Study on Weldability of EN 10025-6 S550 QT Steel

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ABSTRACT

Cracks developed in the 90 mm thick EN 10025-6 S550 QT steel plates assembled to form a box unit. After assembly the surface cracks generated longitudinally along the elongated grains while preheating or performing root run. Root cause analysis was conducted to investigate the reason for the failure and also how to specify the "conditions of materials on delivery" during procurement is generated. Various tests such as visual test, chemical composition, inclusion rating, microstructure, dye penetrant test and hardness tests were conducted. The investigation revealed that the failure cracks could be due to temper embrittlement due to the segregations of impurities such as tin, arsenic, phosphorus and antimony, etc. in the grain boundaries and resulted in ductile to brittle transformation when exposed in the temperature. It is observed that, depends on the concentration of Ti and N in steel, coarse and cuboidal TiN particles of several micrometers in size act as potential sites for cleavage crack initiation. Furthermore, during the steel making process if sulfur is not properly controlled, then large MnS inclusions can also form during solidification. Soft MnS inclusions elongate during the subsequent hot rolling process, which deteriorate ductility and impact toughness. Hence, it is essential to specify the J factor value and inclusion rate during the procurement of steel.

Keywords: Inclusion rate; welding; quenched hardened steel; tempering; J-factor.

1.0 INTRODUCTION

The 90 mm thick EN 10025-6 S550 QT steel plates assembled to form a box unit for fabrication. A proper approved welding procedure and methodology was developed for fabrication of the part. After assembly of the 90 mm plate with 70 mm thick plate. When the plates are preheated the surface cracks generated longitudinally along the elongated grain of the thick plate. A root cause analysis was conducted to understand the reason for failure and also methodology have been taken to weld with the same plate without cracks.

2.0 OBJECTIVE OF THE STUDY

- To find the root cause for the failure of the EN 10025 QT steel and derive the method to weld the plate without defects.
- To provide technical delivery condition for the procurement of material

3.0 THE FABRICATION METHOD

The 90 mm thick plate was assembled with 70 mm plate as shown in the **Figs. 1&2**. The thinner part was beveled and assembled with 90 mm thick plate as box section. The flange of the box section made with 90 mm and the web portion made with 70 mm thick plates.

Fig. 1 : Box section fit- up

Fig. 2 : Assembled box with preheater

4.0 EXPERIMENTAL METHOD

In this method the probable root causes were analyzed and the samples were sent to NABL accredited laboratory to conduct the following tests.

The following tests were conducted to find the root cause of the failure.

1. Chemistry of the parent material
2. Inclusion rate
3. Location of the crack
4. Microstructure

5.0 RESULTS AND DISCUSSION

5.1 Chemical composition of base metal

The chemical composition of the 90mm thick parent material is given in **Table 1**.

The empirical formula to find susceptibility for temper embrittlement of the Quenched and Tempered steel due to the presence of embrittlement elements is calculated by the empirical formula developed by Watanabe is known as J factor and given in equation 1. As per J factor the calculated value is 385. Hence, the risk of embrittlement is more when the J factor value is more than 180 for parent material. The embrittlement issue could be resolved by minimizing the residual elements to an extremely low level [1].

$$\textbf{J Factor} = (Mn + Si) \times (P + Sn) \times 10^4\text{-}1$$

The cracks could be originated due to temper embrittlement due to the segregations of impurities such as tin, arsenic, antimony and phosphorus and antimony etc. in the grain boundaries and result in ductile to brittle transformation when exposed in the temperature.

The presence of inclusions adversely affects the fracture toughness of the material and these inclusions act as stress risers and are potential sites for crack nucleation and micro voids due to plastic deformation resulted in the propagation of cracks. Non-metallic inclusions present in the material will influence the properties of the material [1].

