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A CASE STUDY ON LAMELLAR TEARING

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Abstract

Lamellar Tearing is a form of cracking that occurs in the plate material due to the combination of high localized stresses by the weldments and low ductility of the plate in through thickness direction. This paper presents a typical case study where the problem of lamellar tearing was faced during the fabrication of one of the equipment. The equipment had a typical configuration of double tube sheet welded to spacer shell, where cracks were observed in the spacer shell after the completion of tube sheets to spacer shell welding. Paper also describes details of the various factors contributing to lamellar tearing and certain design considerations for effectively overcoming this phenomenon.

Keywords: Lamellar Tearing, Case study, Joint design

1. INTRODUCTION

For one of the heat exchangers manufactured in past at vendor premises, the equipment design had a spacer shell which joined the main tube sheet and auxiliary tube sheets (Refer Fig. 1). Spacer Shell was fabricated (Refer Fig. 2) from a 25mm thick carbon steel plate, SA 516 Gr.70, procured from one of the stockist. Refer Fig. 3 for orientation of spacer shell plate thickness direction in the assembly. This spacer shell to tube sheet joints was welded by SMAW process.

During fabrication, the spacer shell to tube sheets joint, revealed many circumferential cracks near the toe of the weld in dye penetrant examination (Refer Fig. 4). The length of the crack varied from 1 mm to 4 mm and all the cracks were circumferential. A detailed investigation was carried out to find out the root cause for these cracks.

