DE GRUYTER OPEN

DOI 10.1515/ama-2016-0013 *acta mechanica et automatica, vol.10 no.2 (2016)*

INFLUENCE OF TEMPERING ON MECHANICAL PROPERTIES OF INDUCTION BENTS BELOW 540°C

Peter JANKEJECH[*], Peter FABIAN[*], Jozef BRONCEK[**], Yuriy SHALAPKO[***]

[*]Faculty of Mechanical Engineering, Department of Technological Engineering,
University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia
[**]Faculty of Mechanical Engineering, Department of Designing and Machine Components,
University of Zilina, Univerzitna 8215/1, 010 26 Zilina, Slovakia
[***]Institute of Mechanics and Informatics, Chmelnitckiy National University, Str. Institutskaja 11, 29016 Chmelnitckiy, Ukraine

peter.jankejech@fstroj.uniza.sk, peter.fabian@fstroj.uniza.sk, jozef.broncek@fstroj.uniza.sk, shalapko@yahoo.com

received 22 October 2015, revised 1 March 2016, accepted 10 March 2016

Abstract: The article describes basic principles of induction bending and the change of mechanical properties from as received (straight) pipe made from HSLA steel to induction bend. The main purpose of this article is to experiment with tempering temperatures below 540°C. After tempering at 540°C which is the lowest recommended temperature for post bend heat treatment (PBHT) according to CSA specifications (Canadian Standards Association) the induction bend area in many cases does not achieve the minimum required mechanical properties and therefore it is not accepted for usage. In this article mechanical properties such as tensile, toughness, hardness are evaluated. Also the article contains microstructural analyses and comparison of bended and heat treated samples.

Key words: HSLA, Induction, Bending, Tempering

1. INTRODUCTION

Induction bending is a largely automated free forming process. Bends with small bending angles are fabricated on site by means of cold bending. But for smaller radii and bending angles up to 90° hot induction bending is the common manufacturing process. The „transformation" of straight pipe to bent pipe takes place in the heated narrow annular zone which moves continuously along the length of the bend as the bending process advances (Fig. 1). The heating of this zone is affected by means on an induction ring (also Fig. 1) (Muthmann and Grimpe, 2006).

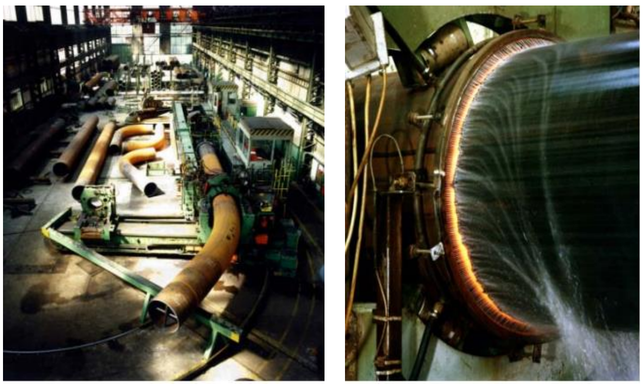

Fig. 1. Description of induction bending machine (left) and the inducted zone where bending takes place (right) (Muthmann and Grimpe, 2006)

An alternating current passes though the inductor and induces a potential which causes an eddy current in the material to be bent. The width of the bending area must be limited to avoid uncontrolled deformation in the bent body. The formed material is cooled by water spray immediately behind the inductor. During bending the temperature of the bending zone is measured continuously and held constant at a predetermined value above Ac3. This results in a short – time austenitizing cycle and a quenched metallurgical structure. The front end of the pipe is clamped to a pivoted arm, the bending force acts axially on the pipe, induced by a hydraulic ram, pushing the pipe through the machine. Set to the desired bending radius, the bending arm then describes a circular arc around its pivot point. As a result of the radial thrust applied to it the pipe automatically follows this curve (Muthmann and Grimpe, 2006; Saga et al.,2010; Tropp et al., 2012). The main advantages of induction bending in comparison to conventional welding of elbows are lower montage costs, lower operational costs, better flow of the transported medium and better corrosion resistance because the whole surface can be uniformly covered by coatings (Fig. 2) (Brezinova et al., 2014; Guzanova et al., 2014).

