

CHARACTERIZATION OF CU-NI ASME SB467 PIPE VIA ASSISTED GTAW : HARDNESS AND TENSILE PROPERTIES

Trinet Yingsamphancharoen^{1,2} and Phuri Kalnaowakul^{2,3,*}

Received: October 15, 2021; Revised: December 07, 2021; Accepted: March 06, 2022

Abstract

Cu-Ni alloys such as 90/10 or 70/30 of Cu-Ni alloys have superior corrosion resistance and other applications. Welding these materials has traditionally been done with shielded metal arc welding or brazing. Gas tungsten arc welding (GTAW) is an energetic technology because of its high productivity, process flexibility and dependability, and superior integrity weld characteristics. In this study, GTAW is utilized to weld 5.5 mm thick Cu-Ni alloy pipe in terms of surface morphology (microstructure) and mechanical characteristics (hardness, bending, and tensile) according to the appropriate international standards organization and requirements. The results show that the characteristics of Cu-Ni alloys of ASME SB467 UNS 70600 Pipe were investigated by XRD pattern found crystallite sizes in a range from 26 to 28 nm. Moreover, surface morphology revealed that copper and nickel were completely miscible in both the liquid and solid states, with the Cu-Ni binary phase being isomorphous, allowing the creation of a face-centered-cubic (FCC) phase structure in the alloy. In addition, the presence of Cu-Ni alloys ASME SB467 UNS 70600 contributed significantly to the improved mechanical qualities obtained during the GTAW process.

Keywords: Copper alloys, Nickel alloys, Cu/Ni alloys, Mechanical properties, Gas Tungsten Arc Welding

Introduction

Cu-Ni alloys are called cupronickel alloys, which have the element composition of Cu and Ni inside their alloys such as 90/10 or 70/30 of Cu-Ni. The cupronickel alloys have superior corrosion resistance and anti-biofouling properties. Thus, they're used in maritime and offshore applications for marine pipes, pipework, thermal storage tubes, boiler sections, pump bodies, and other designed

ship components (Ferro *et al.*, 2005; Copper and Fabrication, 2013). All the welding processes like manual metal Arc (MMA), brazing, For Cu-Ni alloys, all welding procedures such as manual metal arc (MMA), brazing, and gas-shielded metal arc (GMAW or MIG) can be utilized, however controlling the welding pool is difficult (Lahti and Lukkari, 2002; Ferro, *et al.*, 2005). In addition, the

¹ Department of Welding Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand.

² Center of Welding Engineering and Metallurgical Inspection (Science and Technology Research Institute), King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand.

³ Department of Mechanical and Industrial Engineering, Rajamangala University of Technology Krungthep, Bangkok 10120, Thailand. E-mail: phurikalnaowakun@hotmail.com

* Corresponding author

rate of a brazing fault is rather high, resulting in a flame that is regarded as a safety hazard for surrounding structures such as a ship's hull. Furthermore, intermetallic cracking in the weld and heat-affected zone (HAZ) can occur in the two primary Cu-Ni alloys, such as crystallization cracking in the weldment (WM), cracking in the HAZ, and cracking in the reheated weld metal during several layers of welding. Other issues that are commonly encountered in Cu-Ni arc welding include lack of fusion and porosity. GTAW welding without filler metal doping is rarely recommended for Cu-Ni alloys because of the cluster occurrence of porosity (Prager *et al.*, 1977; Devletian and Sullivan, 2006). To avoid the creation of porosity, a filler metal containing the element titanium (Ti) is typically employed to shield reactive nitrogen and oxygen (Ferro *et al.*, 2005). The welded Cu-Ni with other weld joints seemed possible with MMA. However, the MMA welding methods are slow and inefficient. Traditional welding technology approaches, such as GTAW, are, on the other hand, promising technology with numerous advantages. For example, low heat input, the controlled fusion zone with almost parallel fusion boundaries, less residual stress, and thermal distortion which joining the design and preparation in the variety of materials (Cu, Ti, Al, Mg, and others alloys (Cao *et al.*, 2003). Due to its thermal and physical characteristics, which including thermal conductivity and thermal diffusivity, GTAW is the most difficult to weld with purity copper, resulting in an unstable welding process. Then, by adding nickel alloying elements into copper, the thermal efficiency can be reduced, resulting in greatly better weldability of copper alloys (Ferro *et al.*, 2005). Several researchers have suggested that adding nickel alloy components to Cu-Ni alloys can dramatically decrease thermal conductivity while increasing mechanical properties (Hafner, 2015; Vizureanu and Achit, 2018). Recently, only a small amount of work has been done on Cu-Ni alloys utilizing alternative welding techniques. For instance, laser welding using CO₂ to weld plate-on-plate of the Cu-Ni alloys was studied to see how welding speed and power affected the weld properties and microstructure (Copper and Fabrication 2013). Similar researchers used the same process to weld 90/10 Cu-Ni or 70/30 Cu-Ni alloys. It was discovered that the joints had fine, equiaxed, and evenly dispersed grains in the fusion zone, as well as improved mechanical qualities (Chakravarthy *et al.*, 2014). In addition, similar researchers were studied the two processes using CO₂ lasers, one preliminary work and another using GTAW which reported for the Cu-Ni alloys on the microstructure and material properties. The welding of Cu-Ni alloys with a diameter of 6.3 mm showed