Figure 1: Spacer Shell to Tube sheet joint design

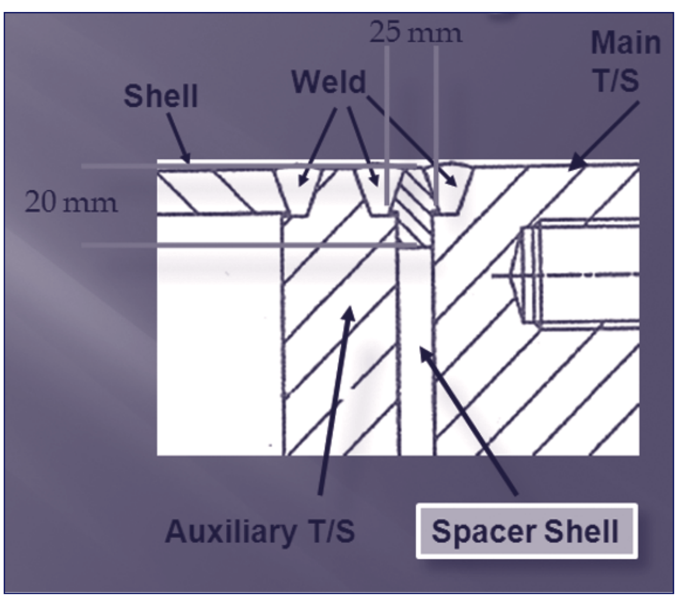


Figure 2: Spacer Shell fabrication method

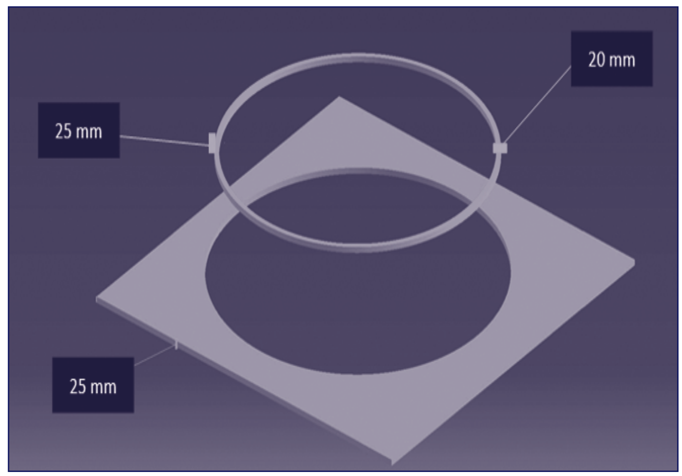


Figure 3: Orientation of plate thickness direction in assembly

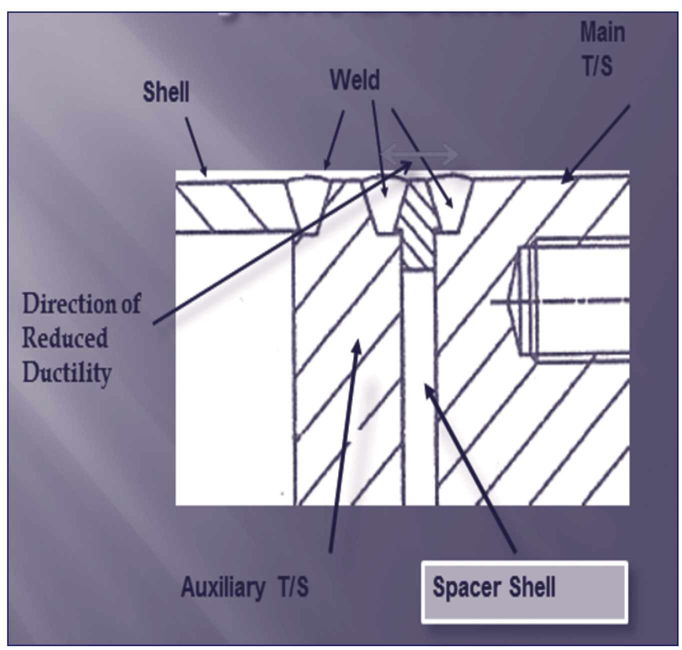
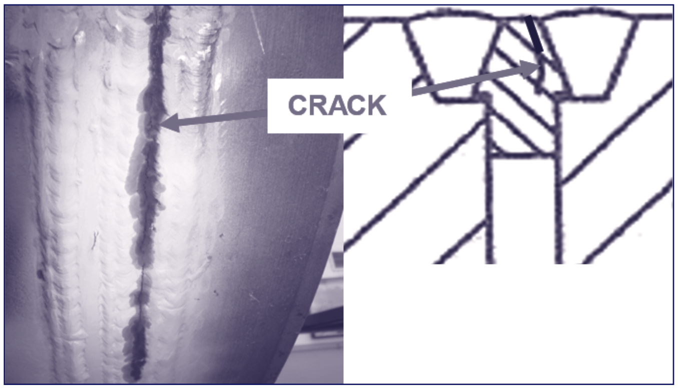


Figure 4: Spacer Shell to Tube sheet joint showing crack



2. INVESTIGATION

Since cracks were visible on the spacer shell, it was decided to first analyze the properties of the spacer shell material. Subsequently, following investigations were carried out on the spacer shell sample.

- **Chemical Examination**

  The specimen was subjected to chemical analysis by Spectrometry and the result was found to be in concurrence with the applicable material specification.

- **Tensile testing**

  In order to determine the mechanical properties, tensile testing was carried out in longitudinal & transverse direction and the same was found meeting the requirements as per material specification (Refer Table - 1). For determining the strength in thickness direction, through thickness tensile test specimens were machined and tested according to ASTM SA-770 [1]. Results are mentioned in Table – 2. Reduction in area in through thickness direction was found very less than the minimum required values.

- **Metallographic Examination**

  Specimen was cut from plate longitudinally for metallographic examination. Specimen was mirror polished as per ASTM E3, etched as per ASTM E407 and examined under microscope at a magnification of 100X, 200X, 500X and 1000X in as polished and etched condition. (Refer Fig. 5 & Fig. 6).