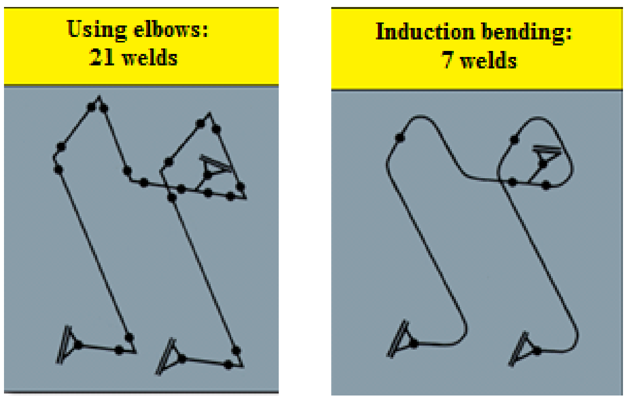

Fig. 2. Advantages of induction bending in comparison with conventional methods of pipeline assembling

DOI 10.1515/ama-2016-0013

2. CHANGES IN MECHANICAL AND STRUCTURAL PROPERTIES OF THE INDUCTION BENTS

Pipes used for induction bending purposes are made from steel manufactured by using controlled rolling technology (large diameter pipes) or by extrusion (low diameter pipes). The goal of controlled rolling is to obtain fine grain microstructure with high tensile properties at a low amount of C (under 0.1%) and other alloying elements. When this kind of material is heated above the transformation temperature the microstructure changes and the mechanical properties mostly drop (approximately 100-150 MPa). That is why pipes made from HSLA steels aren´t able to retain their mechanical properties after induction bending. This drop of after induction bending is also described in Fig. 3. (Broncek et al., 2015; Shome and Mohanty, 2006; Sampath, 2006).

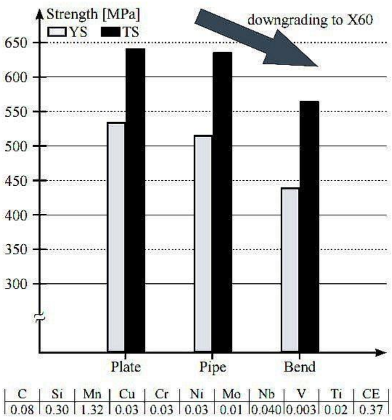

Fig. 3. Changes in tensile properties after induction bending of Gr. X65 steel (Muthmann and Grimpe, 2006)

Fig. 3 represents mechanical properties of pipeline steel grade X65 before and after induction bending. Because of low carbon and alloy content the material after heating and subsequent cooling is not able to retain its mechanical properties. It is important to notice that even the little amount of carbon in this type of steels plays significant role when it comes to mechanical properties after induction bending. (Vervynckt et al., 2012; Fernandez et al., 2014). In the case of microstructural properties the initial microstructure contains a mixture of fine ferrite grains, pearlite and in some cases bainte (depends on the chemical composition, rolling parameters and heat treatment) (Fig. 4). After induction bending in many cases the microstructure contains ferrite grains with a small amount of pearlite. The change in microstructure is shown in Fig. 5. (Broncek et al., 2015; Jun et al. 2006; Chandra et al. 2007).

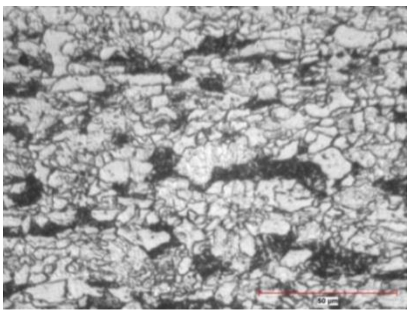

Fig. 4. Microstructure of HSLA steel (Gr.483) before induction bending, Nital 2%, 400x (Broncek et al., 2015)

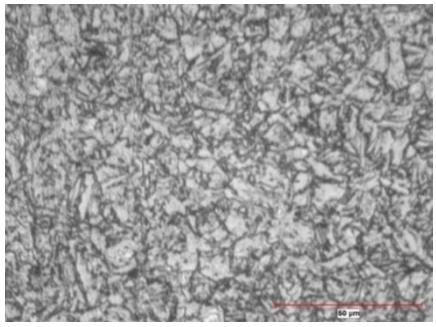

Fig. 5. Microstructure of HSLA steel (Gr.483) after induction bending, Nital 2%, 400x (Broncek et al., 2015)

3. EXPERIMENTAL PART

The examined material is thermo-mechanically rolled HSLA API 5L Gr. X70 steel which mechanical properties ale listed in Tab. 2 and chemical composition in Tab. 1.

