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Forming of Hot Induction Bend from ERW Pipe of API 5L X70M Grade

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Abstract* —High-frequency electric resistance welding (HF-ERW) is the fastest and most efficient method of making small diameter pipes. ERW steel pipes are used for various engineering purposes, fencing, scaffolding, line pipes etc. ERW steel pipes are available from 31.75 mm to 609.6 mm OD and from 2 mm to 12 mm WT. Bends are primary links to the joining of the pipes with respect to geographical and topographical position on earth. With the ERW pipe of API5L X70M grade having lean chemistry, it is very difficult to achieve properties requirements after being hot induction bend. The present paper reveals the effect of induction bend forming parameters like temperature, bend speed, air and water pressure on the mechanical properties. Hot induction bend trials performed on 323 mm OD and 11.1 mm WT ERW pipe of API5L X70M grade and optimum parameters are established based on obtained mechanical properties and microstructures.

***Index Terms*—API5L X70M, bend speed, HF-ERW, microstructure, water pressure to air pressure ratio.**

I. INTRODUCTION

In the HF-ERW process, a strip is fed into a forming mill, shaped into a cylinder and passed through an induction coil or under contacts. The magnetic field around induction coil causes current to flow on the edges of the strip. The edges, in turn, heat up due to resistance to the flow of current. The hot edges are forged together in the weld rolls and a weld is achieved. The HF weld is a true forge weld in that no filler metal is added.

ERW pipes are made in smaller diameter used for water and oil transmission line. Induction bends are used to connect the pipes with respect to geographical and topographical position on earth. The bend is also used for branching the transmission lines. Induction bending process utilized the heat generated due to the resistance of the material and magnetic flux generated by the induction coil to heat up a narrow circumferential heat band in the pipe. Induction bends are formed by passing a length of straight pipe through an induction bending machine. The line diagram of pipe bending machine is shown in Fig. 1. This machine uses an induction coil to heat a narrow band of the pipe material. The leading end of the pipe is clamped to a pivot arm. As the pipe is pushed through the machine, a bend with the desired radius of curvature is produced. The heated material just beyond the induction coil is quenched with a water & air spray on the outside surface of the pipe to set the deformation band.

Hot induction bending was carried out on Electro Resistance welded (ERW) pipe having size 323 mm OD X 11.1 mm WT which was manufactured by Welspun Corp. Ltd., Anjar-Gujarat-India. Six trials were carried out with changing forming parameters temperature, speeds, and water pressure to air pressure ratio. The dimensions of the bend chosen for trial were 323 mm OD X 11.1 mm WT X 6D X 15°.

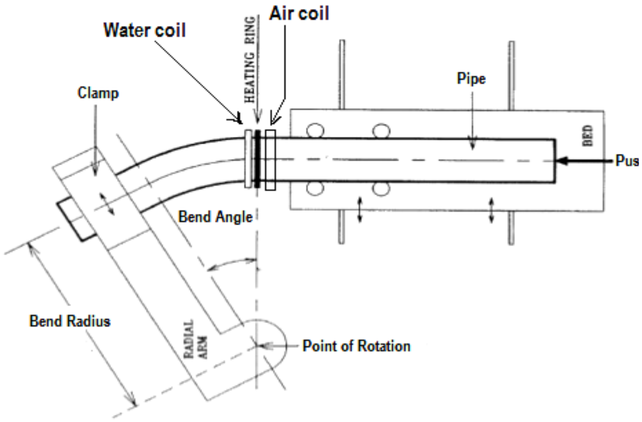

Fig. 1: Line diagram of hot induction bending process

A. Chemistry

The chemical composition of ERW pipe of API5L X70M grade is given in table 1. In the present chemistry, Molybdenum and Titanium are not added as alloying elements. It is found that the variety of carbon and alloy additions such as Mn, Cr, and Ni yield significant differences in the transformation behaviors of the steels, viz. the fine quasi-polygonal ferrite transformation are promoted obviously and polygonal ferrite and/or pearlite transformation are restrained [1]. The parameters (temperature, speed, ratio of water pressure to air pressure) were chosen as these will affect the mechanical properties by changing the morphology of the microstructure. The presence of the carbon and silicon promote the formation of quasi-polygonal ferrite at higher cooling rates. Altering bending speed helps in increasing the cooling rate as it decides the time of cooling at a particular location of the pipe being bent. Proper heating temperature allows complete dissolution of carbide like NbC, Ti(C, N). The ratio of water pressure to Air pressure very significantly affects the cooling efficiency during the hot induction bending process [2].

Table 1: Chemical Composition (Wt %) of API5L X70M.

