

Influence of welding processes on weld bead geometry

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Abstract – In the present scenario of industries, Welding processes becomes increasingly popular. Right from the Manual metal arc welding process to Electron beam welding process, welding undergone tremendous technological innovations over the years. As the requirements are becoming more stringent, advanced technologies are being invented to fulfill that. The end benefit of technologies are depends on the characteristics of the weld which is produced. Weld should be sound enough to meet the functional requirement of the welded structure. The main quality characteristics are weld bead geometry such as weld penetration, HAZ, fusion and metallurgical and mechanical properties of the welded joints. Weld bead geometry is mainly depends on the type of welding process. This paper reviews the influence of different welding processes on weld bead geometry.

Key Words: Weld penetration, Heat affected zone, Fusion width, Weld bead geometry.

1. INTRODUCTION

Welding is vital process which is having wider industrial applications including automotive industries, shipbuilding, aerospace industries, electrical power industries, heavy equipment industries, electronics and medical applications. The requirement of weld quality in each applications are different, which leads to the invention of advanced welding technologies. Generally, weld quality is evaluated in terms of weld bead geometry, microstructure of weld, hardness, tensile strength and aesthetic appearance of weld. Weld bead geometry mainly includes depth of fusion, fusion width, bead height and HAZ width. These geometrical parameters has vast influence on the performance of the welded structure. Meeting to the intended design requirement of these geometrical parameters are always challengeable. In most of the cases, weld penetration should be maximum whereas fusion width, bead height and HAZ width should be minimum in order to obtain the required strength of the weld joint. If any imperfections observed in these parameters, that will have adverse effect on weld joint performance. Lack of penetration is one of the significant factor affecting fatigue life of the weld joint [1]. Changes in weld penetration will reflect in fatigue life of the joint. Lack of penetration allows a natural stress raiser from which a crack may propagate [1]. Amount of heat input is one of the main parameter which influences the depth of penetration. Sufficient heat input is required to achieve the penetration. In most of the conventional arc welding processes heat input

is directly proportional to the depth of fusion. On the other hand, if heat input increases, fusion area and HAZ area increases. Increase in fusion area results in increase in distortion. Microstructure and mechanical property of heat affected zone differs from weld metal and base material. Typically, hardness of the HAZ will be higher than weld metal and base material. As increase in hardness results in increase in brittleness of the weld joint which completely unfavorable for load carrying structure. Increase in bead height or excess bead increases the stress in weld toe region. Stress in weld toe region obviously leads to fatigue failure. On the other hand, lack of weld reinforcement reduces the fatigue strength of the weld joint. So, producing weld joint with maximum penetration and minimum fusion and HAZ width is really a tough task for welding engineers. Numerous process parameter optimization techniques and advanced technologies are invented to achieve this. Generally, the conventional arc welding processes known for its high heat input. Advanced welding processes are available which can deliver maximum penetration with minimum fusion and HAZ area at low heat input.

1.1 Weld bead geometry

The utmost important weld bead geometry parameters are depth of fusion, fusion width or bead width, bead height and HAZ area. These parameters are measured as shown in Fig-1. Imperfections in weld geometrical parameters will have intense effect on weld joint performance. It negatively affects the performance of the welded structure.

Depth of fusion - is defined as the distance that fusion extends into the base material.

Bead width - is defined as the maximum width of the deposited weld metal

Bead height or reinforcement height - is defined as the bead height above the surface of the plate.

Heat affected zone - is defined as the non-melted area that has experienced changes in material properties due to the exposure of welding heat.

Mechanical properties of the welded joint is determines by the weld bead shape [2]. Weld joint is considered to be sound and economical when it has a maximum penetration, bare minimum of bead width, reinforcement height and HAZ width [2].

