CORROSION SCIENCE AND TECHNOLOGY, Vol.14, No.2(2015), pp.47~53 pISSN: 1598-6462 / eISSN: 2288-6524
DOI: http://dx.doi.org/10.14773/cst.2015.14.2.47

Effect of Induction Heat Bending Process on the Properties of ASME SA106 Gr. C Carbon Steel Pipes

Ki Tae Kim[1], Young Sik Kim[1,†], Hyun Young Chang[2], Young Jin Oh[2], and Gi Ho Sung[3]

[1]*Materials Research Center for Clean and Energy Technology, School of Materials Science and Engineering Materials, Andong National University, 1375 Gyeongdongro, Andong, Gyeongbuk, 760-749, Korea*

[2]*KEPCO Engineering & Construction Company, Power Engineering Research Institute, 8 Gumiro, Bundang, Seongnam, Gyeonggi 463-870, Korea*

[3]*R&D Center, Sungil SIM, 1587-4 Songjung, Gangseo, Busan, 618-270, Korea*

(Received February 08, 2015; Revised April 30, 2015; Accepted April 30, 2015)

Recently, the bending process is greatly applied to fabricate the pipe line. Bending process can reduce welding joints and then decrease the number of inspection. Thus, the maintenance cost will be reduced. Induction heat bending process is composed of bending deformation by repeated local heat and cooling. By this thermal process, corrosion properties and microstructure can be affected. This work focused on the effect of induction heating bending process on the properties of ASME SA106 Gr. C low carbon steel pipes. Microstructure analysis, hardness measurements, and immersion corrosion test were performed for base metal and bended area including extrados, intrados, crown up, and down parts. Microstructure was analyzed using an optical microscope and SEM. Hardness was measured using a Rockwell B scale. Induction heat bending process has influenced upon the size and distribution of ferrite and pearlite phases which were transformed into finer structure than those of base metal. Even though the fine microstructure, every bent area showed a little lower hardness than that of base metal. It is considered that softening by the bending process may be arisen. Except of I2, intrados area, the others showed a similar corrosion rate to that of base metal. But even relatively high rate of intrados area was very low and acceptable. Therefore, it is judged that induction heat bending process didn't affect boric acid corrosion behaviour of carbon steel.

Keywords : *Induction heat bending, Carbon steel, Microstructure, Boric acid corrosion*

1. Introduction

Power conversion system feeds the secondary water from the secondary side of steam generator to steam generator through turbine and condenser. Most of pipes were made of carbon steels and ferritic alloy steels. Large parts of power conversion system including turbine are the non-safety system but main pipes to connect the steam generator only are considered as the safety system. Final Safety Analysis Report (FSAR) 10.3.6.2 describes the selection and fabrication of the materials for steam and feed water systems and meets the requirements of Korea Electric Power Industry Code - Mechanical Nuclear (KEPIC MN)[1]. However, since erosion corrosion may affect the wastage of carbon steels and ferritic alloy steels for these systems, the suitable materials should be selected according to EPRI-3944[2] and NUREG-1344[3]. EPRI-3944 explains the effect of chromium and manganese contents on the erosion corrosion of carbon steels and ferritic alloy steels. Therefore, ferritic alloy steel having high chromium content is being applied in newly constructed nuclear power plants in Korea. In the case of induction heat bent pipes, the important alloying elements such as chromium should be checked to insure the bending process[4].

There are many reports that erosion corrosion occurs by corrosion of the pipes of secondary system in many worldwide plants. Typical corrosion examples are flow assisted corrosion and wastage. Therefore, the worldwide regulatory agency is interested in the materials ageing including thermal embrittlement of cast austenitic stainless steels, primary stress corrosion cracking of nickel alloys, design application of leak-before-break, inspection on boric acid corrosion, wastage (flow assisted corrosion, erosion corrosion). Among these damages, this work focused on boric acid corrosion of induction heat bent pipe. Boric acid corrosion has been a hot issue in the nuclear power industry since the accident of Davis-Besse nuclear power plant had been reported in the early 2000s. Primary water

† Corresponding author: yikim@andong.ac.kr

Table 1. Chemical composition of ASME SA106 Gr. C carbon steel (wt%)

C	Mn	P	S	Si	Cr	Cu	Mo	Ni	V	Fe
0.27	0.86	0.012	0.007	0.23	0.06	0.019	0.019	0.05	0.008	bal.