these results, which increased as the material's characteristics increased (Reutzel *et al.*, 2007). To the best knowledge, there are not still reported using the new alternatives of the binary (Cu-Ni) alloys by GTAW process. In addition, the microstructure properties of GTAW welded joints were improved. Other mechanical and physical characteristics of the weld Cu-Ni alloy have not appeared. This work is aimed to investigate the characterization and mechanical properties of Cu-Ni alloys of ASME SB467 UNS 70600 Pipe via assisted GTAW process. The result obtained in welding processes for various industrial applications limits the investigation of GTAW employed in binary alloys. As a result, we investigated the welded Cu-Ni pipe in terms of morphology and physical properties (hardness, tensile, and bending) in compliance with the applicable international standardization and specifications.

Table 1. Chemical composition of the ASME SB467 alloys

ASME SB467	Chemical composition (wt.%)
Cu	Remainder
Ni	9.0-11.0
Fe	1-1.80
Pb max	0.05
Zn max	1.0
Mn max	1.0
S max	0.02
P max	0.02
C max	0.05

Table 2. Chemical composition of the ER Cu-Ni filler wire

ER Cu-Ni	Chemical composition (wt.%)
Cu	Remainder
Ni	9.0-11.0
Fe	1-1.80
Pb max	0.05
Ti max	0.02
Mn max	1.0
P max	0.02
Si max	0.05

Materials and Methods

In this experiment used to Cu-Ni alloys ASME SB467 UNS 70600 pipe which was the composition in accordance with ASME BPVC section II-part B.¹³ For the welding process, the equivalent of UNS 70600 identifications of Cu-Ni alloys pipe might be considered as a substitute. As noticed in Figure 1, size of the specimen 76 mm x 500 mm x 5.5 mm of Cu-Ni alloys pipe was used for wire-cut (JZ, DK7730, Taizhou Jiangzhou Number-Controlled Machine Tool Manufacture

Co., Ltd., Jiangsu, China) to testing pipe, and fully annealed Cu-Ni pipe with the welded of Cu-Ni in according to ASME sec. IX or ISO 15614-6 by using ER Cu-Ni filler wire as referred to (ISO 15614-6, 2006). Cu-Ni alloys have been specified and welded with filler metals. The Base metal composition for Cu-Ni alloys is correlating in Table 1. Because Cu-Ni has a higher copper content than copper filler, used as a filler metal. Table 2 shows the chemical composition of the ER Cu-Ni filler metals. The selected welding technology for creating a component-like structure is gas tungsten arc welding (GTAW). During the welding process, the GTAW uses a 1-2% zirconated tungsten electrode. The nozzle has a diameter of 2.5 mm. Prior to use in the Cu-Ni filler metal, the specimens are cleaned and prepared for welding.