Tab. 1. Chemical composition of examined steel

C	Si	Mn	P	S	Ni	Cu
0.08	0.23	1.69	0.009	0.002	0.02	0.01
Cr		**Mo**	**Nb**	**V**	**Ti**	**B**
0.17		0	0.04	0	0.01	0

Tab. 2. Mechanical properties and dimension of examined pipe before induction bending

Size OD x t (mm)	0,5% Yield Strength (MPa)	Tensile strength (MPa)
762 x 19.1	550	667
Elongation (%)	**Toughness (J)**	**Avg. Hardness (HV)**
36	200(1) 237(2)	213

(1) At 0°C; (2) At -40°C

The minimum mechanical property requirements that the induction bend needs to achieve after induction bending are described in Tab. 3.

Tab. 3. Minimum requirements for API 5L X70 steel according to CSA Z245.11-13

Grade	Yield Strength (MPa)	Tensile Strength (MPa)	Y/T Ratio (-)
483 (X70)	483	565	Max. 0.93(1)
Elongation	**Toughness**	**Hardness (HV)**	
min. 20	27(2)(3)	248(4)	

(1) According to CSA Z245.1 Code for straight pipe; (2) Full size specimen (55 x 10 x 10 mm); (3) Toughness of the weld can have a minimum value of 18J (full size specimen); (4) This value is for sour service, induction bend described in the article is for sweet service (302 HV max)

After induction bending the samples for destructive testing were cut in transverse orientation from six locations (Fig. 6).

DE GRUYTER OPEN
DOI 10.1515/ama-2016-0013 acta mechanica et automatica, vol.10 no.2 (2016)

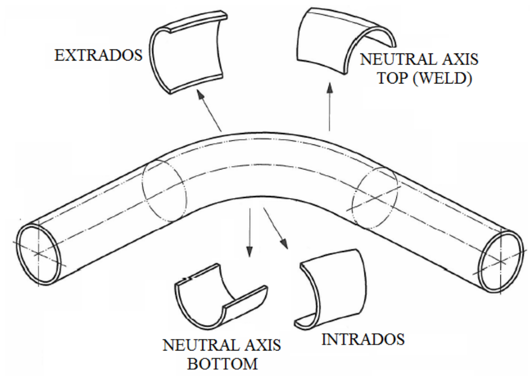

Fig. 6. Drawing of locations in the tested induction bend

These locations were tested in as received condition (no heat treatment) and after providing two experimental post bend heat treatments, one at 540°C for 30 minutes and 420°C for 30 minutes. After providing two experimental heat treatments the samples for tensile and toughness tests were machined according to ASMT A370. Metallographic samples were made according to ASTM E3-11. For hardness measurement nine indents were made in transverse orientation in the extrados, intrados and neutral axis location (Fig. 7a).

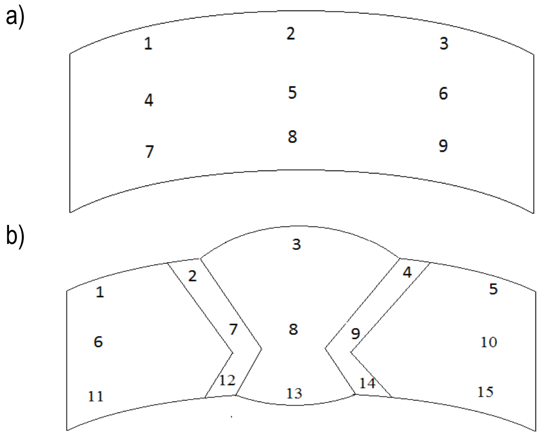

Fig. 7. Drawings of samples for hardness measurement; a. seamless, b. with weld

Neutral axis weld consisted of fifteen indents (Fig. 7b). Heat treatment was provided in a draw (annealing/tempering) furnace Cress 162012. After finishing soaking the samples were unloaded from the furnace and cooled on air.