Table 2. Identification symbols for test areas of ASME SA106 Gr. C carbon steel bended pipe

Areas	Transition (start)	Bend	Transition (End)	Remarks
Intrados	I1	I2	I3	Base metal (BM)
Extrados	E1	E2	E3	
Crown Up	CU1	CU2	CU3	
Crown Down	CD1	CD2	CD3	

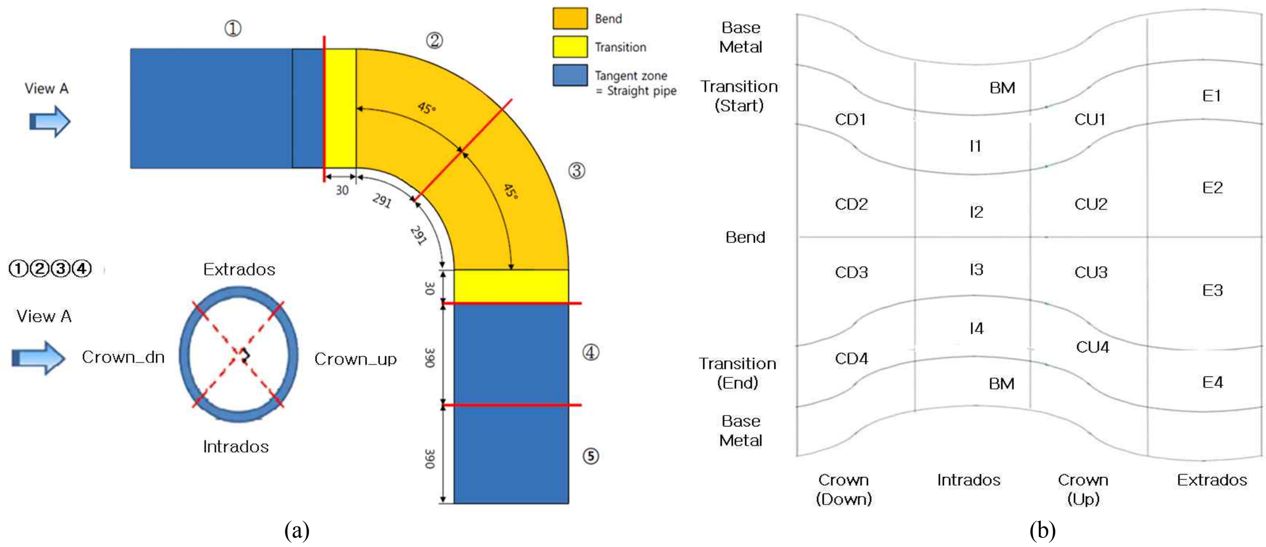


Fig. 1. Schematic diagram of (a) ASME SA106 Gr. C carbon steel bent pipe and (b) identification symbols.

of pressurized water reactor contains boric acid and LiOH and thus this water may induce several types of corrosion as like general corrosion, galvanic corrosion, crevice corrosion, pitting, intergranular corrosion, and stress corrosion cracking[5]. Boric acid itself is a mild acid comparing to hydrochloric or nitric acid. However, if borated water leaks from primary or secondary systems through gasketed[6] joints, valve packing and mechanical seals, etc., significant corrosion problems can be developed. Specifically, the water can become oxygenated and the boric acid can concentrate as the water boils off or evaporates. These factors can increase the corrosion rate of exposed carbon steel from < 0.001 in/yr to as much as 10 in/yr[6]. Five affecting parameters in boric acid corrosion are impurities, oxygen, temperature, pH and flow rate. However, there is less report on the effect of boric acid on corrosion behavior of bent pipes.

In this work, the effect of bending process on the corrosion characteristics of ASME SA106 Gr. C[7] carbon steel in the form of induction heat bent pipes was evaluated. Analysis was performed with microstructure observation, hardness measurement and some corrosion tests.

2. Experimental PROCEDURE

Table 1 shows the chemical composition of ASME SA106 Gr. C carbon steel used in this work. Table 2 and Fig. 1 represent the identification symbols and diagram of each part in bent pipe. Bending was performed using a model HFB-9(N) and its temperature range is 1000 ℃ ~ 1130 ℃ and bending angle is 90°. After bending, the bent pipe was cooled using a compressive air.