Table 1: Chemical composition of 90 mm thick plate (wt%)

Chemical composition of 90 mm thick plate (in wt%)									
C	**Si**	**Mn**	**S**	**P**	**Cr**	**Mo**	**Ni**	**Al**	**Co**
0.13	0.35	1.33	0.004	0.020	0.3	0.151	0.087	0.047	0.03
Cu	**Nb**	**Ti**	**V**	**W**	**Pd**	**Sn**	**B**	**Ca**	**Bi**
0.016	0.001	0.028	0.041	0.01	0.01	0.003	0.0021	0.003	0.0
As	**Sb**	**Ta**							
0.002	0.006	0.01							

5.2 Inclusion count

The inclusions test was conducted as per ASTM E-45-13 Method A. The inclusion rates for 70 mm and 90 mm thick plate is given in **Table 2, 3 & 4** and indicate that the inclusion rate in 90 mm plate is higher than that of the 70 mm plate and the photos of 90 & 70 mm thick plates are shown in **Figs. 3 & 4** respectively. The presence of inclusions leads to different thermal expansions of the steel matrix and of the non-metallic inclusions. The welding/ preheating induce stresses in the steel matrix near the inclusions and increase in stress result in strain as well as nucleation and/or propagation of cracks in the steel matrix. From **Table 2** it is observed that presence of higher inclusions result in an increase in the stress field proportionally to the size and the number.

The values of these stresses depend largely on the difference in the thermal expansion coefficients between the steel matrix and the non-metallic inclusions. The additional stresses in non-metallic inclusions and the steel matrix that arises during heating and cooling create additional stress fields around Non-Metallic Inclusion (NMI) and steel matrix due to different thermal expansions during heating and cooling and resulting in the propagation of crack due to the stress field in the steel matrix around the inclusions.

The magnitude of the effect of non-metallic inclusions on increase in stress depends on coefficient of the thermal expansion of the NMI of the steel. Hence it divulges that, the presence of higher inclusion with heat resulted in originating crack in the base metal.

Table 2 : Type D Globular (90 mm thick plate)

Type D Globular oxide				
No. of fields	70 mm	90 mm	70 mm	90 mm
	Thin	Thin	Thick	Thick
1	1.0	1.0	0.5	0.5
2	0.5	1.5	-	1.0
3	-	1.0	0.5	0.5
4	1.0	1.0	0.5	-
5	0.5	0.5	-	0.5
	Average 0.6	Average 1.0	Average 0.3	Average 0.5

Table 4 : Type B inclusion

Type B inclusion				
No. of fields	70 mm	90 mm	70 mm	90 mm
	Thin	Thin	Thick	Thick
1	0.5	0.5	–	–
2	0.5	–	–	–
3	1.0	1.0	0.5	0.5
4	–	–	–	0.5
5	0.5	1.0	–	0.5
	Average 0.5	Average 0.5	Average 0.1	Average 0.3

Table 3 : Type A inclusion

Type A Sulphide				
No. of fields	70 mm	90 mm	70 mm	90 mm
	Thin	Thin	Thick	Thick
1	1.0	–	0.5	0.5
2	–	1.0	–	–
3	0.5	–	–	–
4	0.5	0.5	–	–
5	1.0	1.0	–	0.5
	Average 0.6	Average 0.5	Average 0.1	Average 0.2

