Lamellar Tearing in Welded Steel Fabrication

By C. C. GIROTRA*

Problem of lamellar tearing in welded steel structures is discussed in detail in this paper, tracing the history of detection, known causes, mechanisms and welding parameters responsible. Later, a survey of tests proposed for assessing susceptibility to lamellar tearing is made.

1. Introduction

Lamellar tearing is a form of cracking that occurs in the base metal of weld due to the combined effects of the anisotropic characteristics of hot rolled steel plate and high stresses generated by weld thermal contraction acting perpendicular to the following plane. This cracking is usually associated with highly restrained tee or corner joints where the weld fusion boundary is parallel to the rolling plane of the plate.

This problem has existed since the inception of fusion welding but was not identified till sophisticated NDT processes were developed. Now it is encountered in ship building, power plant components and off-shore structures. It is of concern because (a) tearing affects integrity, (b) is difficult to detect without ultrasonic inspection, (c) repair is difficult and (d) there is generally no acceptable procedure for assessment. (See Fig. 2).

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2. History

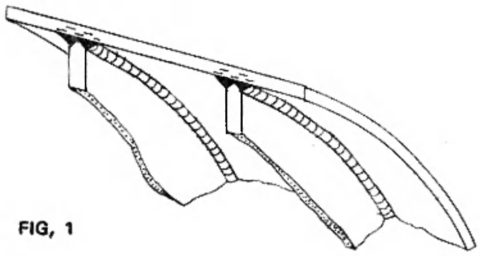
The problem of lamellar tearing was identified in the year 1961 when certain U.K. newspapers carried a report about cracking problems in nuclear submarine 'HMS Dreadnaught'. Ultrasonic examination conducted revealed cracks in the stiffened areas (Fig. 1). This was then named as "pull out cracking" but has been later termed as "Lamellar Tearing".

This problem has been reported in steels of 12 mm to 150 mm thicknesses. It does not occur in thin plates because the joint is less stiff and hence flexure of the plate takes place, thus limiting the strain.

It is not often associated with hydrogen induced HAZ cracking and may well occur even when adequate precautions against hydrogen-induced cracking have been taken.

3. Metallographic features of Lamellar Tearing

Originally, lamellar tears were illustrated which appeared to propagate from the root or toe of a weld possibly from an initial defect and was also confused



FIG, 1

with the underbead cracking. Subsequently lamellar tears were observed away from the toe or the root of a weld, and occasionally well away from the heat affected zone. In places, twin tears can occur or minor discontinuities are visible away from the main tear. Lamellar tears have been found to be completely subsurface, too.

The characteristic stepped formation due to (lamellar) tearing may be divided in to flat terraces divided by vertical shear walls (Fig. 3). Considerable evidence exists to emphasize the importance of inclusions in lamellar tearing. The terraces contain many inclusions identified as silicates, sulphides or mixtures of the two. Silicates tend to form irregular plate-like inclusions at the lower temperatures of rolling, and are often cracked, whereas sulphides are more spheroidal. Silicates may also form sharp extensions from sulphides. Thus silicates appear to be the more dangerous but in the absence of silicates the sulphides can elongate and contribute to tears. Alumina inclusions are also significant. From this thinking, the type of plates in the order of increasing susceptibility are—rimmed, Al-grain refined, Silicon-semikilled, Silicon-fully killed type steel. The appearance of the terrace surfaces, as revealed by the electron microscope is largely of ductile fracture, although there is some evidence of small areas of brittle fracture. The shear walls are often undercut and again the appearance is largely of ductile fracture. The morphology of crack faces, however is unable to explain as to why the peculiar stepped formation occurs and not in continuous line. Possible suggested mechanism will be discussed later.

4. Parent Steel

For tearing to occur, three conditions must be satisfied :

I. Strains must develop in the short transverse direction of the plate.

II. Weld orientation must be such that the fusion boundary is roughly parallel to the plate surface.

III. The material must be susceptible to tearing, that is it must have poor ductility in the short transverse (through thickness) direction.