Non-metallic inclusions were inspected according to ISO 4697 standard[8]. Optical microstructure was observed using a microscope (ZEISS AXIOTECH 100HD) after etching in 3% Nital solution (97ml alcohol + 3ml HNO_3).

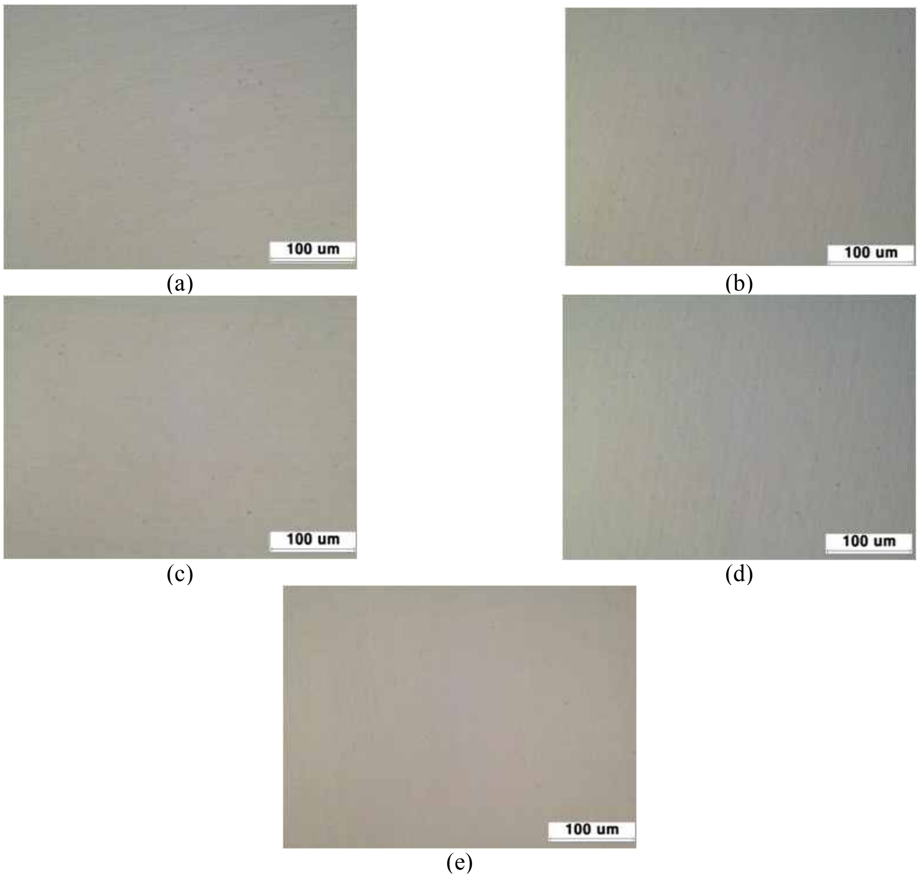


Fig. 2. Inspection of non-metallic inclusion on base metal and bended areas of ASME SA106 Gr. C carbon steel: (a) I1, (b) E1, (c) CU1, (d) CD2 and (e) base metal.

Also, the microstructure was analyzed using a SEM-EDS (TESCAN, model VEGA Ⅱ LMU). Surface hardness was measured by Rockwell hardness tester (Matuzawa SEIKI MRK-M2) and crystal structure was analyzed using X-ray diffractometer (Rigaku Ultima IV) and its scan angle was from 20^o to 80^o and scan rate was 1^o/min by step of 0.05^o. Corrosion rate in boric acid solution was measured in an autoclave (Hastelloy C276). Before heating to test temperature, the test solution (5,700 ppm and 11,400 ppm boric acid)[9,10] was de-aerated with being purged by H_2 gas at the rate of 300 cc/min. The test temperature was maintained at 200^oC (5,700 ppm boric acid) for 100 hours.

3. Resutls and Discussion

Fig. 2 shows the result of non-metallic inclusion inspection on base metal and bended areas of ASME SA106 Gr. C carbon steel (magnification: x100). Test method was ISO 4697 standard and every specimen including base metal showed non-metallic inclusion free under the criteria of 1.5i of the standard[8]. Therefore, it should be noted that induction heat bending process does not affect the non-metallic inclusion in the alloys.