C	Mn	Si	S	P	Cr	Ni	Mo
0.05	1.39	0.265	0.001	0.011	0.17	0.020	0.005
Cu	**Ti**	**V**	**Nb**	**N**	**Al**	**Ca**	
0.014	0.001	0.034	0.036	0.002	0.04	0.005	

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B. Temperature

During bending, a material is heated above Ac_3 point into the austenitic region and subsequently cooled by water. The induction heating temperature is determined based on the dissolution temperature of the alloying elements. Since niobium is a strong carbide and nitride forming element, the soluble Nb as well as Nb(C,N) precipitates can have a great effect on phase transformation and the resulting mechanical properties of the bend. The dissolution temperature of Nb(C, N) is determined by using Irwin's equation [2].

$$T\ ^{0}C = \{-6770/\log (Nb)\ (C + (12/14)\ N) - 2.26\}\ -273.15 \quad (1)$$

The dissolution temperature of Nb(C, N) calculated using equation-1 for the given chemistry as shown in table 1 was 1084 ˚C. However, the temperature calculated by using theoretical formula was slightly higher than the particle value. In the present experimental study, the temperature varied from 1040 to 1100 to study its effects on mechanical properties.

C. Bending speed

Bending speed affects both the through thickness heating and cooling. With increasing pipe wall thickness, the bending speed is reduced to allow the sufficient through wall soak time. For thicker wall pipes, the cooling rate is reduced due to increased distance from pipe inner wall to the water spray at pipe outside surface as well as the slow emergence of a heated annular ring from induction coil into the cooling water spray. This can result in heterogeneity of the microstructure and hence the variation in mechanical properties through thickness [3].

D. Water pressure to air pressure ratio

Cooling of a heated annular ring is carried out by water spray at a particular flow rate and pressure. To avoid the entrapment of water in heated annular ring air is blown from air coil at a specific pressure. Water coil and air coil are positioned on the each side of the induction coil. The water pressure to air pressure ratio is a very important parameter and affect the susceptibility of cooling.

II. EXPERIMENTAL PART

The ERW mother pipes of size 323 mm OD x 11.1 mm WT API 5L X70M grade were used for hot induction bending trials (Table 2). The mother pipes were manufactured at Ratnamani Metal & Tubes Ltd, Anjar-Gujarat-India. The size of the bend selected for trials was 323 mm OD x 11.1 mm WT x 6D x 15˚. Initially, two trials were carried out with varying water pressure to air pressure ratio. In Trial-1 & 2, water pressure to air pressure ratio was changed from 1.08 to 1.60 by keeping all other parameters constant. In Trial-3, Speed was increased from 25 mm/min (Trial-2) to 30 mm/min (Trial-3). In Trial-4 & 5 temperature was increased from 1060 (Trial-4) to 1100 (Trial-5). In Trial-6 all the parameters of Trial-1 are kept same except speed. In Trial-6 bend Speed increase from 25 mm/min (Trial-1) to 35 mm/min. The variations of hot induction bend forming parameters for Trial bends are shown in table 2.

A. Forming parameters of hot induction bending

The heating temperature, bending speed and water pressure to air pressure ratio were chosen as the main parameters (Table 2) to evaluate the effect on the strength of the finished bend. With altering in above three forming parameter different cases are studied based on the obtained mechanical properties and microstructure. The hot induction bending parameters of Trial bends are shown in table 2.

Trial parameters	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
Temperature (˚C)	1020-1040	1020-1040	1020-1040	1040-1060	1080-1100	1020-1040
Frequency (Hz)	99	99	99	99	99	99
Coil Voltage (%KV)	38	38	38	38	38	38
Induction coil current (A)	517	517	517	517	517	517
Bend speed (mm/min)	25	25	30	25	25	35
Water Flow Rate (m^3/h)	10-10.5	10-10.5	10-10.5	10-10.5	10-10.5	10-10.5
water pressure (kg/cm^2)	4	8	8	8	8	4
Air pressure (kg/cm^2)	3.7	5	5	5	5	3.7
Water pressure/ Air pressure	1.08	1.60	1.60	1.60	1.60	1.08

III. RESULTS

A. Mechanical properties of trial bends

The base metal full- thickness (flat-strip) transverse tensile test sample was drawn from extrados bend portion. The full-thickness flat-strip sample of size 38 mm wide having 25 mm fillet radius was used. Sample preparation and testing were performed at room temperature as per ASTM E8. Mechanical properties of trials bend obtained by tensile testing are shown in table 3.

