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Effect of austenitizing temperature on the bainitic ferrite transformation during hot induction bending of line pipe steel

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ABSTRACT

Present work is about the effect of austenitizing temperature on the bainitic ferrite transformation during hot induction bending of steel line pipe of grade API X65 for PSL-2. In subject case, Hot Pulled Induction Bends are manufactured from Submerged Arc Welded steel pipes adopting JCOE forming route from thermo- mechanically controlled process plates. During hot bending process the line pipe is exposed to localized induction heating followed by water cooling. Bent portion of the pipe examination is carried out by observing microstructure and mechanical properties – normally strength, toughness and hardness. The results show significant microstructural changes of varying austenitizing temperature. Between the range of 950 - 990◦ centigrade, the resulting microstructure shows very fine bainitic ferrite & transformed ferrite well exists intragranularly in prior austenitic grain (PAG) pockets. The hot bent pipe acquires greatly improved microstructure, strength and toughness on the existing line pipe steel.

Keywords*: Line Pipe, Austenitizing Temperature, Bainitic-Ferrite, Tensile Strength, Induction Bending*

1. INTRODUCTION

Indian government has taken a number of initiatives (Make in India Concept) which would boost the domestic demand supply of line pipe in oil & gas sector. As well in export market, there are many pipe lines are commencing to replacement and many expansion projects speeded up due to increase in supply demand of oil & gas, to which hot induction bend pipes play a vital role and there is a remarkable supply demand too. Making of induction bends is a big challenging task for line pipe makers due to its limited order quantity and purely an order base requirement, for making of induction bends through special steel casting and rolling is a very cost effective, this study involved in usage of mother pipe chemistry pipes to making bends without impairing properties and obtained results are well meeting the specific requirements of line pipe steel.

Hot induction bending is a common manufacturing process used for making bend pipes, in this process the straight line pipe subjected to heating by induction coil where narrow heat band maintained for smooth control of bending process and subsequently apply water for cooling to control the microstructural properties of the bend, heat generated due to the resistance of the material and magnetic flux generated by the induction coil (Figure-1).

Proper selection of austenitizing temperature and its control in target band is an extremely key parameter and it influence on phase transformations behaviour of the steel while hot bending, bainitic ferrite microstructure in hot induction bending of line pipe steel is play a vital role for attaining a noble combination of strength and toughness. By considering this a better understanding of bainite formation with respect to austenitizing temperature is extremely required, there are many factors that influence the kinetics of bainitic transformation which include chemical composition, austenitizing temperature, water flow rate and bending speed. Girault et al. [1] believed that the total bainitic transformation kinetics depends on the austenitizing temperature.