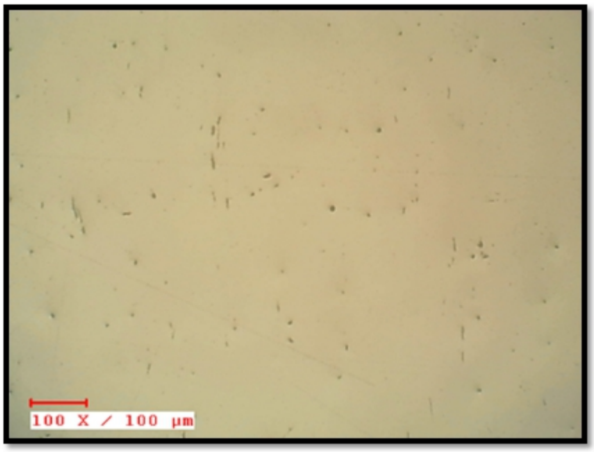

Fig. 3 : Inclusion in the 90 mm thick plate

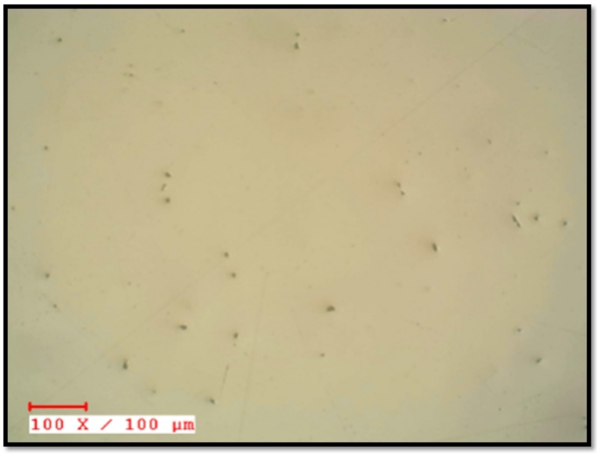

Fig. 4 : Inclusions in the 70 mm thick plate

5.3 Location of crack

The defective job was subjected to visual, dye penetrant test and ultrasonic test. The cracks were observed in the longitudinal direction of the grains and the maximum length of the crack was 350 mm and the depth was 22 mm. **Figs. 5 & 6** show the presence of the crack in the 90mm thick plate in longitudinal direction and the cracks was originated away from the joint.

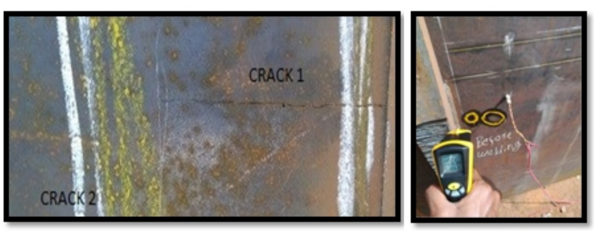

Fig. 5 : The longitudinal crack on the surface

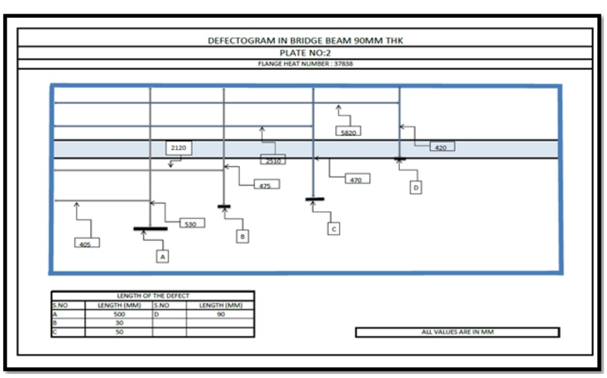

Fig. 6: The crack zone before welding (Stage: During preheating- Plate No: 2)

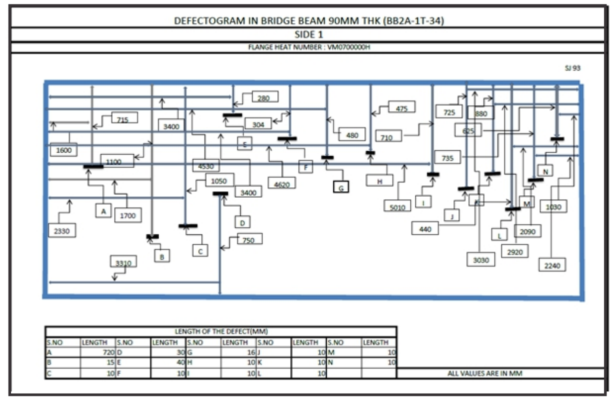

Fig. 7 : The crack zone during welding (Stage: After preheating, 6 layers Welding) - Plate No: 1

5.4 Microstructure analysis

The microstructure of the 90 mm thick plate shows the low carbon martensitic structure and ferrite grains and also reveals non- homogeneity of the structure. The specimen was etched by using 4% Nital and magnified to 200 X. The standard reference used for this study is ASTM E3-11, ASTM E4-07.

The microstructure of the normal area (**Fig. 7**) shows low carbon martensite and ferrite grains in some location and it divulge non -homogeneity in the structure, where as in the near crack area shows ferrite grain structure (**Fig. 8**). The microstructure of the 90 mm thick plate reveals (**Fig. 9**) fine grained low carbon martensite and coarse grained microstructure in 70mm plate is observed and shown in **Fig. 10**.