- **Sulphur Print Examination**

  Specimen was cut from plate longitudinally and macro-polished to check Sulphur segregation in plate (Refer Fig. 7)

Table 1: Tensile testing (Room temperature in Longitudinal & Transverse direction)

Mechanical Properties	Longitudinal	Transverse	Acceptance
0.2 % YS (MPa)	346	348	260
UTS (MPa)	518	519	485
% Elonga-tion	37.70	35.02	21 %

Table 2: Tensile testing (Room temperature through thickness direction)

Specimen	% Red. (Area)	Acceptance
T1	3.77	20% Min.
T2	0.95	

Figure 5: Photomicrograph revealing sulphide segregation in rolling direction

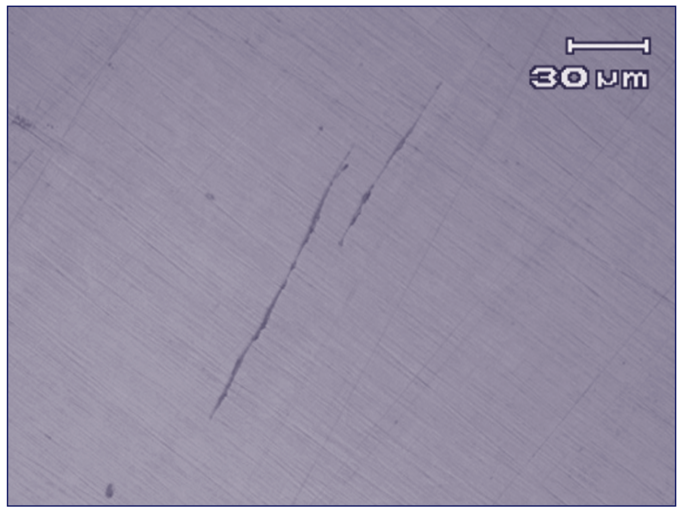


Figure 6: Photomicrograph revealing ferritic and pearlitic structure along with segregation in rolling direction

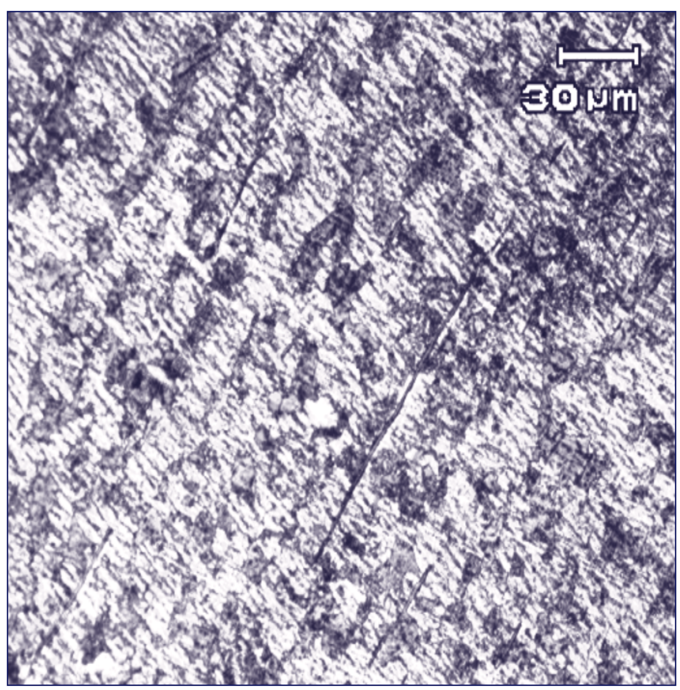
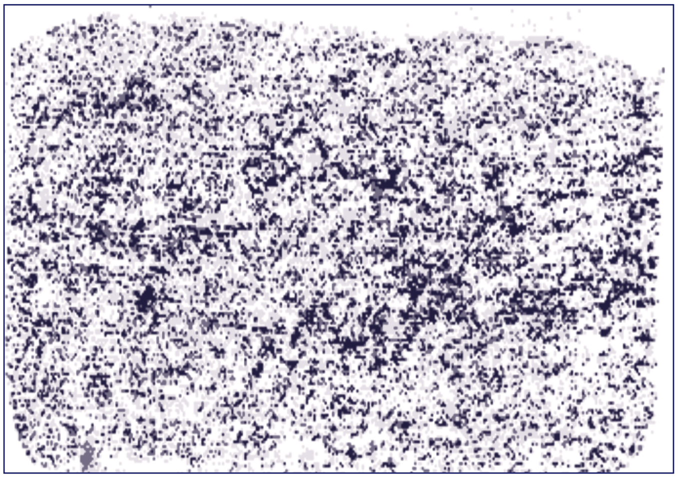


Figure 7: Sulphur Print showing the presence of sulfide inclusions



3. CONCLUSION

This is a typical case of lamellar tearing failure in steel. Investigation revealed segregation of Sulphur in rolling direction of spacer shell plate, which has led to loss of ductility in through thickness direction. Spacer shell design was done in such a way that less ductile direction has come in the weld stress zone. Such low ductile material, when subjected to stress in thickness direction has resulted in crack by lamellar tearing.