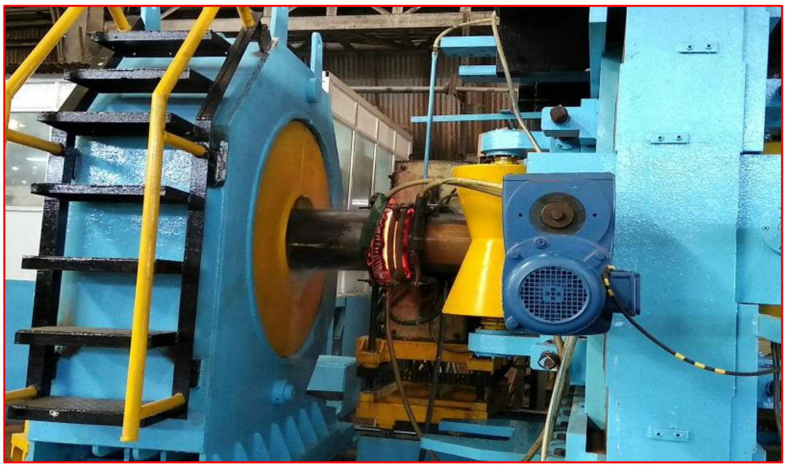


Fig. 1: Hot Induction Bending Process at Jindal Saw Limited, Samaghogha, India

Austenitizing temperature is well known to have a significant influence on the austenite grain size (AGS). The general theory of principle the austenitizing temperature is AC3 +20°C but for effective phase transformation the selection of austenitizing temperature play a vital role while heat treatment with respect to achieve the target mechanical properties of the line pipe steels. Junjun Cui, Wenting Zhu. [2] reported that for HSLA (High Strength Low Alloy Steels) Steels as the austenitizing temperature was increased, the microstructure was changed from polygonal ferrite and granular bainite to lath bainite and lath martensite, while Hu F, Hodgson PD, Wu KM [3] suggested that the transformation of bainite is accelerated by a coarse AGS. This is due to the fact that coarse austenite grains provide less nucleation sites and this is beneficial for bainite sheaf growth. There is a critical AGS, below which there is a distinct grain size effect and above which this is not evident, and the bainite sheaf length of critical AGS is equal to AGS. So it is thought that below the critical AGS there is large number bainite nucleation at grain boundary and that there exists a lot of hard impingement. Above the critical AGS the nucleation density is markedly reduced and the bainite sheaves grow across the austenite grain. Matsuzaki and Bhadeshia [4] found that different steels can show opposite effects of the AGS on the bainitic reaction rate and that the difference in kinetic behavior is accompanied by obvious distinctions between the bainite microstructures. Most commonly the austenitizing temperature set points are varying by grade chemistry, wall thickness, operating conditions and by the target microstructure.

The hot induction trial conducted at different austenitizing temperatures to evaluate microstructure and its influence on Strength, Toughness, Hardness of the hot bend line pipe for grade API 5L X-65 PSL-2. To establish the microstructural and mechanical properties relationship.

2. EXPERIMENTAL METHOD

Steel grade of API 5L X65 PSL-2 of line pipe size 610mm outer Dimeter X 14.33mm wall thickness produced by JCOE process used for this study. Steel plates produced by thermo-mechanical controlled rolling and accelerating cooling(TMCP). This line pipes are produced from base line pipe steel chemistry. Steel chemistry and carbon equivalent levels of the line pipe shows in Table-1. Hot Bending trial performed at three different temperatures, details described in table-2 and in all three trials of line pipes made from same heat of same chemistry. Other varying parameter which are directly effects on microstructure are like bending speed, bending temperature and water flow rate kept constant in all three trials. Austenitizing temperature theoretically evaluated from the formulas of Andrews, Brandis, Kunitake & Kotou, Brandis referred hand book of “Steel Forming and Heat Treating by Antonio Augusto Gorni, Brazil” [5].

Table 1: Chemical Composition

Element (Weight %)											
C	Mn	Si	P	S	Al	N ppm	Ca ppm	Mo	Nb+V+Ti	CE	Pcm
0.07	1.59	0.24	0.012	0.0007	0.03	36	26	0.11	0.05	0.36	0.17

Table 2: Bend Parameters and Theoretical AC3 Temperature Calculations

Bend Operating Parameters					Calculated Ac3 Temperature in °C			
Trial No	Minimum Target Temperature (°C)	Speed (mm/Min)	Water Flow (lpm)	Bend Angle (°)	Andrews	Brandis	Kunitake & Kotou	Hougardy
Trial-1	920	~30	~200	90	914	873	885	873
Trial-2	940	~30	~200	90				
Trial-3	960	~30	~200	90				

Figure 2 shows the principle mechanism of hot induction bending, arm guide pushes the line pipe end after reaching certain temperature during bending according to the bend radius, the other end remaining fixed. The line pipe passes through the high frequency of induction coil, heat generated due to the resistance of the material and magnetic flux generated by the induction coil, the pipe resistance to the flow causes fast and narrow band heating followed by the water cooling subsequently to achieve desired microstructural properties.