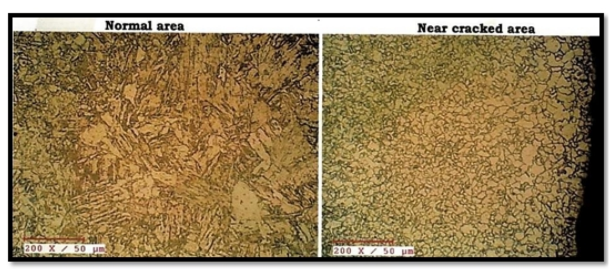

Fig. 8 : Microstructure of 90 mm plate (normal area), Microstructure of 90 mm plate near cracked zone

When carbon or low alloy steels are cooled slowly from 575 degree centigrade or tempered for extended times between 375 and 575 degree a loss in toughness occurs that manifests itself in reduced notched-bar impact strength resulting from tempering cycles and relatively fast cooling rates. The cause of temper embrittlement is believed to be precipitation of compounds containing trace elements such as tin, arsenic, antimony, and phosphorous along with chromium and manganese. It suggest that the embrittlement occurs at prior austenite grain boundris. Although manganese and chromium cannot be restricted, a reduction of the elements and quenching from above 575 degree are the most effective remedies for this type of embrittlement [3].

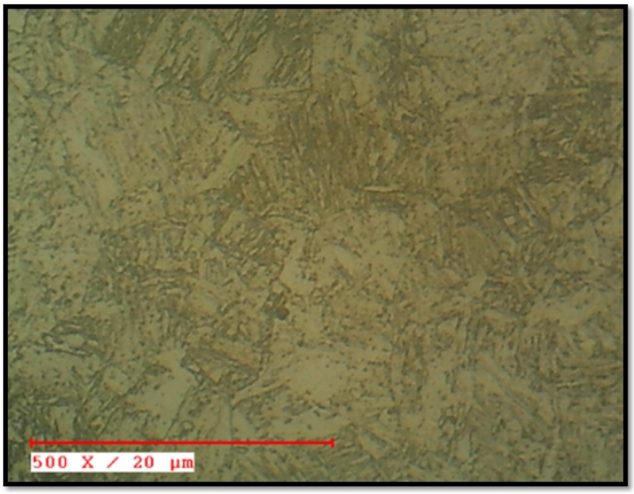

Fig. 9 : Microstructure of 90 mm plate

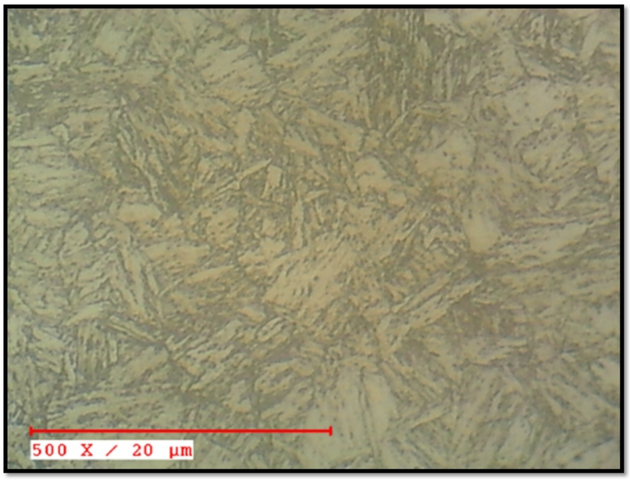

Fig. 10 : Microstructure of 70 mm plate

It is also observed that the grains are elongated in 90 mm plate. However, the 70 mm thick plates did not show any cracks though both materials are pertaining to the same heat. It could be due to that, during the reduction from the ingot due to multiple rolling the 70 mm thick plate grain underwent recrystallization and resulted in uniform grain size and inclusions are broken down.

5.5 Specification for Purchasing Quenched and Hardened Material

Longitudinal and Transverse tensile test : longitudinal & transverse, impact test, J factor (less than 180), through thickness test.

5.6 Stress Relieving

The 90 mm plate which cracked during the heating was subjected to stress relieving and shown in **Fig. 14**. The plates of 300 X 600 mm size were selected. The parameters for stress relieving are given in **Table 5**. The stress relieved plate was welded with restraint and found that the weldment, Heat Affected Zone (HAZ) and base metal are free from cracks (Visual & UT). The microstructure of base metal reveals ferrite and pearlite, The HAZ consists of bainite and ferrite and the weldment divulge veins of ferrite and shown in **Figs. 11, 12 & 13** respectively.