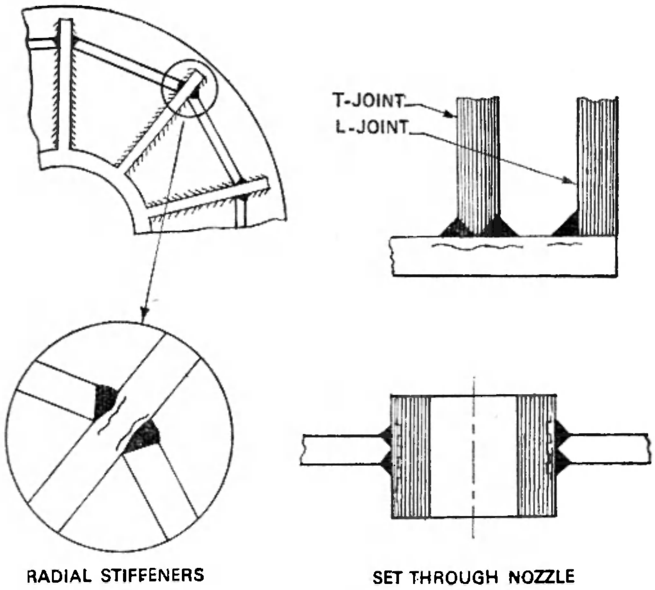


FIG 2

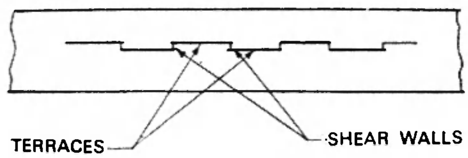


FIG. 3: METALLOGRAPHIC FEATURES OF LAMELLAR TEARING

The low ductility in the short transverse direction has been known to steel makers for many years but it is only recently that its significance has been realised. Short transverse or through thickness tensile tests often show low elongation values well below those obtained with conventional tensile tests on steel plate. These low tensile elongations are not solely due to the presence of small non-metallic inclusions. Grain flow and hence the direction strength is more in one direction in case of plates.

Any tendency to strain aging may make a secondary contribution to lamellar tearing in or near to the visible heat affected zone. Some susceptible steels have been shown to exhibit a low ductility trough in the 200°C-300°C region whereas a non-susceptible steel plate maintained high ductility at all temperatures. Dangerous temperatures can be incurred and maintained for several minutes during welding or in service.

No evidence has been reported of creep relaxation properties or the presence of hydrogen being significant in the context of lamellar tearing.

Steel making practice and subsequent treatment is very important in determining susceptibility to lamellar tearing. The significance of treatment prior to welding depends on the type, incidence, distribution and morphology of non-metallic inclusions. In general, silicates are worse than suphides and aluminates because they become brittle at higher temperatures and are therefore likely to crack or shatter during hot rolling. Equally, flat like inclusions, especially if cracked, are worse than linear or spheroidal inclusions. Rolling practice can also influence inclusions, distribution ; the lower the finish rolling temperatures the greater danger of cracking the inclusion. Initial rolling of an ingot, to some 75 mm thickness, will tend to maintain inclusions in a spheroidal form, so that material above this thickness should be reasonably safe although lamellar tearing has been reported in thicknesses of 150 mm as well. This steel below 12 mm thickness, was considered to be non-susceptible because the material would bend if load was applied in the thickness direction, although as mentioned earlier, this is not always the case. It may be noted that the requirements of high finish rolling temperatures and low finish temperatures are contrary to normal good practice. A further problem is that the inclusions do not have to cover a large area ; even small inclusions of 0.2 mm diameter have been shown to be significant.

5. Mechanism of Lamellar Tearing

Earlier thinking was that the tearing propagated from an initiating point. Explanation of formation of characteristic stepped shape is as follows. As the steel is strained in the thickness direction decoherence or possibly void formation will occur at steel inclusion boundaries. Decoherence in regions where clusters of inclusions are present may result in multiple microcracks at several levels. Sound metal between inclusions in the same plane will then fracture in a ductile manner giving the characteristic terraces. Around a cluster of inclusions on the same plane the sound material will possess good strength and ductility and will resist propagation of a tear. At this stage, the weakest link between adjacent terraces will fracture giving shear walls.

As yet, no satisfactory explanation for the crack propagation mechanism has been arrived at.

6. Influence of welding parameters

6.1 *Preheat and Heat input*

The value of high preheat temperatures or high heat input is disputed. Both techniques have proved satisfactory for simple fillet welds but have actually increased cracking in complex situations, such as nozzles in boiler drums. In any case, preheat temperatures need to be high-well above 150°C (300°F) for most steels ; which is going to be uncomfortable for welders, thereby reducing the value of this technique.

6.2 *Weld Metal*

The deposition of highly ductile weld metal is also beneficial since it will deform in preference to transferring stresses to the parent steel.

6.3 *Type of electrodes*

The use of deep penetration electrodes is beneficial in that the weld metal changes the direction of loading on the susceptible planes.

6.4 *Joint design*

Although welding procedure (in general) has not been able to eliminate lamellar tearing in all cases and all joint designs it has proved beneficial in many cases. The avoidance of rotation in fillet and T-butt welds is essential, this may be done by reducing the number of runs to a minimum and the application of restraint.