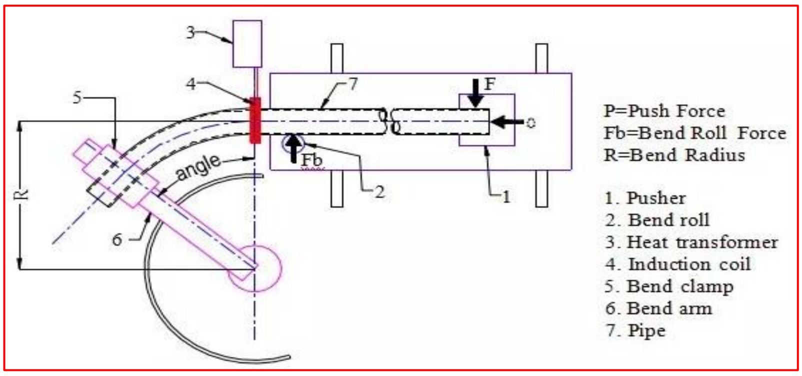


Fig. 2: Hot Induction Bending schematic diagram

Data Analysis carried of Microstructure & Mechanical properties of tensile strength, impact toughness, hardness. samples collected as per the ISO 15590-1 [6], tensile properties measure in transverse to rolling direction and impact properties measure in transverse direction, hardness and micro samples evaluated from selective locations as per ASTM standard requirements.

Purpose of this study is to evaluate suitable austenitizing temperature by which to achieve recommended microstructure to improve strength and toughness of the bend pipes and to compile the standard requirements of API 5L X65 PSL-2.

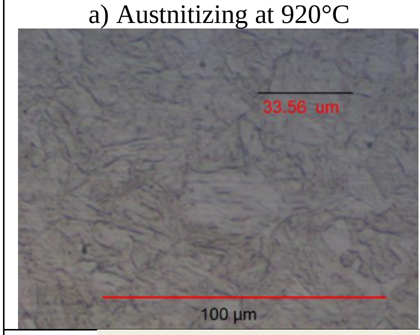
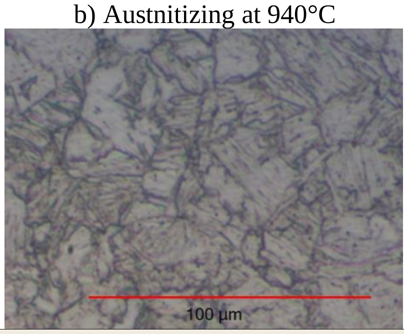
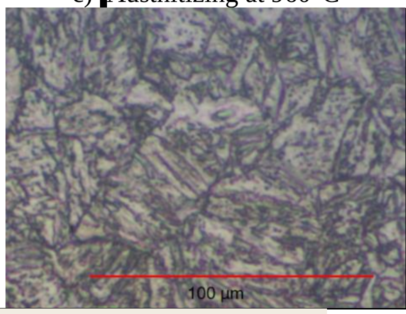
3. RESULT AND DISCUSSION