Bending process is operating at high temperature and thus the microstructure may be changed. Fig. 3 represents optical microstructures on base metal and bended areas of ASME SA106 Gr. C carbon steel (magnification: x200). In the case of base metal, coarse primary ferrite and pearlite phases well developed. However, these ferrite and pearlite phases transformed to very fine structure. It is judged that these fine phases can be arisen by rapid cooling after heating during the bending process. Also, each area showed a little different microstructure and this is due to the different heating and cooling rates of the process. Fig. 4 shows X-ray diffraction (XRD) patterns on base metal and bent areas of ASME SA106 Gr. C carbon steel. Every specimen showed the same crystal structure (BCC structure-(110), (200)) and thus it means that the bending process didn't affect crystal structure but changed the size and distribution of phases. Fig. 5 shows SEM images on extrados areas (E2) of bended pipe of ASME SA106 Gr. C carbon steel (magnification: x5000).

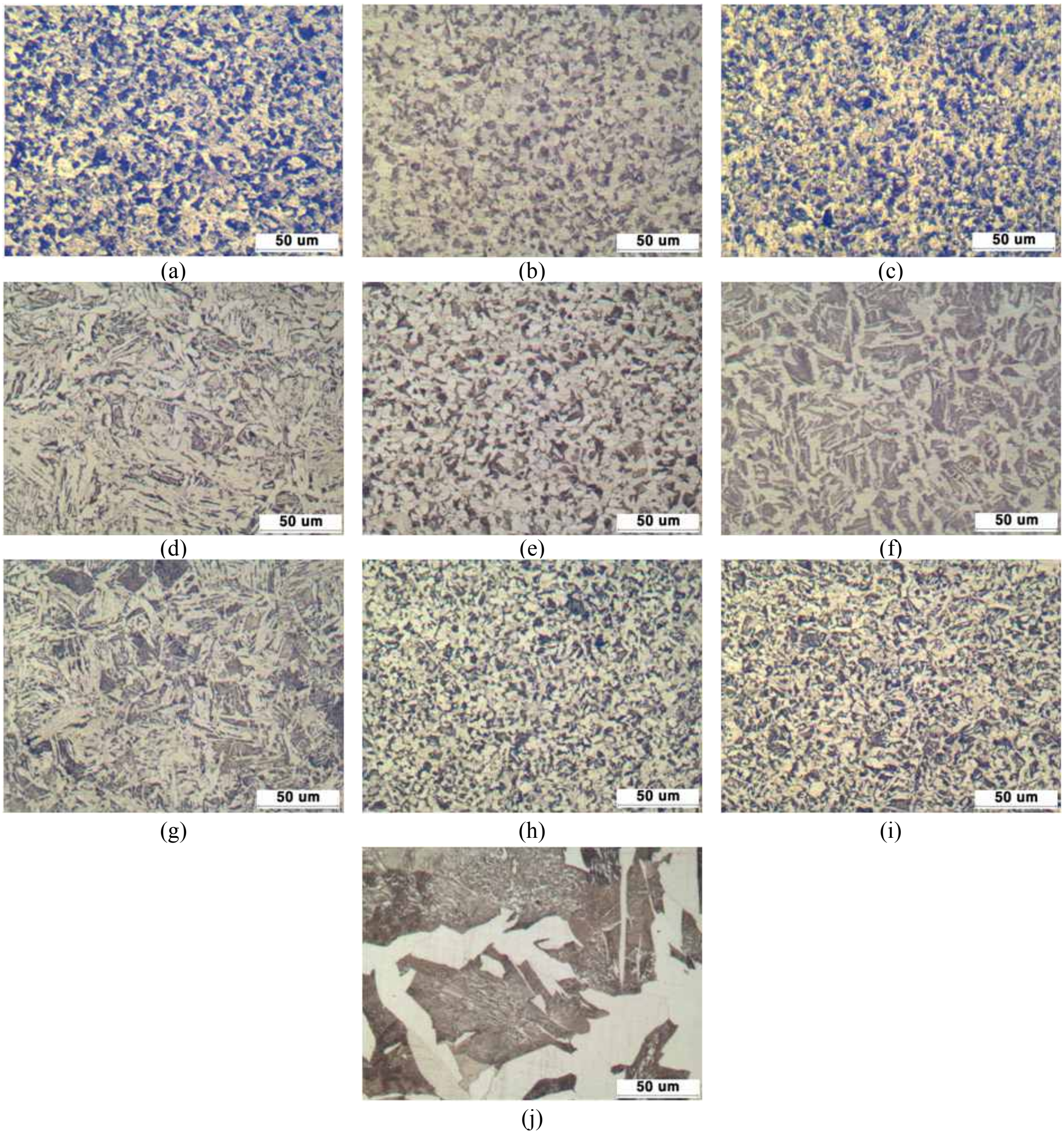


Fig. 3. Optical microstructures of base metal and bended areas of ASME SA106 Gr. C carbon steel: (a) I1, (b) E1, (c) CU1, (d) I2, (e) E2, (f) CU2, (g) I3, (h) E3, (i) CU3 and (j) base metal.