Fully All non-destructive testing, including visual and liquid penetrant tests, were performed preparatory to cutting the welds in their as-welding state, in accordance with ISO 17637 and ISO 3452 criteria (ISO 3452, 2013; ISO 17637, 2016). For morphologies structural examination also strength testing, samples were cut out each of the workpieces. Next, The automated process has been used to mount and polish the specimens. Specifically, the welded specimens were abraded using successively finer silicon carbide papers (300, 400, 600, 800, 1000, 1200, and 1500 grits) and then washed with ethanol and ultrasonicated in distilled water. The specimens were etched in 3% nitric acid to open the microstructure in the weld zone and HAZ for approximately 3s. The microstructure profiles and surface analysis of the welded Cu-Ni alloy was observed by scanning electron microscope (SEM:Philips XL 30 series, Philips, USA) and X-ray diffractometer (Philips X-Pert-MPD X-ray diffractometer, Netherlands). The Vickers microhardness data at the weldment of the sample was detected by SONOHARD (SH-75, JFE Advantech Co., Ltd., Japan). A stationary hardness tester was used to determine the hardness of the interior of the weld and the base positions (Wilson Instruments, Campbellford, Canada). According to ASTM E384, the hardness of a welded connection was tested utilizing a 0.1 mm dent distance, a load trial of 100 kgf, and a 15-second rest time (ASTM E384, 2017). The welded specimen for tensile tests were also measured by transverse tensile testing at room temperature. The dimensions with the shape of mechanical testing samples as per ASTM A370 or ISO 4136 are shown in Figure 2 (ASTM A370, 2020; ISO 4136, 2012). Three specimens for the tension test were also taken from this one as material to compare the physical behavior of the welds to those of Cu-Ni. As illustrated in Figure 3, the

ductility of the welds was assessed using a guideline bend test performed according to ASTM E190-92 on according to ASTM E190-92 on measuring instrument (ASTM E190-92, 2011).

The workpieces were put through their limitations in both root and face bend testing. During the testing, the specimens were examined under an investigation of cracking and assessed using the ISO 15614-6 pass/fail standards (ISO 15614-6, 2006).

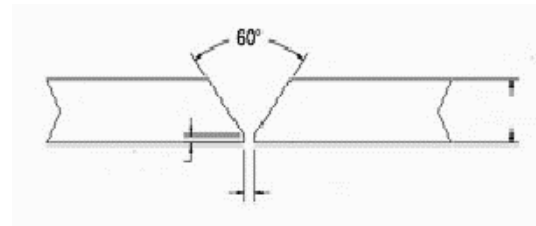


Figure 1. Preparation of the specimens were followed by ASME sec. IX for welding

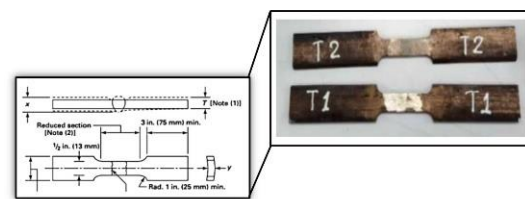


Figure 2. Preparation of the specimens used for tensile testing

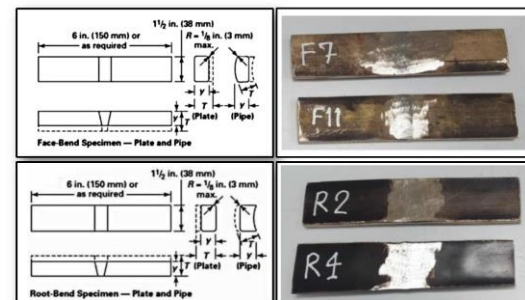


Figure 3. Preparation of the specimens used for bend testing

Results and Discussion

The XRD patterns of the welded Cu-Ni alloy throughout the GTAW process is shown in Figure 4. Figure 4 shows the diffraction peaks of the most Cu-Ni alloy located at 2θ of 44.36° , 50.4° , 74.55° , 90.33° and 95.55° respectively, which represent the major phase of Ni, Cu, Fe-Ni, Ni-Cu and FeNi₃ elements. This is probably the result of