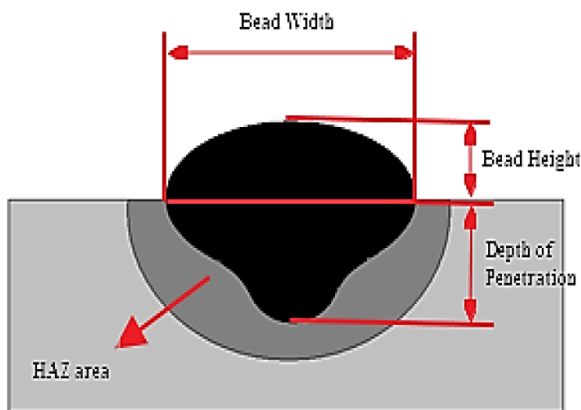


Fig-1: Schematic representation of bead geometry and HAZ area [3].

1.2 Effects of weld bead geometry imperfections

The major weld bead geometry imperfections are lack of penetration, high HAZ width, high fusion width, excess bead height. Lack of penetration directly affects the strength of the weld joint. Load bearing capacity of weld joint gets affected. Moreover lack of penetration acts as natural stress raiser which may results in crack propagation. So fatigue life of the weld joint will affect considerably [1]. As HAZ experiences sufficient amount of welding heat, that undergoes microstructural and metallurgical changes that significantly differs from base material. This changes may leads to residual stresses, reduction in material strength, increase in brittleness and reduction in resistance to crack and corrosion. As HAZ deciding the mechanical properties of around the weld joint, it becomes weakest portion of the weld joint. HAZ in weld joint increases the tendency to the formation of cold cracks and affects its resistance to brittle cracking[4]. Similarly increase in fusion area increases the distortion which affects the dimensional accuracy, load carrying capacity and aesthetic quality of the welded structure.

2. LITERATURE REVIEW

(Sun *et al.*, 2016) [5] has done comparative study of Laser beam welding (LBW) and Gas metal arc welding (GMAW) of 800 Mpa grade Nb-Ti-Micro alloyed C-Mn steel with thickness of 5 mm. 8.2 KJ/cm is applied in GMAW process to achieve complete penetration whereas LBW process produces complete penetration at much lower heat input of 1.8 KJ/cm. Due to low heat input, LBW produces weld joint with less fusion width and HAZ width. Width of the weld seam in GMAW is 3 to 7 times of LBW. Width of the HAZ in GMAW is 4 to 5 times of LBW. LBW provides better depth to width ratio than GMAW. LBW provides 5 to 6.25 times higher depth to width ratio than GMAW. Compared GMAW process, LBW process produces complete penetration at low heat input also less fusion width and HAZ width was observed. Welds were produced with no surface defects.

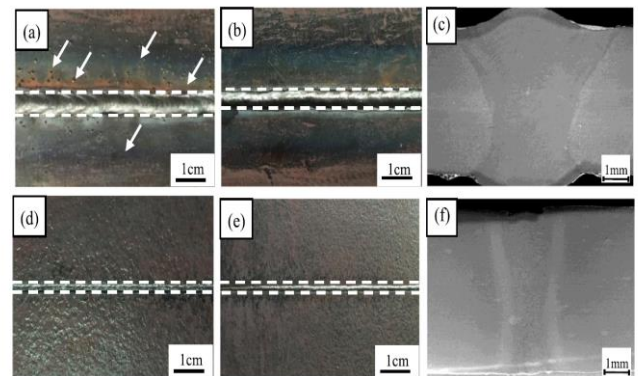


Fig-2: Surface morphologies (a) the top surface of GMAW, (b) the bottom surface of GMAW, (c) cross section morphology of GMAW, (d) the top surface of LBW, (e) the bottom surface of LBW, (f) cross-section morphology of LBW [5]

(Sun *et al.*, 2014) [6] has compared Laser beam welding and CO₂ gas arc welding and evaluated the fusion zone and HAZ area along with distortion analysis. Experiment was carried out in Q235 steel (low carbon steel) with specimen size of 300 mm x 100 mm x 2.3 mm sheet.