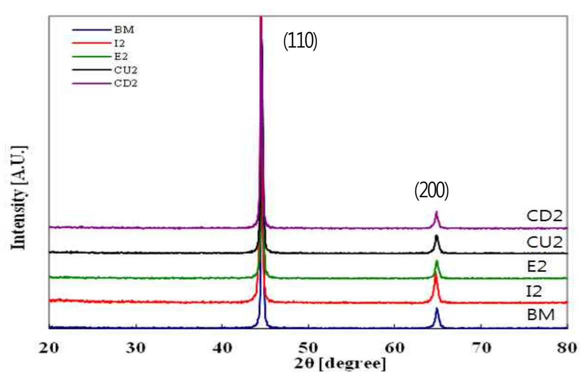


Fig. 4. X-ray diffraction analysis on base metal and bend areas of ASME SA106 Gr. C carbon steel.

As shown in the Fig., dark area in the optical micrographs was composed of ferrite and cementite phases[11].

Fig. 6 shows the Rockwell Hardness of base metal and bended areas of ASME SA106 Gr. C carbon steel. Hardness of base metal showed HRB 91.3, but transition start areas show HRB 85.9 ~ 87.1, and bend areas have HRB 86.6 ~ 89, and transition end areas show HRB 87 ~ 88.2 hardness ranges. Even though the fine microstructure, every bent area showed a little lower hardness than that of base metal. It is considered that softening by the bending process may be arisen - outer surface area was air-cooled during bending process after heating, and slow cooling rate may induce the softening.

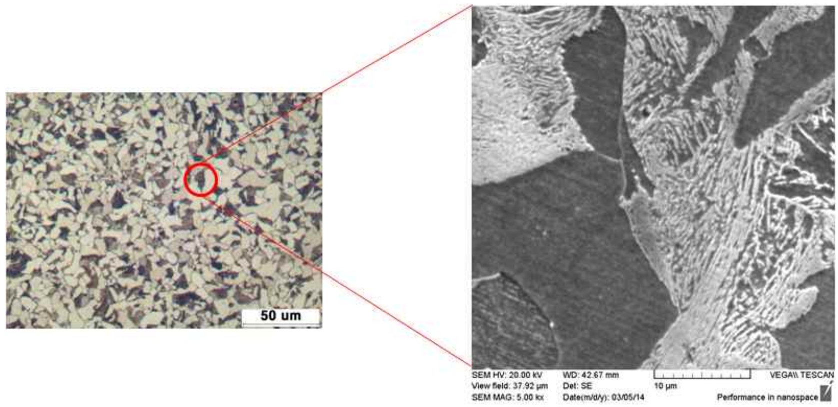
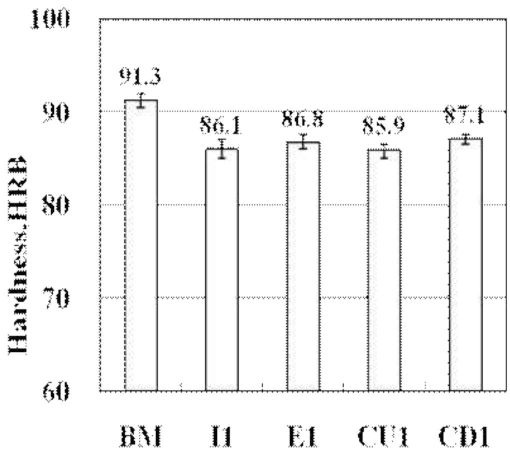
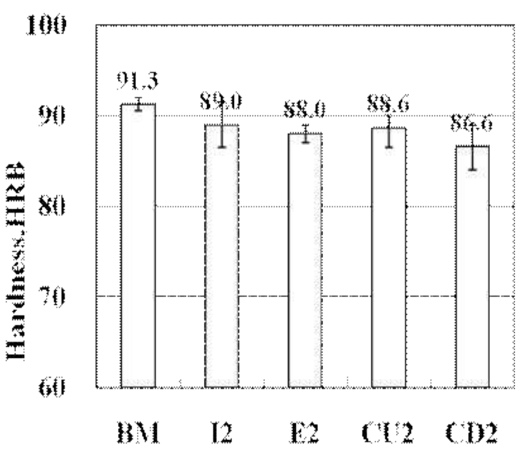