an incomplete reaction in FeNi₃ during the welding and calcination processes. The existence of these phase crystal structure arises from the calcination conditions as per other studies (Beccaria *et al.*, 1994; Li *et al.*, 1991). To confirm this, we ran rocking scans on Cu-Ni alloy at $2\theta=44.36^\circ$, the value for the (111) diffraction peak. We also used Scherrer's equation to determine the crystallite sizes in Cu-Ni alloy: $\tau = k\lambda / (\beta \cos\theta)$ where k is a constant that ranges from 0.89 to 1.54, λ is the X-ray wavelength, β is the FWHM of the peak (measured in radians) and θ is the Bragg angle in radians. We utilized $k = 0.89$ in this experiment, assuming that the crystallites size and calculated using peak fits with the XRD software. To compare the Cu-Ni alloy on the Ni peak has larger dominating crystallite sizes than the Cu in each location, which has the same preferential development along the (111) direction as pure Cu-Ni of the diffraction pea (Huang *et al.*, 2003; Sadeghi and Zolanvari, 2009). As confirmation of the XRD results, the Cu-Ni alloy is an isomorphous binary alloy, which means the two metals are completely soluble in each other and have one type of crystal structure (fcc) with little to no strain which the values of Cu-Ni reflection (JCPDS No. 00-004-0836) with (JCPDS No 00-004-0850) as presented by (Kou and Yang, 2007; Alper *et al.*, 2008). The average crystallite diameters for the base metal, heat affected zone (HAZ), and Fusion zone (Weld) are 28.53, 26.33, and 28.49 nm as shown in Table 3, respectively. The average crystallite diameters of this study are similar to copper-stainless steel pipe by a different welding process (Hardik *et al.*, 2021). It is clear that adding nickel increases mechanical characteristics, which is likely related to the influence of welded melting in the presence of the GTAW process (Amer *et al.*, 2010; Wang *et al.*, 2016).

The surface morphology of Cu-Ni alloy was investigated by using GTAW process. Figure 5 shows the surface microstructural variations under the GTAW process at different zone such as Base metal, HAZ, and Weld. Copper and nickel were discovered to be entirely combined in both the liquid-solid states, with the Cu-Ni dual-phase being in the FCC structure. A fine dendritic structure is obviously formed in the fusion zone, and its growth is directed against the heat flux.

As seen in Figure 6, the dendritic branches are enriched in Ni, while the intergranular zones are rich in Cu. Similar results described that the grain growth occurred along the heating transfer direction (from the base metal towards the fusion zone). The columnar grain growth in the FZ (Figure 6) and heterogeneous epitaxial grain growth in the HAZ of base metal (Figure 5) was observed for Cu-

Ni materials at all deposition heat flux, and thus the secondary dendritic arm spacing can be used to measure fine dendritic structure (SDAS), (Strid and Easterling 1985; Beccaria *et al.*, 1994; Misra *et al.*, 2005).

Table 3. The average crystallite sizes for the Cu-Ni system are summarized here

Sample	Average crystallites size (nm)
Base metal	28.53
Heat affected zone (HAZ)	26.33
Fusion zone (Weld)	28.49

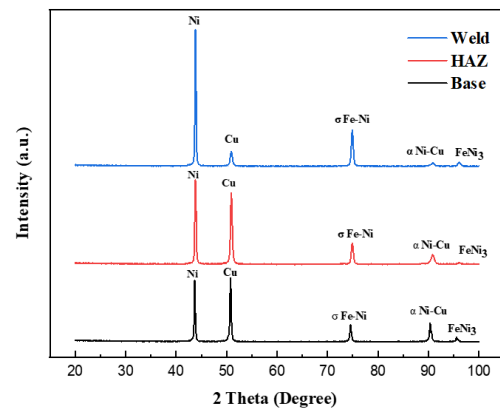


Figure 4. The XRD patterns of Cu-Ni alloy used in GTAW process

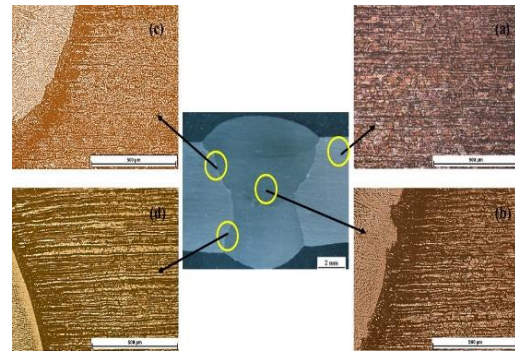


Figure 5. Typical microstructures under the GTAW process: (a) base metal, (b) middle weld in HAZ, (c) weld cap in HAZ, and (d) weld root in HAZ

