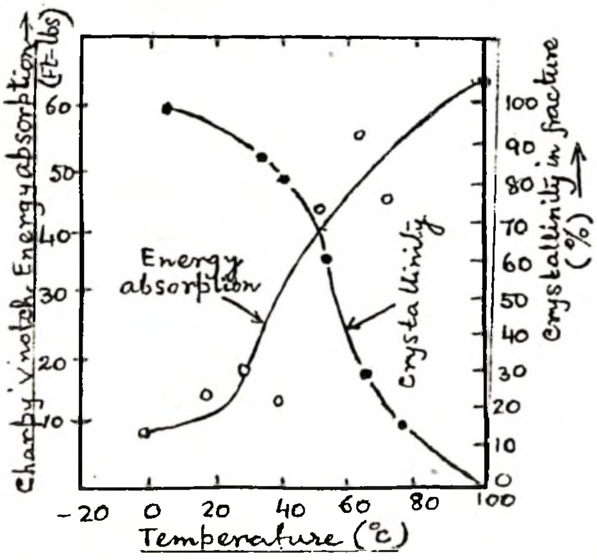


Fig. 3c : Typical curves from charpy 'V' notch specimen that occurs over a few degrees for 'C' steels but is a range of temperature band width as shown in the energy-temperature curve in Fig. 3a. A convenient method of constructing this curve is by carrying out charpy V notch Impact test at various temperatures (Fig. 3b).

It goes without saying that as the ambient temperature decreases, the risk of brittle failure increases Fig. (3c).

Thickness of Material

For a given steel, the transition temperature will vary with plate thickness. This is due to a physical difference in size and also because the micro-structure of the material varies with plate thickness due to difference in rolling & cooling cycles the material undergoes. In thicker plate, transition temperature is usually higher.

Stress concentration (notches)

In order to produce any fracture below the actual UTS, some notch, however small, is required. The worst forms of notch are welding defects like crack, lack of fusion & lack of penetration. These defects are all potential brittle crack starters. Large cracks are worse than small cracks but condition of the material at the crack tip is an important factor in fracture initiation.

Stray arc strikes on plate often produce minute hairline cracks on the surface of the material and a ship has broken in two from such an arc strike on the deck.

Stress

Usually to produce any fracture, tensile stress is required in the material. In a welded structure, the residual stresses that result from the laying of weld beads may be sufficient to initiate a brittle fracture without any externally applied stress. Compressive stresses, however do not lead to brittle fracture. Impact loading aggravates the situation for brittle fracture at a higher temperature than static loading.

We can now summarise the 3 basic requirements for brittle fracture to occur. These are :

a) A working temperature below the transition temprature of the material being used. Thick material generally has a higher transition than thin material. In case of mild steel, an energy absorption of 20ft. lbs in charpy V notch test at the minimum temperature (transition) implies a high expectation of freedom from brittle fracture in service for material of about 1 inch thickness.

b) A notch or severe stress concentration.

c) Tensile stress, applied or residual.

Fatigue Crack

A welded joint subjected to repeating cycles of stress will usually fracture at a load below that at which it would likely fail under static loading. This is known as Fatigue failure.

The load producing fracture decreases with an increasing number of cycles and when the maximum stress that the metal will sustain without fracturing is plotted against the no. of cycles, a curve (S/N Curve) results (See Fig. 4). The curve eventually tends to be parallel to the horizontal axis, indicating that there is a limiting stress that can be applied indefinitely without producing fracture. This value is termed as Fatigue Limit. The endurance limit at 'N' Cycles of a specimen is the stress which just produces fracture after 'N' stress cycles.

Four main types of loading producing fatigue may be distinguished. These are (1) Pulsating, (2) Repeating, (3) Reversing and (4) Alternating (See Fig. 5).