7.0 Tests for susceptibility to Lamellar Tearing

The determination of the susceptibility of a particular plate to lamellar tearing is obviously desirable, but considerable disagreement exists with regard to a satisfactory test. Ideally, a non-destructive test is required but even a generally acceptable small scale destructive test would be an improvement over the existing situation.

7.1 *Non destructive tests*

The only two non-destructive tests suggested involve the use of ultrasonics. The use of conventional waves to locate the individual inclusions is of very little value because the minimum detectable size is much greater than the smallest inclusions that can contribute to lamellar tearing. The second method, that af attenuation measurement is more logical but as yet there is no method of distinguishing the attenuation caused by inclusions and grain boundaries. In this work, ultrasonic frequencies of the order of 10 to 20 MHz have been used.

It is reported that frequencies of 2 MHz are quite suitable for the rapid location of true tears and that precise dimensions can then be fixed by the use of 4/5 MHz probes.

7.2 *Destructive Tests*

Several destructive tests have been devised and used, although they have the general disadvantages of destructive tests for quality control purposes. These tests include the measurement of mechanical properties and actual weld tests. A number of tearing tests such as notched bend tests and COD tests have been suggested but remain to be proved. We shall discuss below a few important tests proposed by various research workers.

7.2.1 *Through thickness tensile test* is a useful method for steel thicknesses above 25 mm but the minimum acceptable reduction of area, which is the criteria for ductility, remains to be determined. It may be 10% for Si-killed carbon steel. Note that tensile strength in logitudinal L) and through thickness (Z) direction correspond to the same level, only % reduction in area and elongation in Z—direction are distinctly lower. The criticism is that it does not cover the most dangerous sub surface regions or indicate the significance of weld thermal cycles.

Extensions for conducting this test have been welded by conventional or friction or even electron beam welding. (See Fig. 4). This test has been recommended by IIW for further investigations as this seems to be the most promising of all.

7.2.2 *Through thickness bend test*—Also called "Slice bend test' consists of bending sample slices of the steel plate to be used. This has given encouraging results but the test needs to be more closely defined.

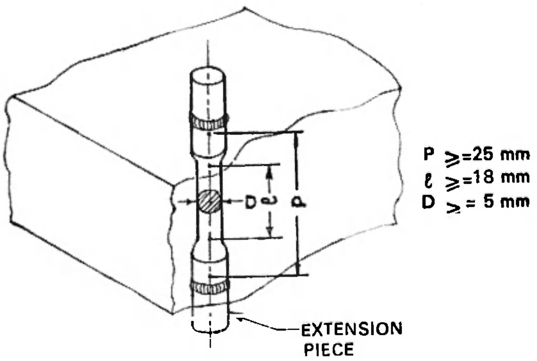
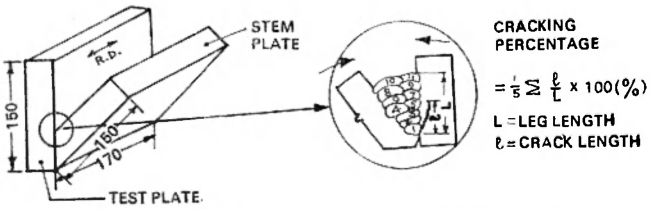


FIG. 4: SPECIMEN FOR THROUGH THICKNESS TENSILE TEST WITH EXTENSION PIECES



(a) SPECIMEN GEOMETRY OF CRANFIELD TYPE TEST

(b) DEFINITION OF CRACKING PERCENTAGE

FIG. 5 CRANFIELD TYPE TEST

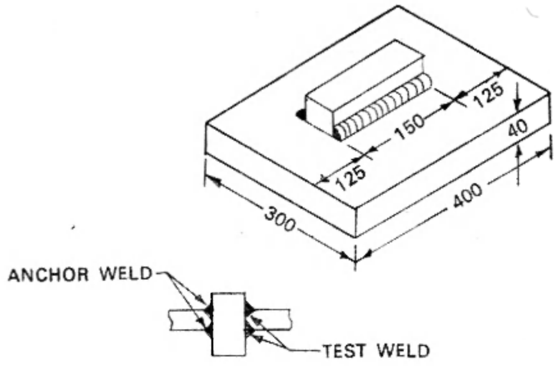


FIG. 6 : WINDOW TYPE TESTING

7.2.3 *Cranfield Test*—Cranfield test is one of the first tests proposed for lamellar tearing (See Fig. 5) by the workers at the Cranfield Institute of Technology, U.K. This has not gained wide acceptance because it is found to be a very severe test. It produces cracking in almost any steel. The cracking percentage obtained and also the method of causing lamellar tears is not characteristic of practical situations.