Failure of this particular joint in view of lamellar tearing resulted in substantial loss of cost & cycle time and also affected the overall equipment delivery schedule. A need was felt that this phenomenon should be understood in detail to prevent recurrence.

Lamellar Tearing

A lamellar tear is a separation or crack in the base metal caused by through-thickness weld shrinkage stress. Tearing always lies within the base metal, generally outside the HAZ and parallel to the weld fusion boundary [2]. The problem is caused by welds that subject the base metal to high shrinkage stresses in the thickness direction. Tearing is not visible on the outside surface, generally, but it can be found by Non-Destructive Examination (NDE) like ultrasonic testing.

When steel is hot-rolled, sulphides or other inclusions are elongated to form microscopic platelets in the plane of the steel plate. These inclusions reduce the ductility of the steel in the through-thickness direction. While special practices are available to produce low-Sulphur steel which is resistant to lamellar tearing and ASTM A770 provides a testing method by which the through-thickness ductility of the base metal may be measured [3], it is difficult to assure freedom from the possibility of lamellar tearing. Lamellar tearing is a phenomenon which can occur even in material with superior mechanical properties. Instead, the joint design is most important in preventing lamellar tearing. Some joint designs are inherently susceptible to lamellar tearing.

Factors influencing Lamellar Tearing

It is generally recognized that Lamellar Tearing is mainly due to following factors.

Transverse Stress:

- Prime cause is the shrinkage stress acting in through thickness direction.
- As the stresses on welding do not act through the thickness of the plate, there is low risk of tearing in butt joints [4].
- Tearing may occur in thick section joints, where the bending restraint is high.
- Where possible, arrange connections so as to avoid welded joints which induce through-thickness stress due to weld shrinkage.
- Lower strength fillet or partial penetration welds may often be used to join higher strength steels when the joint is designed for shear.

Material Susceptibility

- Plates having poor ductility in through thickness direction are highly prone for lamellar tearing [5].
- Tearing generally occurs in rolled steel plates and not in forging and castings.
- Steels with higher strength have a greater risk, when plate thickness > 25 mm [6].
- Steels with STRA (short transverse reduction area) > 20% are resistant to tearing.
- Aluminum treated steels with low Sulphur content (<0.005%) will have a low risk of lamellar tearing [6].

Weld Joint Design

Weld joint design plays a vital role in avoiding lamellar tearing. Lamellar tearing occurs in joints producing high through thickness stress for example, T joints or corner joints. In 'T' or cruciform full penetration welds will be particularly susceptible. The cruciform structure in which the susceptible plate cannot bend during welding will also greatly increase the risk of tearing. Following points shall be given due consideration while designing a joint to avoid lamellar tearing [7].

- Weld Joint design should minimize the weld size and, therefore, the resulting shrinkage stress.
- The design should reduce the restraint which intensifies the local stress.
- Fusion boundary, roughly parallel to the plane of the inclusions causes Lamellar Tearing.
- Design corner joints with proper consideration of edge preparation.
- Whenever practical, completely weld subassemblies prior to

final assembly of the connection. Sequence the welding of individual joints so that restraints will be minimized on the largest welds.