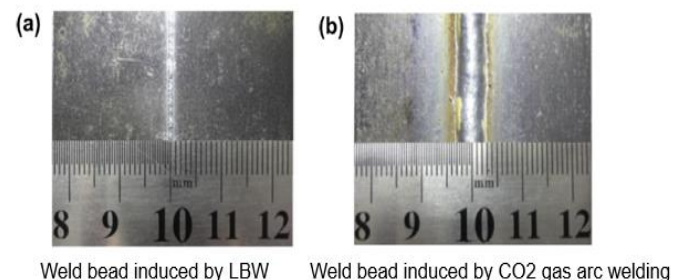


Fig-3: (a) Top view of LBW joint (b) Top view of CO₂ gas weld joint [6]

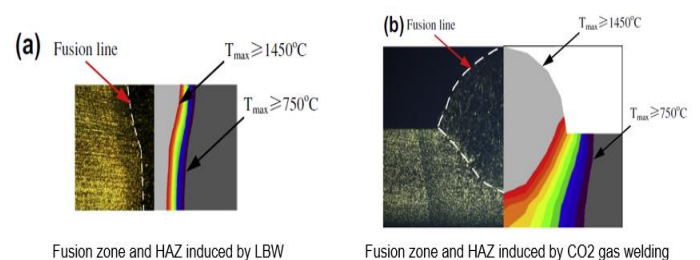


Fig-4: (a) Zones induced by LBW (b) Zones induced by CO₂ gas welding [6]

We can infer from this results that the width of weld bead produced by LBW was 1.2 mm whereas the width of weld bead produced by CO₂ gas arc welding was 4.2 mm. So LBW weld bead was around 70% narrow than CO₂ gas arc welding. They have got the almost same result in FEM analysis as well.

(Němeček, Mužík and Míšek, 2012) [7] has done comparative study of DOCOL 1200 steel welding between MIG and laser beam welding process and TRIP steel welding among GTAW, MIG and laser beam welding processes. They found HAZ produced by Laser welding is very minimal than conventional arc welding. Laser welding produced HAZ width of 0.2 mm where arc welds produced 2 mm (10 times more than arc welds). The strength of laser welds higher than arc welds. In laser welded joints, hardness of weld and HAZ is almost equal to the base material hardness. Only slight decrease is observed. On the other hand, MAG weld exhibits very low hardness in weld and HAZ. The laser welding has minimal impact on the material adjacent to weld bead.

(Ren *et al.*, 2011) [8] has done numerical investigation of difference between laser hybrid GMA welding and conventional GMAW process weld bead profile, residual stresses, temperature fields and microstructure. They predicted that, laser hybrid GMA welding process produces narrow weld bead with less HAZ whereas GMAW produces wider weld bead with high HAZ. The similar result was verified in existing published work where the experimental comparison of Submerged arc welding and GMAW has been done.

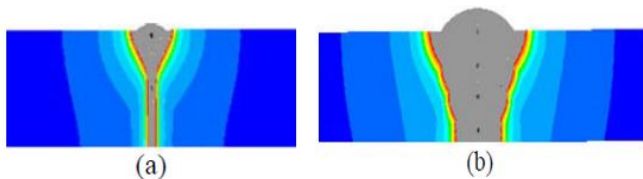


Fig-5: Predicted weld bead profile at maximum temperature 1450°C (a) Hybrid laser GMA welding (b) GMAW [8]

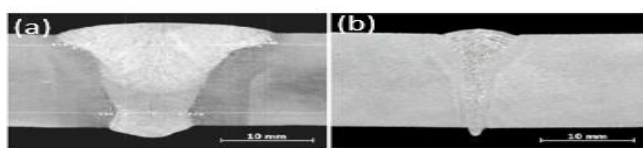


Fig-6: Comparison of the weld bead profile (a) Submerged arc welding (b) Gas metal arc welding [8]

(Shanmugarajan *et al.*, 2011) [9] has investigated the effect of heat input and beam intensity on microstructure and mechanical properties of Modified 9Cr-1Mo steel plates of 6 mm thickness by using CO₂ laser. Laser beam mode, laser power and laser welding speed has been varied to get various range of heat input from low to high. All set of parameters has been selected based on the achievement of 100% Weld penetration. Full weld penetration can be achieved in different set of parameters. But the other parameters such as weld bead geometry, Fusion width, HAZ width, Concavity or convexity and Excess weld bead will vary mainly with respect to the heat input. At lower heat

input (168 J/mm), minimum fusion width and HAZ width was achieved. As heat input increases, fusion width and HAZ zone width increases. Maximum width was observed at highest heat input of 1500 J/mm. Moreover, Concavity also observed in the top of the weld bead at high heat input whereas at lowest heat input flat profile exist in the top of the weld bead.