4. RESULTS AND DISCUSSION

The yield strength (0.5% extension under load) in as bent condition compared with the values stated in Tab. 2 decrease significantly, below the minimum requirements. After applying 540°C/30 min. regime the yield strength in the bend zone increases, especially in the extrados and intrados location and slightly decreases in neutral axis location. However this increase of yield strength isn't sufficient enough and extrados location doesn't meet the minimum requirements stated in Tab. 3 (Fig. 8). When applying the 420°C/30 min. regime the yield strength in all locations increases. According to the values stated in Tab. 5 it is possible to assume that tempering below 540°C has positive impact on yield strength. All the locations after applying 420°C/30 min. regime meet the minimum requirements for yield strength. Yield strength of neutral axis weld isn't recorded because according to the CSA specification it is not recommended.

Tab. 4. Measured values of tensile strength

Location (Orientation)	No PBHT		540°C/30 min.		420°C/30min.	
	UTS (MPa)	EUL 0.5% (MPa)	UTS (MPa)	EUL 0.5% (MPa)	UTS (MPa)	EUL 0.5% (MPa)
Extrados (Transverse)	617	427	542	463	611	518
Intrados (Transverse)	630	475	574	489	645	557
Neutral Weld (Transverse)	670	-	603	-	670	-
Neutral Axis (Transverse)	666	531	612	529	664	573

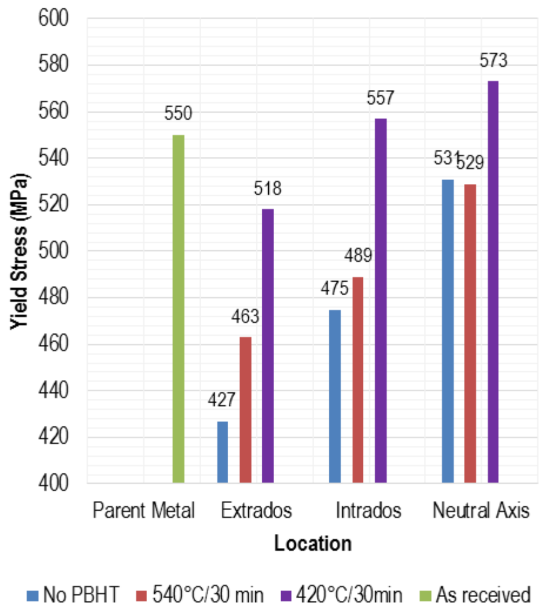

Fig. 8. Values of yield strength in the bend zone

In as bent condition (no PBHT) the tensile strength meets the criteria for minimum tensile strength (see Tab. 3). After applying PBHT 540°C/30 min. tensile strength of the received test bend in all locations decreases (Tab. 4). Here is important to notice that in the extrados location the tensile strength decreases rapidly, below the minimum criteria. However after applying 420°C/30 min. regime the drop of tensile strength is less significant (Fig. 9). In the intrados location slightly increases. According to the values listed in Tab. 5 it is possible to assume that tempering bellow 540°C has a smaller negative impact on tensile strength.

After applying PBHT the Y/T ratio of the received test bend in all locations is approximatelly the same (Fig. 10). Y/T ratio from neutral axis weld location wasn't measured because it is not required in the specification. The values of Y/T ratio in as bent and PBHT condition meet the requirements listed in Tab. 3. The elongation of the received test bend in all locations slightly increases, and also meets the requirements (Fig. 11). Elongation from neutral axis weld location wasn't provided because it was not required.