Following are some of the good design practices to be followed:

- Do not specify stiffeners when they are not required by design calculations. Stiffeners induce restraint.
- In case of "T" butt joints, two-sided fillet joints are more preferable than full penetration joints (Refer Fig. 8)
- Double sided welds are more preferred than large single sided welds (Refer Fig. 9)
- Redesigning the joint configuration so that the fusion boundary is more normal to the susceptible plate surface will be more effective (Refer Fig. 10).
- When the plate is known to have lesser through thickness ductility, buttering the surface of the susceptible plate with a low strength weld metal can be employed. Surface of the plate may be grooved such that buttered layer will extend 20 to 25 mm beyond toe of the weld (Refer Fig. 11)

Figure 8: Susceptible (left) Improved (right)

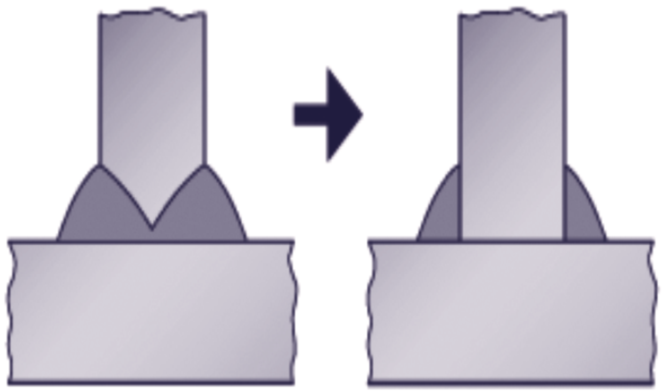


Figure 9: Susceptible (left) Improved (right)

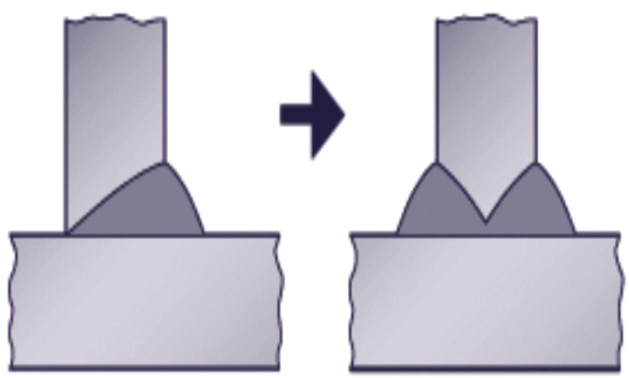


Figure 10: Susceptible (left) Improved (right)

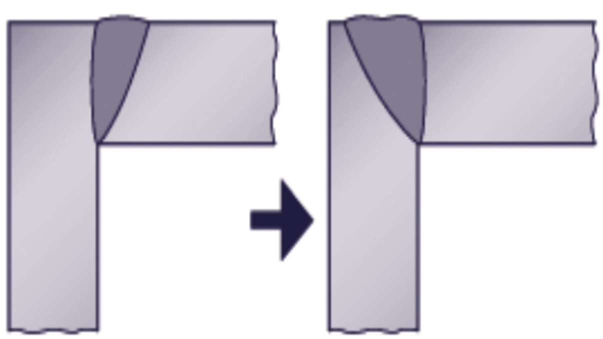
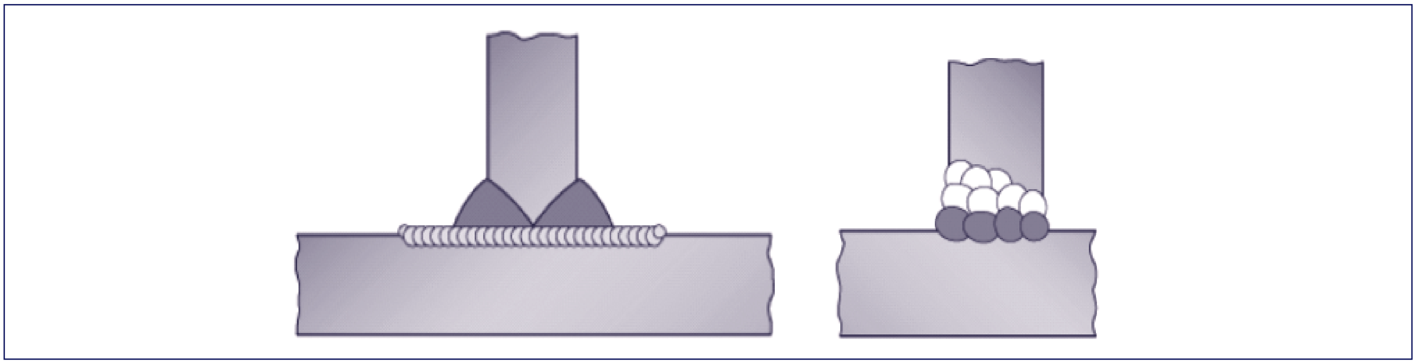


Figure 11: Buttering of the susceptible plate



Other important factors

In addition to above, there are various other factors which are responsible for tearing.