Table 3 Mechanical properties of trial bends

	Trial	YS0.5 (MPa)	UTS (MPa)	%Elongation @2"GL	YS/ UTS
Tangent	-	559	624	33	0.90
Extrados at bend portion in transverse to bend axis	1	456	588	37	0.78
	2	417	583	36	0.72
	3	411	593	38	0.69
	4	457	608	32	0.75
	5	459	615	34	0.75
	6	494	650	38	0.76

The CVN impact energy at -29 °C was very high (>100 J against the requirement of minimum 44 J) at base metal, HAZ,

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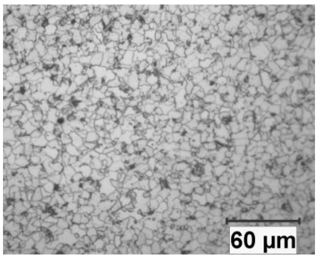
and weld in all the trials. Similarly, the hardness was quite low (<200 HV10 kgf against the requirement of maximum 248 HV10 kgf). Therefore, strength (YS and UTS) was considered for optimization of bending parameters. In view of using flat-strip sample, elongation at 2" gauge length was considered for ductility measurement in place of reduction of area.

B. Microstructural Analysis

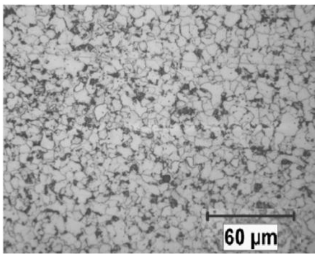
Metallographic specimens were drowned from the extrados portion and conventional polishing technique used to obtained fine polished surface. The specimen were first rough polished on 150 grit emery papers followed by polishing on 240 grit, 360 grit, 400 grit, 600 grit and 1000 grit emery paper. Final fine polishing carried out on cloths disc with diamond paste. Etching was carried out with 2% Nital solution. The microstructural examination was carried out on an optical microscope. Microstructure changes (Fig. 2) from coarse polygonal ferrite + pearlite to fine quasi-polygonal ferrite + acicular ferrite were observed in Trial-1 to Trial-6. Microstructure observation carried out at Subsurface of the Extrados specimen.

Trial-1



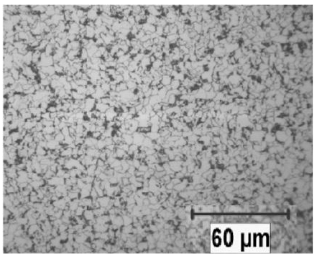
Coarse Polygonal Ferrite (PF) + less Pearlite (P)

Trial-2



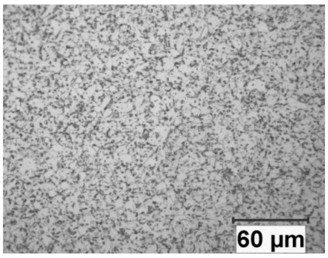
Coarse Polygonal Ferrite (PF) + more Pearlite(P)

Trial-3



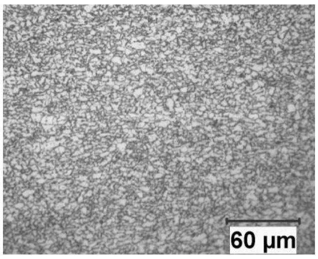
Coarse Polygonal Ferrite (PF) + more Pearlite (P)

Trial-4



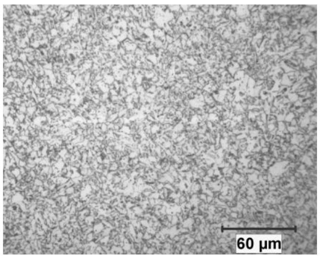
Fine Polygonal Ferrite(PF) + Fine Pearlite(P)

Trial-5



Fine Quasi Polygonal Ferrite (QPF)+ very less Pearlite(P)

Trial-6



Fine Quasi Polygonal ferrite (QPF)+ Acicular Ferrite(AF)

Fig. 2: Microstructure at Sub surface of Extrados in trial 1 to 6.

IV. DISCUSSION

A. Graphical representation of forming parameters and mechanical properties

Mechanical properties of trial bends shown in table 3 are graphically represented with the bend forming parameters in below Fig. 3, 4 & 5.

The variations of transverse strength in trail bends are shown in Fig. 3. Trial-1 to 5 was unsuccessful to obtain the minimum required Strength properties. Trail-6 was successful in meeting the minimum required transverse strength.