DOI 10.1515/ama-2016-0013

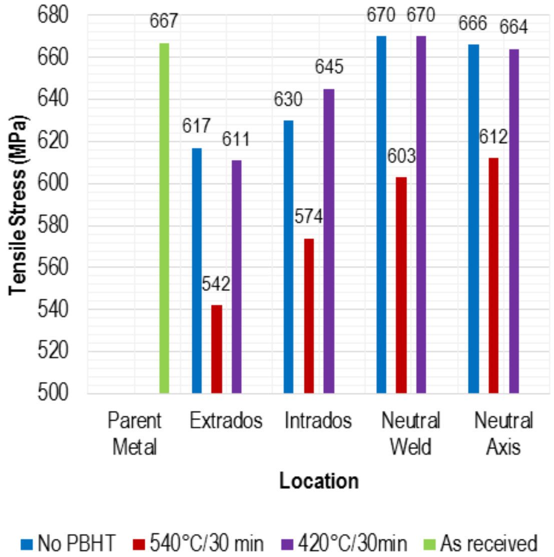

Fig. 9. Values of tensile strength in the bend zone

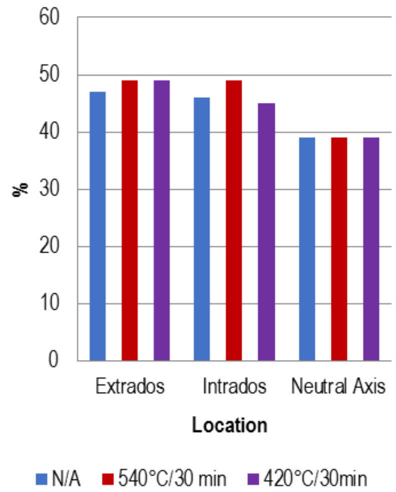

Fig. 10. Values of Y/T ratio in as bend and PBHT condition

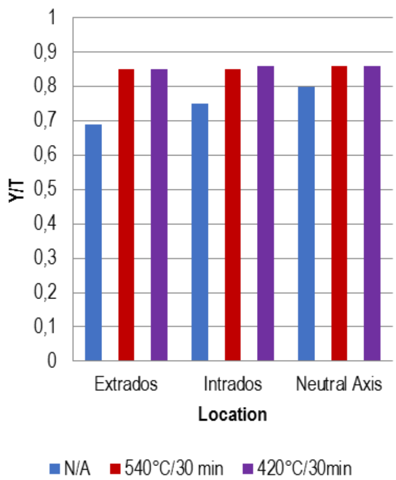

Fig. 11. Elongation values of locations in as bent and PBHT condition

Induction bends also must meet the minimum requirements for toughness. That's why an appropriate temperature, and amount of quenching, must be chosen to provide the induction bend with good toughness properties. According to Tab. 3 the minimum absorbed energy for this grade is 27 J (seamless locations), and 18 J for locations containing welds. In as bend condition the toughness values listed in Tab.5 meet these minimum requirements.

After applying PBHT the toughness in all locations increases (Fig. 12). This means that tempering at temperatures from 540°C and below has positive effect on toughness properties for steel with the chemical composition listed in Tab. 1.

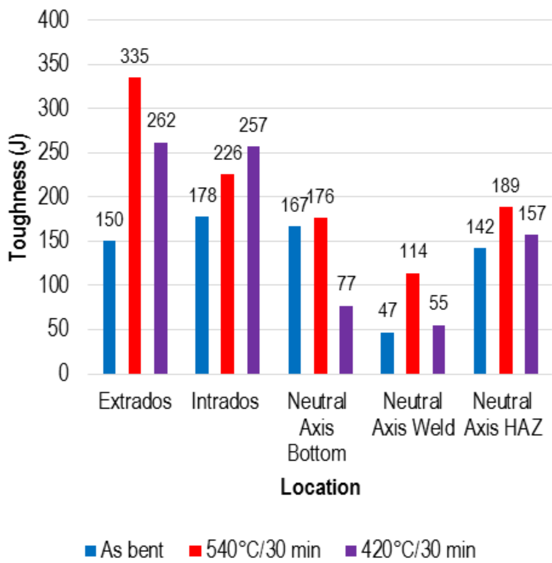

Fig. 12. Toughness values of the bend zone

Single hardness values of induction test bend do not exceed 302 HV10 and therefore meet the requirements for sweet condition. Sweet condition means that the pipe can be used only for transportation of natural gas that does not contain significant amounts of hydrogen sulfide. Again due to increased toughness properties the hardness after PBHT decreases thanks to the softening processes during tempering. The average hardness value of each location is stated in Tab. 5.