Welding process: As the material and joint design are the primary causes of tearing, the choice of welding process has only a relatively small influence on the risk. However, higher heat input processes which generate lower stresses through the larger HAZ and deeper weld penetration can be beneficial. As weld metal hydrogen will increase the risk of tearing, a low hydrogen process should be used when welding susceptible steels [8].

Welding Consumables: Where possible, the choice of a lower strength consumable can often reduce the risk by accommodating more of the strain in the weld metal. A smaller diameter electrode which can be used to produce a smaller leg length has been used to prevent tearing. A low hydrogen consumable will reduce the risk by reducing the level of weld metal diffusible hydrogen [9]. The consumables must be dried in accordance with the manufacturer's recommendations.

Preheating: Preheating will have a beneficial effect in reducing the level of weld metal diffusible hydrogen. However, it should be noted that in a restrained joint, excessive preheating could have a detrimental effect by increasing the level of restraint produced by the contraction across the weld on cooling. Preheating should, therefore, be used to reduce the hydrogen level but it should be applied so that it will not increase the amount of contraction across the weld.

Fabrication aspects

- Whenever practical, completely weld subassemblies prior to final assembly of the connection. Sequence the welding of individual joints so that restraints will be minimized on the largest welds [2].
- Tack welds should be limited to a minimum size and number.
- Before making repairs to highly restrained connections, determine whether the repair will be more detrimental than the original cause for repair. Usually, a repair must be made under greater restraint than the original weld.

4. SUMMARY

Lamellar tearing is characterized by the cracking that can occur in vulnerable steel members beneath the weld, especially in rolled plates, due to low through-thickness ductility and localized stress [10]. Lamellar tearing can be prevented to certain extent by following the various recommendations mentioned in this paper. Even with plates those having less ductility in through thickness direction, lamellar tearing can be prevented by suitable joint design & other fabrication aspects. For example, in the above-mentioned case study, the lamellar tearing could have been avoided by following:

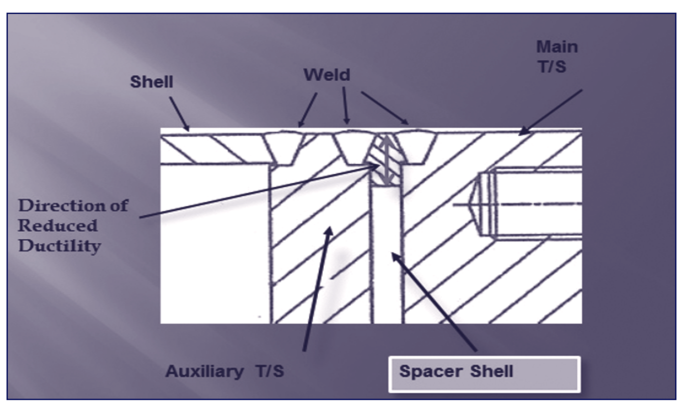
i) Alternate design of equipment where massive welds at close proximity could have been avoided. But in the present case, design of the equipment was performed by the customer and hence no change was permitted at the fabricator end.

ii) Usage of a forged ring in place of plate material for spacer shell. However, this would have increased the overall cost and lead time in getting the forged ring.

iii) Carrying out Tensile testing in through thickness direction as mentioned in ASME Sec II-A before the spacer shell plate was taken for fabrication.

iv) The spacer shell would have been fabricated in such a way that the weld shrinkage stress does not act through the joint across the plate thickness (Refer Fig.12).

Figure 12: Proposed orientation of plate thickness direction in assembly



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