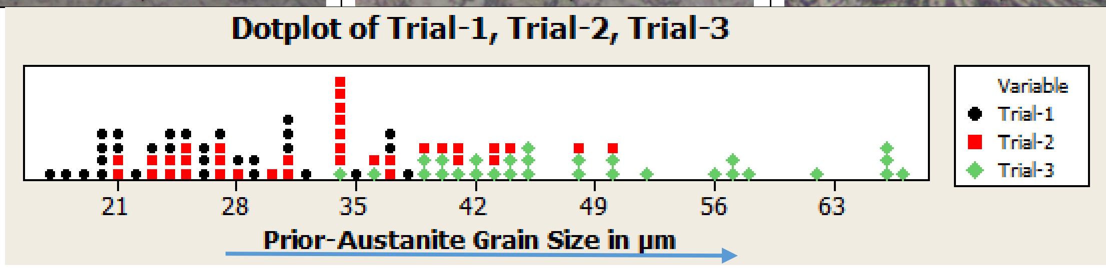
3.1 Microstructural Observations

During induction bending the line pipes are heated above the austenitizing temperature (above the Ac3) and followed by desired water cooling at constant bend travel speed. In good austenitizing condition favorable for formation bainitic ferrite, since the carbon is uniform and achieve adequate austenite grain size, it will help to improves the strength and toughness of the line pipe steel. Where in partial austenitizing (mixture of austenite and ferrite) conditions the strength and toughness deteriorates due to the carbon of austenite is higher than the fully austenite, during heating the second phase transform firstly, this is directly related to the carbon concentration profiles, a highly inhomogeneous carbon distribution develops during the transformation, both in ferrite and austenite resulting low strength and low toughness properties. Even higher the austenitizing temperature the rate of transformation is high, the resulting microstructure enriched with MA phase which impairs on yield strength & toughness properties. Micro samples collected from all three test trials from transition start region, bend region and at transition stop region after final preparation the samples conducted etching with nital to reveal microstructure and to measure prior austenite grain size.

Referring to Table-3, the PAG measured by using quenching technique for samples of Trail-1, Trail-2 & Trial-3 austanitization done at temperature 920, 940 & 960°C respectively and followed by water quenching. The average PAG size observed to be for trial-1 is 26.10µm, in trial-2 is 32.72µm and in Trial-3 is 49.08µm measured by linear intercept method, the average PAG increased by increasing austanitization temperature. revealing of PAG grain boundaries by quenching technique is a little challenging task and more difficult towards the low austenitizing temperature may be due to the pre-matured transformation while heating.

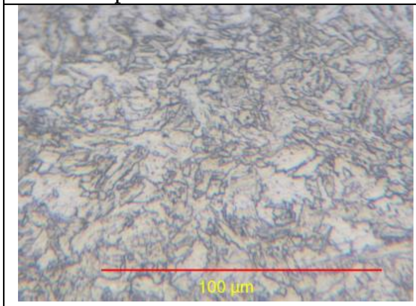
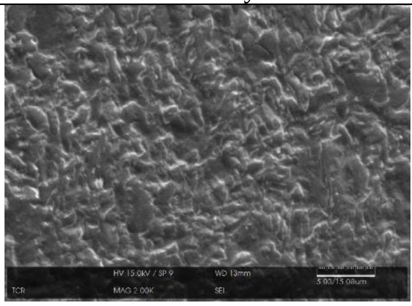
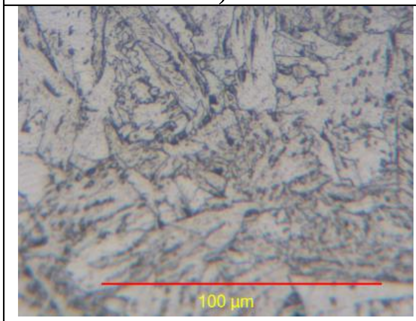
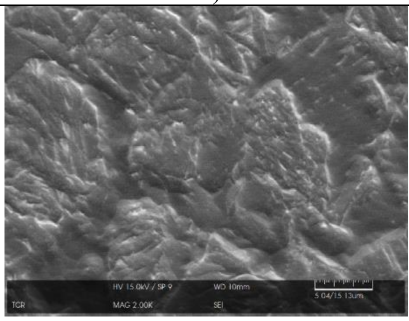
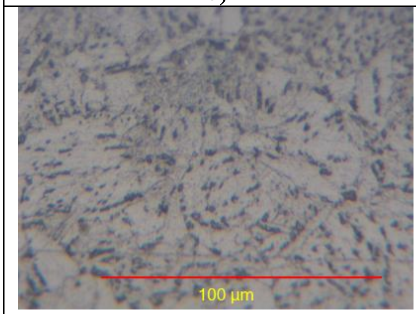
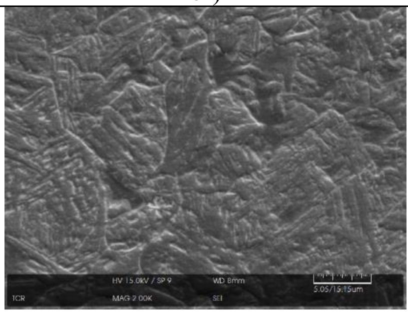
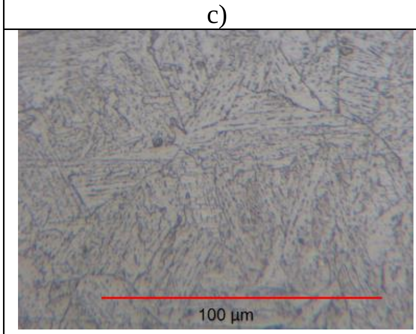
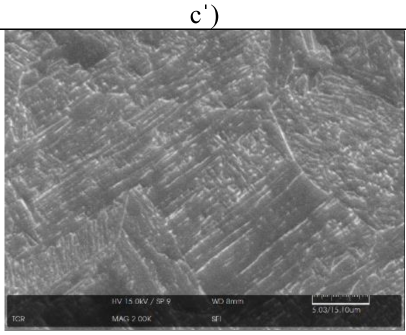
Table3: Effect of Austenitizing Temperature on Prior Austenite Grain Size a) 920°C, b) 940°C and c) 960°C