Tab. 5. Average values of harness in each location

	Hardness HV10 (Average)		
	No PBHT	540°C/30min.	420°C/30min.
Extrados (Transverse)	216	180	207
Intrados (Transverse)	213	193	215
Neutral axis bottom (Transverse)	227	211	217
Neutral axis weld (Transverse)	240	201	226

As mentioned above, temperature used in the induction bending process exceeds the Ac3 transformation temperature and therefore a new microstructure is obtained. Instead of a mixture of elongated ferrite grains with upper bainite (or pearlite) (Fig. 13a.), the microstructure in Fig. 13b. contains a mixture of ferrite grains with (probably) small islands of pearlite.

DE GRUYTER OPEN

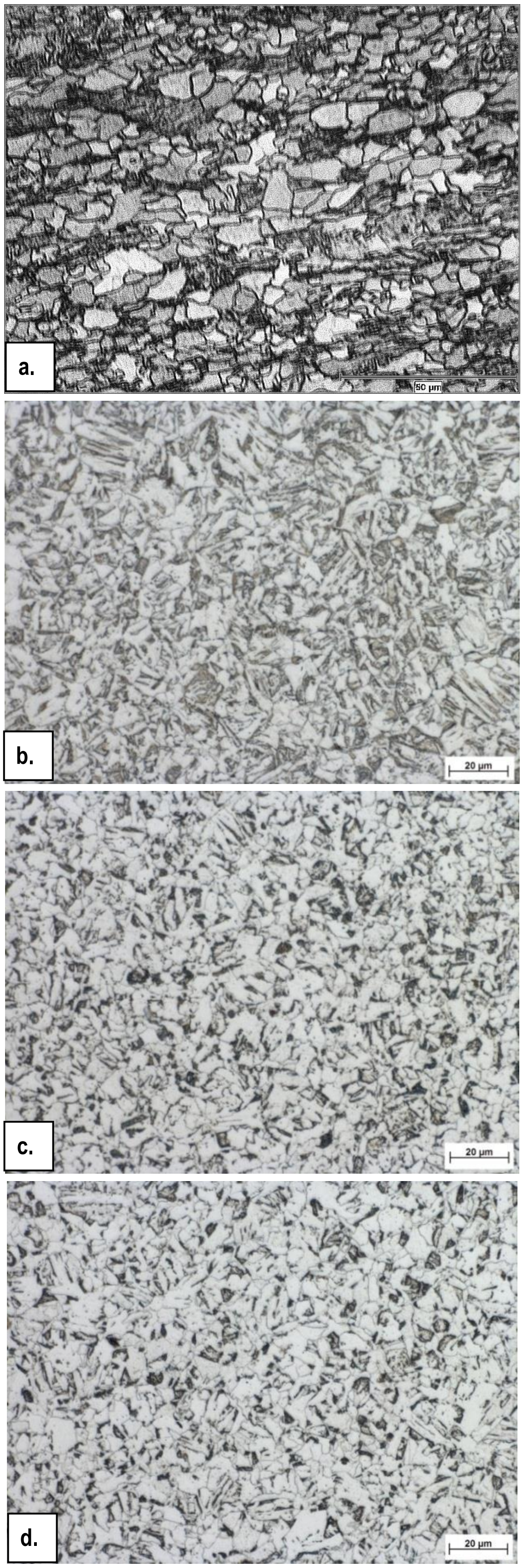

Fig. 13. Microstructure of parent material (a.), extrados location after induction bending (b.), after PBHT 540°C/30 min (c) and after PBHT 420°C/30 min. (d.); etched nital 2%, 400x (a.) 500x (b.c.d.)

Fig. 13c. represents the microstructure of extrados location after applying PBHT 540°C/30 min. As one can see during tempering on this temperature the grains get coarser which can explain the loose of tensile strength stated in Tab.5. The increase of yield strength can be due to precipitation strengthening mechanism mostly because of niobium carbide (NbC) particles or free nitrogen contained in the steel.

Fig. 13d. represents microstructure of the same location after applying PBHT 420°C/30min where the grain coarsening is less pronounced due to lower temperature. That's why the loss of tensile strength isn't that significant as in the previous heat treatment. Also the secondary precipitation takes place which can explain the increase of yield strength.