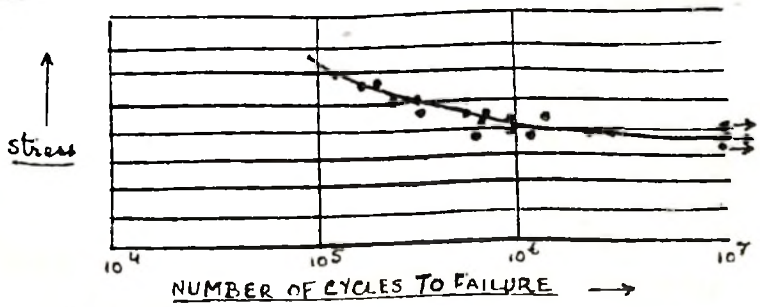


Fig. 4 : Typical curve of stress/cycles. Stress values plotted are upper limits of stress range

Repeating stress is a particular case of pulsating stress where the lower limit is zero. Alternating stress is particular case of reversing stress where the mean stress is Zero.

Apart from the nature of loading and no. of stress cycles, the strength of a joint in fatigue varies with the actual physical shape or Surface Contours. Sharp Corners, angles, notches or discontinuities in section upset the flow of stress through the joint and produce local increase in stress intensity rising in some cases to several times the average stress over the section. Such discontinuities are commonly referred to as "Stress raisers" which initiate minute cracks that gradually develop and spread until fatigue fracture occurs. In welded joints, defects like blowholes, undercut, slag inclusion, lack of root penetration, reinforcement metal act as stress raisers.

The fractured surface in a fatigue failure consists of two areas. One portion is smooth, discoloured and has concentric rippled markings like a mussel shell, indicating the gradual creeping of the crack from one or more stress raiser points, while the remainder of the surface shows either a crystalline or fibrous appearance which indicates the final tearing, which occurs when the are can no longer sustain the load (Fig. 6).

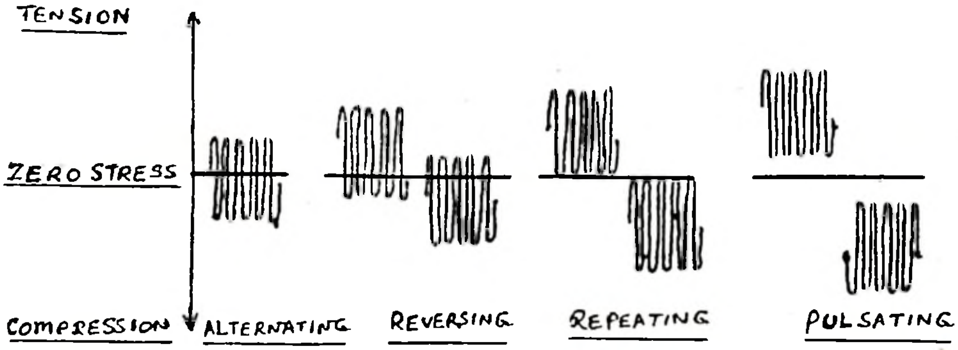


Fig. 5 : Main types of loading producing fatigue

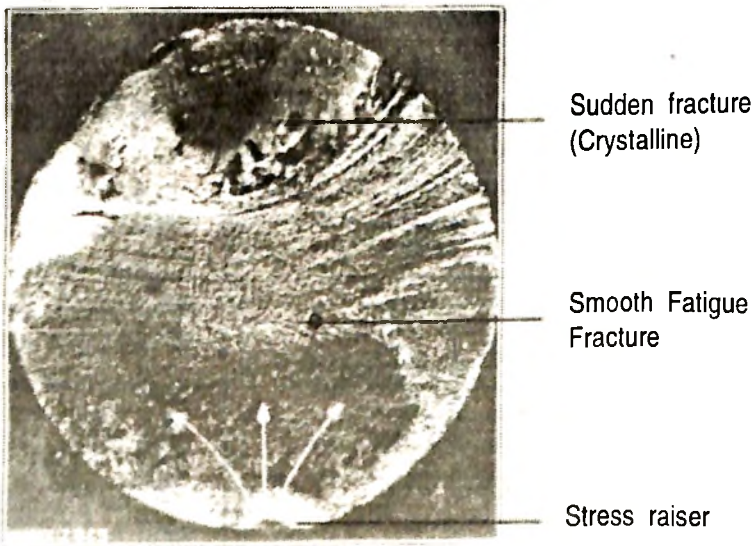


Fig. 6 : Fatigue fracture of an automobile axle shaft