a) Austnitizing at 920°C	b) Austnitizing at 940°C	c) Austnitizing at 960°C
		



Microstructural Study carried by Optical microscope and by SEM analysis:

Table 4: SEM Analysis and Optical Microstructural Analysis for trial of (a, a') Tangent, (b, b') Trial-1, (c, c') Trial-2 and (d, d') Trial-3

Optical Microstructure	SEM Analysis	Observations
 a)	 a')	The base (tangent) Sample: Figure-a: Microstructure reveals acicular ferrite in nature. Figure-a': High angular grain boundaries of acicular ferrite conforming by SEM analysis.
 b)	 b')	Trial 1 Sample: Figure-b: Microstructure reveals mixture of upper bainite & second phase of may be Perlite/ martensite. Figure-b': SEM analysis conforming that upper bainite and second phase of martensite.
 c)	 c')	Trial 2 sample: Figure-c: Microstructure reveals mixture of upper bainite. Figure-c': SEM analysis conforming that upper bainite well-formed with in prior austenite grain boundary.
 d)	 d')	Trial 3 sample: Figure-d: Microstructure reveals mixture of Bainitic Ferrite. Figure-d': SEM analysis conforming ferrite well exists intragranularly in prior austenitic grain(PAG) pockets

Results of Trial-3 refer Table-4 clearly appear that bainitic ferrite microstructure well achieved at austenitizing temperature of 960°C possibly due to formation of sufficient austenite grain size during induction heating, which has improved the bainite transformation kinetics.

3.2 Mechanical Properties

Test samples are extracted from the Tangent Region, Transition Start Region, Bend Region and from the Transition Stop Region for evaluate the tensile, toughness and Hardness Properties. Referring to the figure-3 the tensile properties of Ultimate Tensile Strength (UTS) and Yield Strength(YS) has a significant improvement found in trial-3 test results as compared to other two trials. The percentage of elongation found on lower side in trial-3 as compared to trial-1 and trial-2. the trial results found well meeting the specific requirements of API 5L X65 PSL-2.