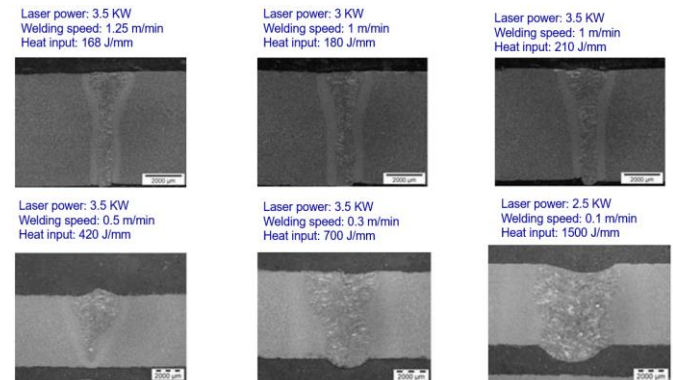


Fig-7: Macroscopic image of weld joints at various parameters [9]

(Oyyaravelu, Kuppan and Arivazhagan, 2018) [10] has investigated the metallurgical and mechanical properties of autogenous laser and laser hybrid GMA welded joints of HSLA SA516 grade 70 steel with thickness of 4 mm. Parameters are optimized in both the processes in order to achieve 100% of penetration. With that parameters weld joints were made and further analysis were carried out.

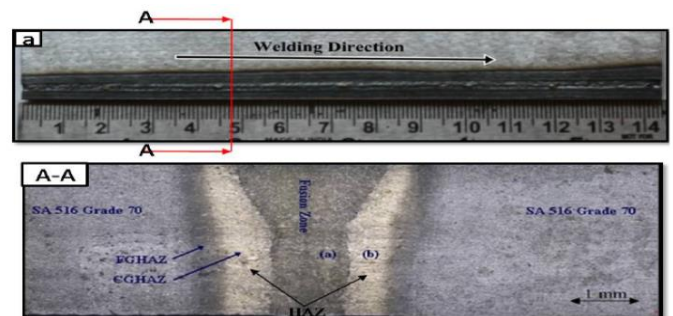


Fig-8: (a) Laser weldment (A-A) Macrograph of laser weldment [10]

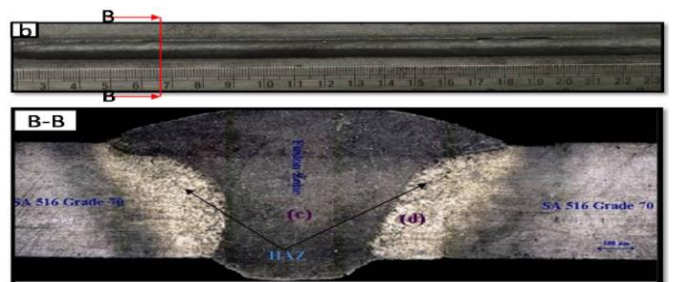


Fig-9: (b) Laser GMA hybrid weldment (B-B) Macrograph of laser GMA hybrid weldment [10]

From the macroscopic analysis, it can be inferred that, autogenous laser welding produces weld bead with narrow fusion zone and narrow HAZ. Laser welded joint looks like a well-known nail head shape whereas laser GMA hybrid welded joint looks like semi-hemispherical shape which is larger in top surface and smaller in root surface. But both processes produced complete penetration at low heat input. Moreover both weldments were produced without any defects such as distortion, cold cracking and hydrogen induced cracking. So, both can be an alternate for conventional arc welding processes. Depends on the application, suitable process can be selected.