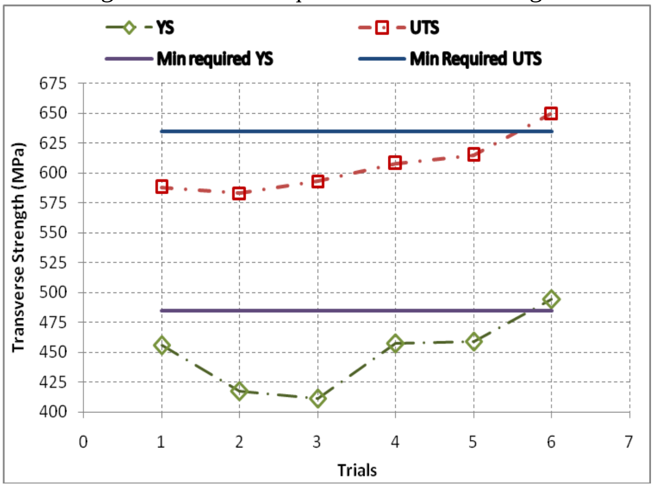


Fig. 3: Bend YS & UTS in Transverse Direction.

In Trial 1 & 2, the bending speed 25 mm/min, temperature 1040 ˚C and other parameter were kept constant and water pressure to air pressure ratio was an increase from 1.08 (trail-1) to 1.60 (trail-2), results in the decrease in yield strength as shown in figure 4. Keeping water pressure to air pressure ratio 1.60 constant and increasing bending speed 25 mm/min (trail-2) to 30 mm/min (trail-3) results into the decrease in the Yield strength as shown by blue dotted line (Trial 2 & 3) in Fig. 4.

The possible explanation of this decrease in YS was due to a reduction in cooling rate effectiveness with increased in water pressure to air pressure ratio from 1.08 to 1.60 (water pressure increase from 4 to 8 kg/cm^2 and air pressure increased from 3.7 to 5 kg/cm^2) in Trial-2. At 1.60 water pressure to air pressure ratio, the effect of air pressure is more compared to water pressure resulted in an air film between hot bend surface and water spray and thereby, ineffective water cooling as confirmed by the microstructure (Fig. 2) and mechanical properties (Table 3).

Keeping water pressure to air pressure ratio 1.08 constant and increasing bending speed 25 mm/min (trail-2) to 35 mm/min (trail-3) results into the increase in the Yield strength as shown by red dotted line (Trial 1 & 6) in Fig. 4. The reason behind an increase in YS was a cumulative effect of low water pressure to air pressure ratio and higher bend speed increase the effectiveness of cooling rate and can be confirmed by the microstructure and Mechanical properties (Trial-6).

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The increase in UTS is more predominant with 1.08 water pressure to air pressure ratio compared to 1.60 water pressure to air pressure ratio as shown in Fig. 5.

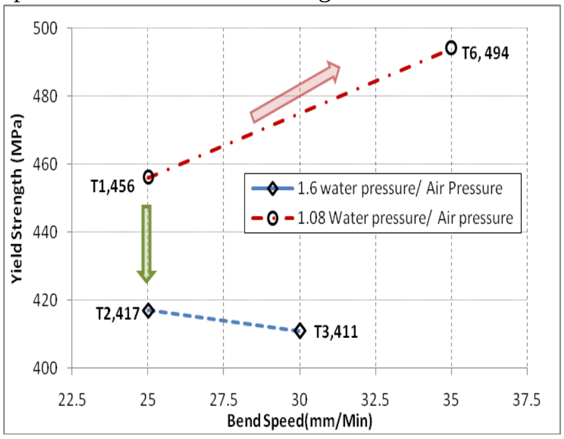

Fig. 4: Effect of bending speed & water pressure to air pressure ratio on YS.

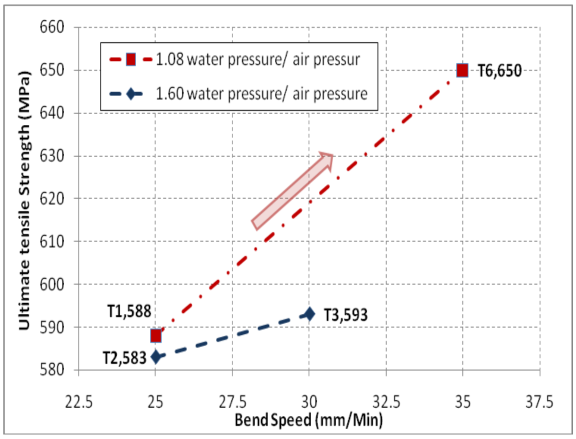

Fig. 5: Effect of bending speed & water pressure to air pressure ratio on UTS

In Trial 2, 4 & 5 temperature increase from 1040˚C, 1060˚C and 1100˚C respectively. The increase in temperature is effective upto 1060˚C. With further increase in temperature upto 1100˚C results in negligible effect in improving YS and UTS. The possible explanation for this was at a temperature around 1060˚C the dissolution of Carbides completed and further increase in temperature shows the negligible effect in improving YS & UTS as shown in Fig. 6.