Figure 7 depicts the hardness data obtained using the GTAW technique at the moderate thickness on the Cu-Ni welded transversal sections. The creation of subtle dendrites at high cooling rates, as seen in the GTAW process, gives the fusion zone somewhat greater hardness values than the base metal. The hardness in the weldment areas

gradually increases from 82 to 110 HV. In the present work, the dimension of Cu-Ni is rather thick (more than 5 mm) for the welded Cu-Ni alloy under this process, and thus the welding process is relatively narrow. Because there isn't expected to be any major fluctuation in the fusion zone's hardness levels. The values in the Heat-affected zone somewhat drop from the weld boundary to the base metal in a contrast to the hardness in the weldment zone (Beccaria *et al.*, 1994).

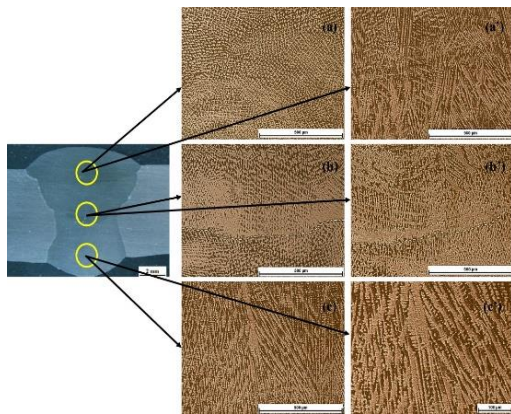


Figure 6. Topographical microstructures under the GTAW process: (a, a') top fusion zone, (b, b') interface fusion zone, and (c, c') bottom fusion zone

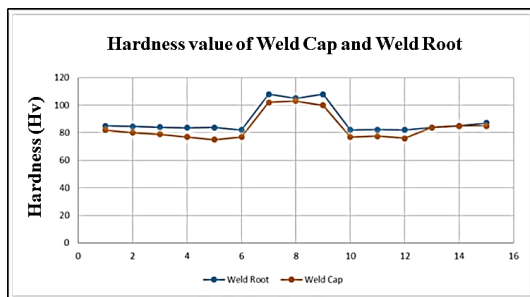


Figure 7. Hardness value along the mid-thicknesses on Cu-Ni by using the GTAW process

Figure 8 shows the tensile profiles for all this experiment under the GTAW process. It was noticeably that the variations of the tensile properties before using the GTAW process parameters is 275.8 MPa but when the use of the GTAW process, tensile testing shows a significant increase of 185 (326.15 MPa) from base metal. Moreover, the previous study suggested that the use of Cu-Ni filler metal wire is a little higher than mechanical properties with pure Cu or Ni filler metal (Wang, *et al.*, 2014; Xiaohu Hao *et al.*,

2021). However, it should be emphasized that all the specimens were investigated by visual and liquid penetration before use in the mechanical properties (ISO 17637, 2016; ISO 3452, 2013). Figure 9 displays all tensile and bend specimens of the welded under the GTAW process, demonstrating that the bend testing specimens met the ISO 15614-6 transverse bend criterion (ISO 15614-6, 2006) by attaining the desired deformation and the creation of cracks is demonstrated in Table 4. It can be noticed that there was no link found between the production of these cracks and the specimen orientation or welding techniques. The bend testing results indicate that all of the welded specimens under GTAW welds had good ductility in both the weld metal and HAZs, and that defects in the joints such as undercut, porosity, and sag were not harmful to the welds' performance.