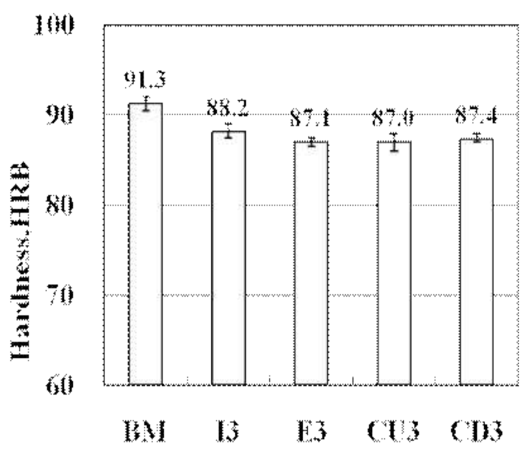
Fig. 5. Optical and SEM images on extrados areas (E2) of bended pipe of ASME SA106 Gr. C carbon steel.



(a)



(b)



(c)

Fig. 6. Rockwell hardness of base metal and bended areas of ASME SA106 Gr. C carbon steel: (a) transition start, (b) bend and (c) transition end.

Fig. 7 represents corrosion rate for base metal and bended areas of ASME SA106 Gr. C carbon steel. The solution was deaerated using a hydrogen gas and the concentration was 5,700 ppm boric acid at 200℃ and test was performed