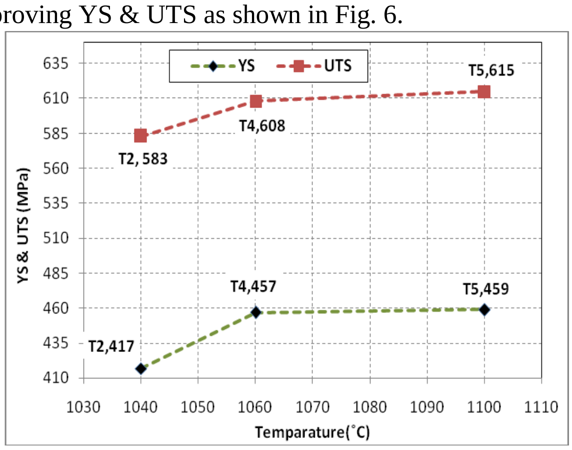

Fig.6: Effect of temperature on YS & UTS

V. CONCLUSION

The achievement of desired properties in finished bend made from hot induction bending process extremely depends on the optimal setting of forming process parameters. It is necessary to derive optimum process parameters from trial and error methods. In this present study optimal setting of parameter established were: 1040˚C temperature, 35 mm/min bend speed, 1.08 water pressure to air pressure ratio for ERW bend of Size 323 mm OD X 11.1 mm WT X 6D API 5L X70M grade.

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Mr. Rajesh K. Goyal is holding a Master Degree in Metallurgy from IIT Kanpur and having more than 25 years of experience and presently working with Welspun Corp Ltd as Assistant Vice President. He is responsible for Technical Services and R&D activities for manufacturing facilities located in India. He has 39 publications in various International and National conferences and journals. He has supervised B.Tech (Metallurgy) & ME (Industrial Metallurgy) thesis as an industrial guide. He is a qualified Six Sigma Black Belt by Wipro Info Tech Ltd., Bangalore and also qualified Lead Auditor ISO 9001-2015 from DNV. He is a Life Member of Indian Institute of Metal (IIM)-Calcutta. He has been awarded Certificate of Excellence for the Best Employee for the significant contributions made in Quality Assurance Department in JSW Steel Ltd. (formally known as Ispat Ind. Ltd.).

He has been awarded the SAIL Gold Medal by Indian Institute of Metals, Calcutta for a paper on "Heat Treatment of Coke in the Temperature Range of 1400-1650 ˚C"

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Mr. Tushal Kyada is holding a BE (Metallurgy and Materials Engineering) from MSU Baroda. He has 5 years of experience and presently working with Welspun Corp Ltd in the R&D departments. He has worked in the areas such as product development, failure analysis, hot induction bending, metallography etc. He has 9 publications including International and National conferences and journals. He has presented a paper "Optimization of Hot Induction Bending Process Parameters" in ASME conference IOGPC2017 held at Mumbai, April 2017.

One of his paper "Co-relation of Micro structural Features With Tensile and Toughness Characteristics of X70 Grade Steel" presented at TMS conference 2017 held at California, USA and this paper has been included as a chapter in Springer Book "Energy Material-2017".

Mr. T.S. Kathayat is holding a Master Degree in Mechanical Engineering & MBA. He is Technical Member of various International & National bodies such as ASME, API, NACE, PRCI, AGA, IIM, ASQ, AIMA, TMS, and SFA etc. Having more than 20 years of work experience in the manufacturing industry and presently working with Welspun Corp Ltd [Global Pipe Business - 2nd largest Pipeline Manufacturer in the World] based at Corporate office in Mumbai. He is responsible for Corporate Quality & Technical Services for manufacturing facilities located in India, USA & Saudi Arabia.

He is the Existing Chair of ASQ- LMC, Mumbai Chapter and Petron for the Society of Failure Analysis of India. Has presented & published various technical papers on linepipe for Oil & Gas Industry across the World and few of them include Offshore Technology Conference in Houston-USA, Malaysia, Brazil and actively involved in Technical Committees of Linepipe and Steel Standards and Joint Industry Project Research Group for Oil and Gas Industry.

He has organized various National and International Pipeline conferences for Oil and Gas Onshore and Offshore applications and delivered various technical lectures on Linepipe Steels for International Oil and Gas majors like TOTAL, SHELL, PETRONAS, Saudi Aramco, Enterprise, USA and Spectra Energy etc.

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