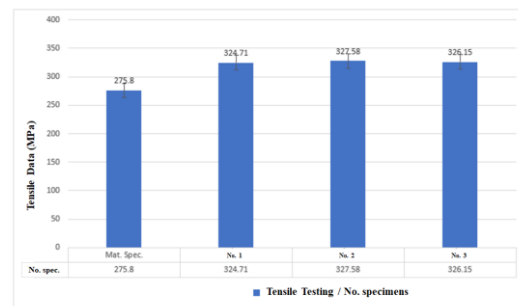


Figure 8. Tensile properties of Cu-Ni alloy under the control of the GTAW process



Figure 9. Failed tensile and bend specimens for a welded joint on Cu-Ni alloy

Table 4. Transverse Face bend and Root bend results in as-welded conditions

Sample No.	Orientation	Flaws and remarks
0213	Root and face bend	None
0214	Root and face bend	None
0215	Root and face bend	None

Conclusions

Cu-Ni alloys of ASME SB467 UNS 70600 Pipe were successfully assisted by GTAW process, which resulted in the crystallite sizes in a range from 26 to 28 nm depending upon the GTAW process parameters. In addition, the Cu-Ni alloy and all results in the mechanical properties showed a reasonable hardness data and tensile increase more than without the GTAW process. Furthermore, all of the welding processes passed the transversal guided bend tests in both root-face bend setups. Moreover, the results of this work represented that the presence of Cu-Ni alloys ASME SB467 UNS 70600 under the GTAW process, resulted in higher mechanical qualities including hardness and tensile values.

Author Contribution Statement

Phuri Kalnaowakul: Investigation, Methodology, Software, Writing and editing. Trinet Yingsamphancharoen: Supervision, Resources, Writing - review and original draft.

Funding

This research was funded by King Mongkut's University of Technology North Bangkok, Contract no. KMUTNB-64-DRIVE-17

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgement

We would like to express our deepest thanks to King Mongkut's University of Technology North Bangkok. In addition, all the instruments and facilities from the Center of Welding Engineering and Metallurgical Inspection, and the Institute of Science and Technology Research to finance support for the investigation of this work are greatly appreciated.

References

Amer, A.E., Koo, M.Y., Lee, K.H., Kim, S.H., and Hong, S.H. (2010). Effect of welding heat input on microstructure and mechanical properties of simulated HAZ in Cu containing micro-alloyed steel. *J. Mater Sci.*, 45:1,248-54.

- Alper, M., Kockar, H., Safak, M., and Baykul, M.C. (2008). Comparison of Ni-Cu alloy films electrodeposited at low and high pH levels. *J. Alloys Compd.*, 453(1-2):15-19.
- ASME Boiler and Pressure Vessel Code. (2015). Nonferrous Material Specifications. Sec. II, Part B. ASME International, NY, USA.
- ASTM E384. (2017). American Society for Testing and Materials (ASTM). Standard Test Method for Micro indentation Hardness of Materials. West Conshohocken, PA, USA.
- ASTM A370. (2020). American Society for Testing and Materials (ASTM). Standard Test Methods and Definitions for Mechanical Testing of Steel Products. West Conshohocken, PA, USA.
- ASTM Standard E190-92. (2011). Standard Test Method for Guided Bend Test of Ductility of Welds. Vol. 3.01, ASTM International.
- Beccaria, A.M., Poggi, G., and Wang, Y.Z. (1994). Effect of heat treatments on Cu-Ni 70/30 alloy pitting susceptibility in seawater at different temperatures. *Werkst. Korros.*, 45:562-569.
- Cao, X., Wallace, W., Poon, C., and Immarigeon, J.P. (2003). Research, and Progress in laser welding of wrought aluminum alloys. I. Laser welding processes. *Mater. Manuf. Process.*, 18(1):1-22.
- Copper-Nickel Welding and Fabrication. (2013). Copper Development Association Inc. Publication A7020-99/13, Revised in February 2nd edition Nickel Institute Publication 12014, February.
- Chakravarthy, M.P., Ramanaiah, N., and Sundara Siva Rao, B.S.K. (2014). Effect of laser welding on mechanical properties of 70/30 Cu-Ni alloy welds, *Proc IMechE Part B. J. Eng. Manu.*, 228(9):1,153-1,161.
- Devletian, J.H. and Sullivan, M.J. (2006). Flux Cored Arc Welding of CuNi 90/10 Piping with CuNi 70/30 Filler Metal: All Position Flux Cored Electrode of Final Report. Portland State University.
- Ferro, P., Bonollo, F., and Tiziani, A. (2005). Laser welding of copper-nickel alloys : a numerical and experimental analysis. *Sci. Techno. Weld. Joining.*, 10(3):299-310.
- Hafner, M. (2015). Aluminum-copper-nickel thin-film compositional spread: Nickel influence on fundamental alloy properties and chemical stability of copper. *Thin solid films.*, 580:36-44.
- Huang, H., Wei, H.L., Woo, C.H., and Zhang, X.X. (2003). Copper thin film of alternating textures. *Applied Physics Letters.*, 82:4,265.
- Hardik, D.V., Kush, P.M., Vishvesh, B., Bharat, D. (2021). Friction welding of dissimilar joints copper-stainless steel pipe consists of 0.06 wall thickness to pipe diameter ratio. *J. Manuf. Process* 68:1,176-1,190.
- ISO 15614-6. (2006). Specification and Qualification of Welding Procedures for Metallic Materials-Welding Procedure Test- Part 6: Arc and Gas welding of Copper and its Alloys. ISO International, Geneva, Switzerland.
- ISO 3452. (2013). Non-Destructive Testing-Penetrant Testing-Part 1: General Principles. ISO International, Geneva, Switzerland.
- ISO 17637. (2016). Non-Destructive Testing of Welds-Visual Testing of Fusion-Welded Joints. ISO International, Geneva, Switzerland.
- ISO 4136. (2012). Destructive Tests on Welds in Metallic Materials-Transverse Tensile Test. ISO International, Geneva, Switzerland.
- Kou, S., Y.K. and Yang, Y.K. (2007). Fusion-boundary macrosegregation in dissimilar-filler welds. *Weld. J.* 86:303s-312s.
- Lahti, K. and Lukkari, J. (2002). Welding of Copper-Nickel Alloys at Kvaerner Masa-Yards. *Svetsaren.*, 2:9-10.