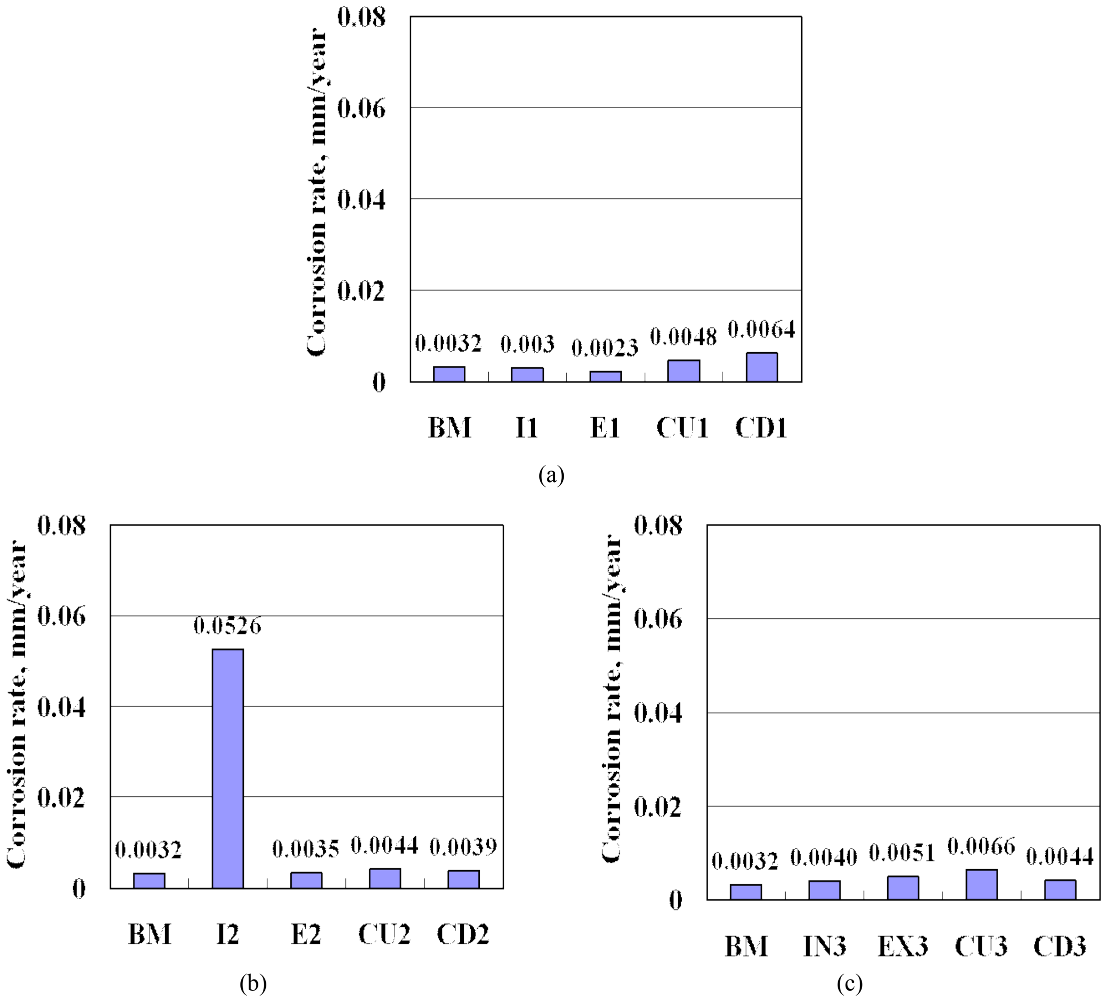


Fig. 7. Corrosion rate for base metal and bended areas of ASME SA106 Gr. C carbon steel in deaerated 5,700 ppm boric acid 200℃ for 100 hours: (a) transition start, (b) bend and (c) transition end.

for 100 hours. Test was performed according to Moscow power institute test condition in EPRI 1000975[6]. Corrosion rate of base metal was 0.0032 mm/y. Also, transition start and end areas showed a similar corrosion rate of base metal, i.e. 0.003 mm/y (I1), 0.0023 mm/y (E1), 0.0048 mm/y (CU1), 0.0064 mm/y (CD1), 0.004 mm/y (I3), 0.0051 mm/y (E3), 0.0066 mm/y (CU3), 0.0044 mm/y (CD3). However, bent areas showed rates of 0.052 mm/y (I2), 0.0035 mm/y (E2), 0.0044 mm/y (CU2), 0.0039 mm/y (CD2). Except of I2, intrados area, the others showed a similar corrosion rate to that of base metal. But even relatively high rate of intrados area was very low and acceptable.

4. Conclusions

Induction heat bending process does not affect the non-metallic inclusion in the alloys and every bent area showed inclusion-free under 1.5i on the base of ISO 4967 but this process has influenced upon the size and distribution of ferrite and pearlite phases and thus transformed finer structure than that of base metal. Even though the fine microstructure, every bent area showed a little lower hardness than that of base metal. It is considered that softening by the bending process may be arisen. Except of I2, intrados area, the others showed a similar corrosion rate to that of base metal. But even relatively high rate of intrados area was very low and acceptable. Therefore, it is judged that induction heat bending process didn't affect boric acid corrosion behaviour of carbon steel.

Acknowledgments

Research for this paper was supported by Sungil SIM

Company funded from the Korea Institute for the Advancement of Technology. Authors wish to thank both organizations.

References

1. Korea Hydro & Nuclear Power Co, Ltd., Final Safety Analysis Report on Shinkori 1&2 NPP (2011).
2. EPRI, EPRI NP-3944, Erosion/Corrosion in Nuclear Plant Steam Piping: Causes and Inspection Program Guideline (1985).
3. US NRC, NUREG‐1344, Erosion/Corrosion‐Induced Pipe Wall Thinning in U.S Nuclear Power Plants (1989).
4. M. C. Shin and Y. S. Kim *Proceedings of CSSK fall meeting*, p. 97, CSSK, Jeju (2013).
5. S. W. Kim and H. P. Kim, *Corros. Sci. Tech.*, **12**, 85 (2013).
6. EPRI-1000975, Boric Acid Corrosion Guidebook, Revision 1 (2011).
7. ASME II, Part A Ferrous Materials Specifications (Beginning to SA-450) (2011).
8. ISO 4967, Steel-Determination of content of non-metallic inclusions Micrographic method using standard diagrams (2013).
9. T. Kh. Margulova, L. M. Bursuk, *Therm. Eng.*, **17**, 13 (1970).
10. Yu. I. Babei, V. V. Zhitkov, Yu, I, Zvezdin, I. Yu. Liskevich and A. A. Nazarov, *Soviet Mater. Sci.*, **18**, 135 (1982).
11. W. D. Callister, Materials Science and Engineering An Introduction, p. 293, John Wiley & Sons, Inc., New York (2007).