A modified version of this test has been proposed by workers at the Le-high University in U.S.A., where arrangment for prevention and measurement of exact force required to produce tearing are made.

7.2.4 *Window frame type test* is nearer the practical situation (See Fig. 6) but remains insensitive.

7.2.5 *Box type test* has been proposed by the U.K. welding institute which uses edge welds and may prove more selective.

8. How to avoid Lamellar Tearing

It is better to prevent lamellar tearing rather than face costly repairs. The various recommendations can be grouped under the following three headings :

8.1 Metallurgical
8.2 Technological
8.3 Structural

8.1 *Metallurgical*—Choice of steel with lower inclusions and laminations content will prevent the problem of lamellar tearing. This works quite well but is very costly and cannot avoid lamellar tearing completely.

8.2 *Technological*

8.2.1 Buttering the plate surfaces gives wider base of a ductile metal. Buttering can be done above the plate or after cutting a required depth of groove in the plate (See Fig. 7).

8.2.2 *Balanced Welding*—Modified run procedure balances strains and hence avoids tearing.

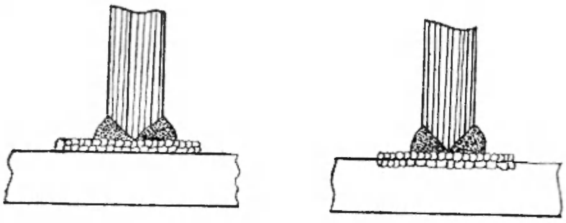


FIG. 7:BUTTERING TECHNIQUES

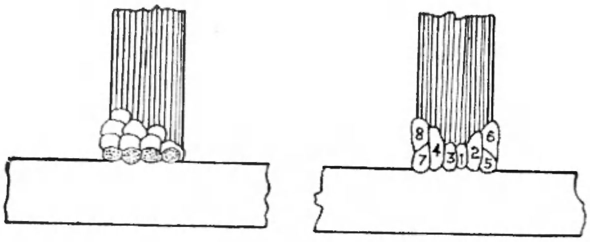


FIG.8 . BALANCED WELDING

8.2.3 *Intermediate stress relief*—Just as the effect of preheat, interpass temperature on lamellar tearing is disputed. So is the case with intermediate stress relief. Probably, high heat input in itself increases incidence of cracking.

8.2.4 *Type of electrode*—Use electrode giving weld metal strength lower than the parent metal.

8.3 *Structural*

8.3.1. Replace 'T' or 'L' joints by butt joints wherever possible.

8.3.2 Locate 'T' joints into junctions with lower rigidity.

8.3.3 Replace plates by forgings or extrusions in critical 'T' and 'L' joints etc. (Fig. 9).

8.3.4 Replace 'set through nozzle' with 'set on' nozzles. (Fig. 10).

9. Role of I.I.W.

International Institute of Welding Commission IX-F has been entrusted with the study of lamellar tearing problem. It has prepared a questionnaire in order to collect information on practical cases. It is counting on this information to check the validity of its recommendation and to establish the values to be laid down when the through thickness tensile test, which has been recommended as the standard test, is carried out.

Blank questionnaire forms can be collected from the Secretary, Indian Intitute of Welding, who will arrange to do the needful, after the relevant information has been given in the proforma by the fabricators.

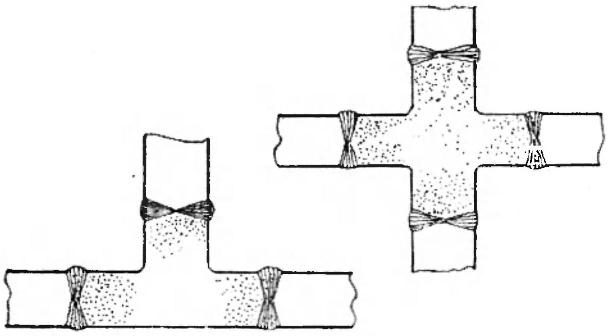


FIGURE 9.

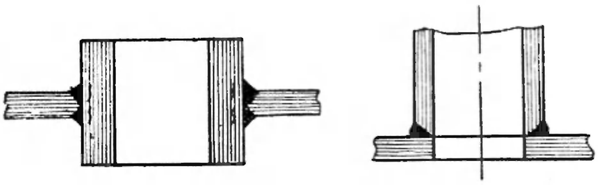


FIGURE 10.

10. The author is thankful to Power Project Engg. Division-Department of Atomic Energy for granting permission to publish this paper.

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