5. CONCLUSION

Because the requirements for heat treatment of induction bents have not been revised for years and the procedures for thermo-mechanical controlled rolling as well as the chemical composition of the material have improved, the purpose of this article was to refer that temperatures below 540°C could be also considered as a part of post bend heat treatment in the future. After destructive testing of induction bended pipe and provided experimental heat treatments it is possible to assume that both regimes increase the yield strength and decrease the tensile strength, decrease hardness, and increase toughness. However when applying lower tempering temperature (420°C) the decrease of tensile strength is not that significant as it is when applying 540°C. The most important thing is that when tempering at 420°C the yield strength increases more than at 540°C. After taking to account the measured values after applying 540°C tempering temperature, the test bend would not meet the minimum requirements because it would fail in the extrados location on low yield and tensile strength. But after applying 420°C tempering temperature all locations in the bend zone would meet the minimum requirements. Of course these conditions can be related only to the material with such (or approximate) chemical composition as stated in Tab. 1. However the CSA specification for pipe fittings requires PBHT also for tangent body and weld location (straight part of the pipe). In this case additional tests must be done to assure that PBHT below the minimum recommended temperature stated in CSA specification doesn't have negative influence on mechanical properties of this location.

REFERENCES

1. **Brezinova, J. - Guzanova, A. - Spisak, E**. (2014), Assessment of properties thermal sprayed coatings realised using cermet blend powder, *Metalurgija*, 53(4), 661-664.
2. **Broncek J., Jankejech P., Fabian P., Radek N.** (2015), Influence of mechanical anisotropy in low carbon microalloyed steel, *Communications : scientific letters of the University of Žilina*, 17(3), 25-30.
3. **Chandra T., Tsuzaki K., Militzer M., Ravindran C.,** (2007), Optimization of Nb HSLA microstructure using advanced thermo mechanical processing in a CSP plant, *Materials Science Forum,* 539-543, 28-35.
4. **Fernandez J., Illescas S., Guilemany J.M.,** (2014), Effects of microalloying elements on the austenitic grain growth in a low carbon HSLA steel, *Materials Letters* , 61(11-12), 2389-2392.
5. **Guzanova, A., Brezinova, J., Draganovska, D., Jas, F**. (2014), A study of the effect of surface pre-treatment on the adhesion of coatings, *Journal of Adhesion Science and Technology*, 28(17), 1-18.

DOI 10.1515/ama-2016-0013

6. **Jun H.J., Kang J.S., Seo D.H., Kang K.B., Park C.G.,** (2006), Effects of deformation and boron on microstructure and continuous cooling transformation in low carbon HSLA steels , *Materials Science and Engineering: A*, 422(1-2), 157 – 162.
7. **Muthmann E.**, **Grimpe F.** (2006), *Fabrication of hot induction bends from LSAW large diameter pipes manufactured from TMCP plate*, Microalloyed Steels for the Oil and Gas Industry International Symposium, Araxá, Brazil.
8. **Saga M., Handrik P., Kopas P**. (2010). Contribution to computer simulation of induction bending of large diameter pipes. *Metalurgija = Metallurgy*, 49, 498-502.
9. **Sampath K.** (2006), An Understanding of HSLA-65 Plate Steels, *Journal of Materials Engineering and Performance,* 15, 32-40.
10. **Shome M., Mohanty O.N.** (2006), Continuous Cooling Transformation Diagrams Applicable to the Heat-Affected Zone of HSLA-80 and HSLA-100 Steels, *Metallurgical and Materials Transactions*, 37A, 2159-2169.
11. **Tropp M., Handrik M., Kopas P., Saga M.** (2012), Computer simulation of induction bending process, *Pipeline & Gas Journal*, 239(11), 3.
12. **Vervynckt S., Verbeken K., Lopez B., Jonas J.J.,** (2012), Modern HSLA steels and role of none-recrystallization temperature, *International Materials Reviews,* 57(4), 187-207.

Acknowledgment: Authors would like to thank Triple D Bending for material providing (induction bending) and Prooftest Consulting Inc. for providing laboratory equipment and space for sample machining and destructive testing.