(Wahba, Mizutani and Katayama, 2016) [11] has analyzed the effect of 100% CO₂ shielding instead of argon-rich shielding gas in laser-GMA hybrid welding. Experiment was carried out in K36D shipbuilding steel of 14mm and 17mm thickness. Butt joint configuration with 0.5 mm root gap has been set. Parameters are optimized to obtain desired weld quality.

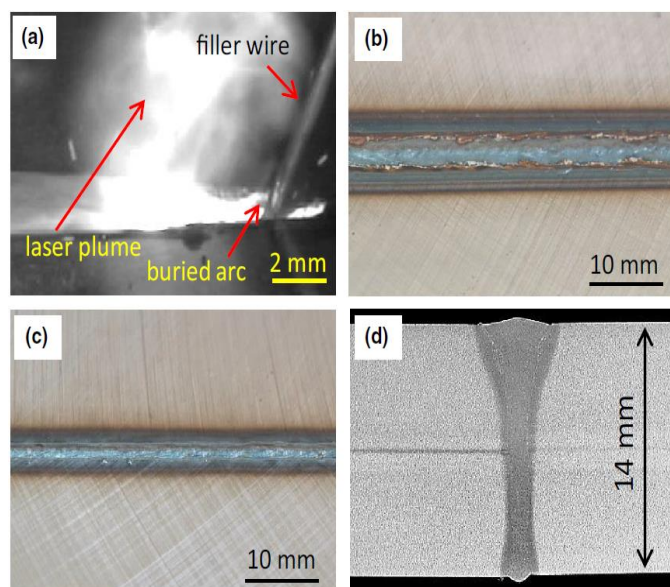


Fig-10: Hybrid welding of 14 mm thick joint (a) high speed camera observation of droplet transfer mode (b) top surface appearance of welded joint (c) bottom surface appearance of welded joint (d) cross sectional macrostructure of weld fusion zone [11]

Macrostructure analysis shows that 100% penetration can be achieved in high thickness (14 mm) plate, with narrow fusion zone and HAZ width. As parameters are optimized to obtain buried arc transfer, spatter formation was suppressed. So the main issue of using CO₂ shielding was resolved. Moreover, CO₂ shielding will give better benefits in terms of consumable cost. In laser-GMA hybrid welding, weld reinforcement can be increased by increasing the wire diameter without much increase in fusion and HAZ width. As shown in Fig-9, better weld reinforcement obtained with 1.6 mm diameter wire.

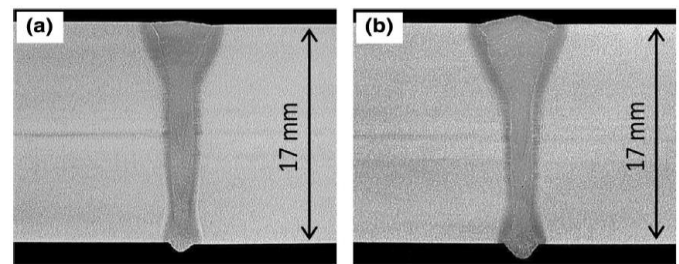


Fig-11: Cross-sectional macrostructure of weld fusion zones of 17 mm thick butt joint welded with wire (a) 1.2 mm diameter (b) 1.6 mm diameter [11]

(Liu *et al.*, 2014) [12] has studied the synergic effect between laser beam and electric during hybrid welding. They compared hybrid welding with autogenous laser welding, GMAW and laser cold-wire welding. Experimentation was done with AHSS – Advanced high strength steel of 8 mm thick, T joint configuration. Weld penetration and weld width were measured and compared. Overall 21 experiments were conducted in which Laser power kept constant and 3 set of laser to arc power ratio were maintained. Based on the preliminary test results, these optimal parameters were arrived.

Table-1: Weld penetration and bead width of the weld beads

Process	Weld penetration (mm)	Weld width (mm)
Autogenous laser welding	5.76	5.07
GMA welding	5.42	11.00
Laser cold-wire welding	4.15	3.20
Hybrid laser-GMA welding	11.64	10.84

Results shows that, hybrid laser-GMAW process combines the laser power and arc power that increases the penetration by 114% in comparison with autogenous laser welding and by 102%. Comparing with GMAW, laser welding processes provides better depth to width ratio.