Table 5 : Stress relieving parameters

Parameters	Type/ time/temp
Process	Stress relieving
Loading temperature	80 degree
Rate of heat	100 degree centigrade /hour
Soaking temperature	500 degree
Soaking time	135 minutes
Rate of cool	100 degree centigrade/hour
Unloading temp	300 degree

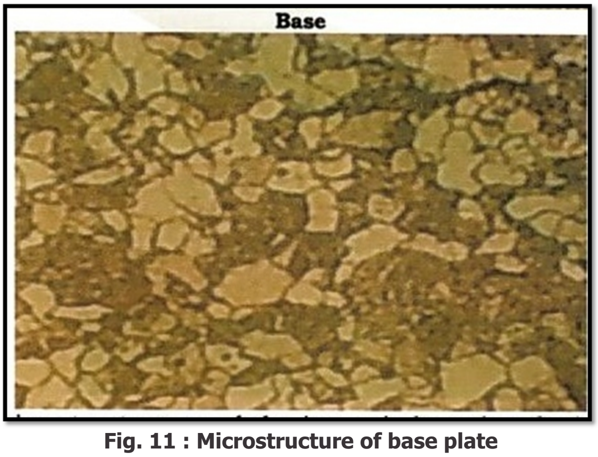

Fig. 11 : Microstructure of base plate

Fig. 12 : Microstructure of HAZ

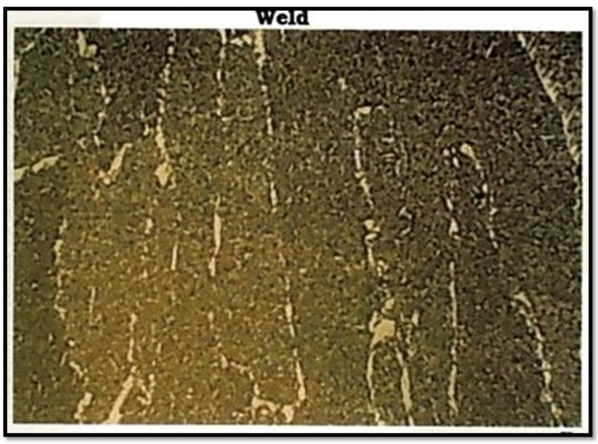

Fig. 13 : Microstructure of Weldment

Fig. 14 : Stress relieving chamber

5.7 Hardness Analysis Before and After Stress Relieving

The hardness survey has been conducted and the values before and after Stress Relieving didn't have significant difference.

Table 6 : Hardness Test before and after Stress Relieving

SURFACE HARDNESS TEST - Before Stress Relieving									
Job. No. 170148									
Reference : SIDE 1									
	SECTION 1 (TOP)			SECTION 2 (MIDDLE)			SECTION 3 (BOTTOM)		
Sl. No.	Weld Area	HAZ	Parent Material	Weld Area	HAZ	Parent Material	Weld Area	HAZ	Parent Material
1	240	206	213	230	206	198	236	235	230
2	232	210	215	219	213	201	246	235	235
3	294	248	230	204	185	230	240	215	222
4	267	267	198	210	190	210	252	210	242
5	261	213	226	200	220	212	284	250	195

SURFACE HARDNESS TEST - Before Stress Relieving									
Job. No. 170148									
Reference : SIDE 1									
	SECTION 1 (TOP)			SECTION 2 (MIDDLE)			SECTION 3 (BOTTOM)		
Sl. No.	Weld Area	HAZ	Parent Material	Weld Area	HAZ	Parent Material	Weld Area	HAZ	Parent Material
1	227	194	200	214	206	185	236	224	216
2	221	199	202	206	213	184	220	227	222
3	281	235	216	189	185	219	226	208	210
4	251	254	185	194	179	194	244	199	229
5	250	201	215	185	206	196	271	241	183

6.0 CONCLUSION

- It is essential to specify the proper technical specification while purchasing the quenched and hardened steel.
- The presence of impurities in the steel leads to failure in the thicker material.
- It is essential to control temperature during tempering process
- The stress relieving of the material avoids crack during the welding process. But the changes from low carbon martensite in to ferrite and pearlite structure.

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