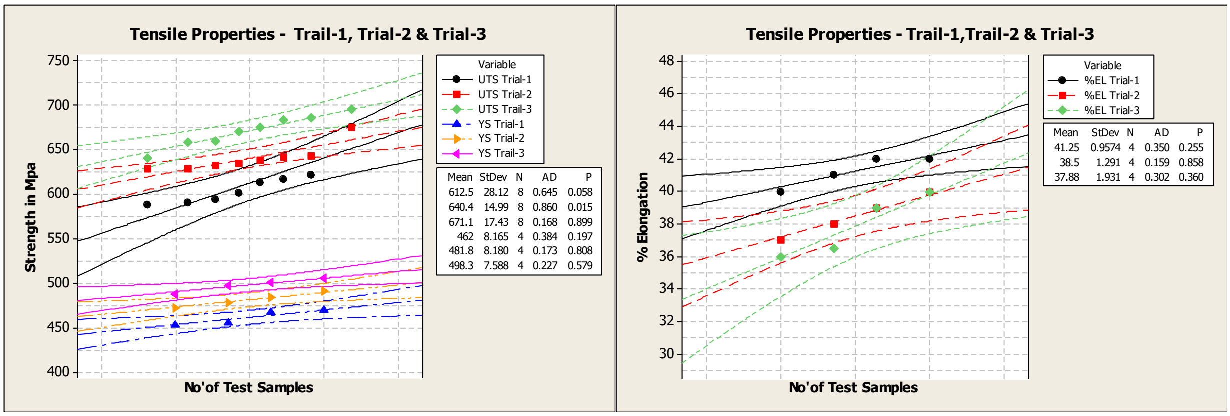


Fig. 3: Tensile Properties of Trail-1, Trail-2 and Trial-3

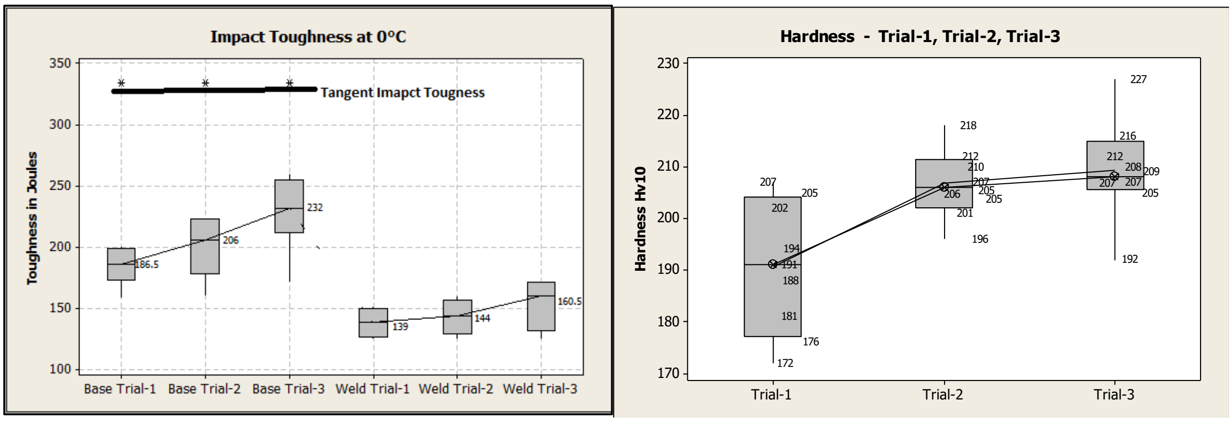


Fig. 4: Impact Toughness and Hardness Results of Trail-1, Trail-2 and Trial-3

Referring to Figure-4 the impact toughness at zero-degree temperature considerable improvement found in trial-3 samples compared to other two trials in pipe samples. Trial-1 & Trial-2 toughness properties are similar in range and the individual samples impact toughness found major variations may be due to the mixture of coarse grain size. Impact properties of weld region found similar results in all three cases and no major deviations found with respect to microstructure at weld region in all three cases. All the results are well meeting the specific requirements of API 5L X65 PSL-2 standards. The hardness measured with Vickers hardness of HV10, test results of trial-3 properties found at higher side as compared with trial-1 & Trial-2, high hardness in trial-3 may be due to the bainitic ferrite microstructure. Trial-1 hardness found on lower side may be due to higher volume fraction of ferrite.

4. CONCLUSION

Finished Hot Induction Bend product of desired mechanical properties achievement possible only by selection of suitable austenitizing temperature by which to achieve a desired microstructure. appropriate austenitizing temperature helps in formation of Bainitic Ferrite microstructure, which is best suitable to achieve good combination of strength & toughness. And it is required to derive process parameters on trial and error methods since austenitizing temperature varying by chemistry, grade and wall thickness of the line pipe.

5. ACKNOWLEDGEMENT

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