- Li, J., Mayer, J.W., and Colgan, E.G. (1991). Oxidation and protection in copper and copper alloy thin films. *J. Appl. Phys.*, 70:2,820-2,827.
- Misra, R.D.K., Nathani, H., Hartmann, J.E., and Siciliano, F. (2005). Microstructural evolution in a new 770 MPa hot-rolled Nb-Ti micro-alloyed steel. *Mater. Sci. Eng. A.*, 394:339-352.
- Prager, M., E.W. Jr., and Thiele. (1977). Welding copper-nickel ships. *Welding J.*, 15-23.
- Reutzel, E.W., L. Kern, L., J.F. Tressler, J.F., and Avalos, J. (2007). Laser-GMA hybrid pipe welding system, Final Technical Report, Center for Naval Shipbuilding Technology.
- Sadeghi, H. and Zolanvari, A. (2009). Characterization of annealed Ni/Cu multilayers on Si (100). *Armenian Journal of Phy.*, 2(4):302-306.
- Strid, J.J. and Easterling, K.E. (1985). On the chemistry and stability of complex carbides and nitrides in micro-alloyed steels. *Acta Metall.*, 33:2,057-2,074.
- Vizureanu, P. and Achit, D.C. (2018). Aspects Regarding Thermal-Mechanical Fatigue of Shape Memory Alloys. *Shape-Memory Materials*, 17.
- Wang, X.Y., Sun, D.Q., and Sun, Y. (2016). Influence of Cu-Interlayer thickness on microstructures and mechanical properties of MIG-Welded Mg-Steel joints. *J. Mater Eng. Perform.*, 25:910-20.
- Wang, T., Zhang, B.G., Wang, H.Q., Feng, J.C. (2014). Microstructures and mechanical properties of electron beam-welded titanium steel joints with vanadium, nickel, copper, and dilver filler metals. *J. Mater. Eng. Perform.*, 23:1,498-504.
- Xiaohu, H., Honggang, D., Fengyun, Y., Peng, Li., Zhonglin, Y. (2021). Arc welding of titanium alloy to stainless steel with Cu foil as interlayer and Ni-based alloy as filler metal. *J. Mater. Res. Technol* 13:48-60.