(Yamamoto *et al.*, 2015) [13] has investigated the hot wire laser welding method to weld a large diameter pipe with a narrow gap. Parameters were optimized to avoid lack of fusion, solidification cracks and other defects.

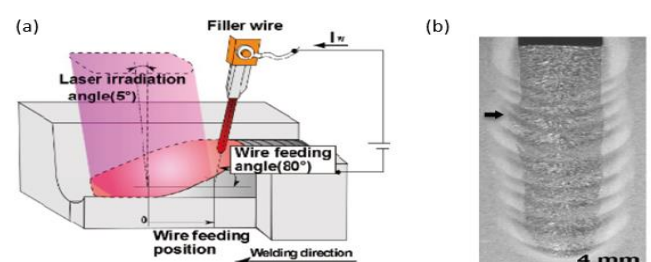


Fig-12: (a) Schematic illustration of narrow gap hot-wire laser welding (b) Cross-sectional macrostructure of weld fusion zone of pipe specimen [13]

They concluded that, the hot wire laser welding process can be used to weld large diameter pipe which produces sound weld joint with low dilution and narrow heat affected zone.

3. SUMMARY

There is a multitude of welding processes to choose for the industrial applications. **Laser welding processes are promising welding technologies which can deliver desired weld characteristics at low heat input and high welding speed.** As it benefits for less distortion and high productivity. **Replacing the conventional arc welding processes by advanced laser welding processes, results in better quality and productivity.** This study clearly shows that, through laser welding processes, maximum penetration can be achieved even in high thickness materials with minimum of fusion width, reinforcement height and HAZ width. Thus improving the mechanical properties of the weld joint. **Moreover it reduces the amount distortion and reduces the consumable cost as well.**

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REFERENCES

1. Deshmukh AR., Venkatachalam G., Divekar H., Saraf MR. Effect of weld penetration on fatigue life. *Procedia Engineering*. 2014. Available at: DOI:10.1016/j.proeng.2014.12.277
2. Mistry PJ. Effect of Process Parameters on Bead Geometry and Shape Relationship of Gas Metal Arc Weldments. *International Journal of Advanced Research in Mechanical Engineering & Technology (IJARMET)*. 2016; 2(2): 24. Available at: www.ijarmet.com
3. Anbarasan N., Oyyaravelu R., Kuppan P. International Journal of TechnoChem Research Effect of GMAW process parameters on the influence of bead geometry and HAZ area on ASTM A516 grade 70 Low alloy Pressure vessel steel. 2015; 01(01): 1–10. Available at: www.technochemsai.com
4. Sloderbach Z., Pajak J. Determination of ranges of components of heat affected zone including changes of structure. *Archives of Metallurgy and Materials*. 2015; Available at: DOI:10.1515/amm-2015-0421
5. Sun Q., Di HS., Li JC., Wu BQ., Misra RDK. A comparative study of the microstructure and properties of 800 MPa microalloyed C-Mn steel welded joints by laser and gas metal arc welding. *Materials Science and Engineering A*. 2016; Available at: DOI:10.1016/j.msea.2016.05.079
6. Sun J., Liu X., Tong Y., Deng D. A comparative study on welding temperature fields, residual stress distributions and deformations induced by laser beam welding and CO₂ gas arc welding. *Materials and Design*. 2014; Available at: DOI:10.1016/j.matdes.2014.06.057
7. Němeček S., Mužík T., Míšek M. Differences between Laser and Arc Welding of HSS Steels. *Physics Procedia*. 2012. Available at: DOI:10.1016/j.phpro.2012.10.015
8. Ren X., K.S.S., Akselsen OM., Nyhus B. Comparison of Hybrid Laser-arc and Conventional Welding for Arctic Applications. *Proceedings of the Twenty-first (2011) International Offshore and Polar Engineering Conference*. 2005; 8(216): 1–236.
9. Shanmugarajan B., Padmanabham G., Kumar H., Albert SK., Bhaduri AK. Autogenous laser welding investigations on modified 9Cr–1Mo (P91) steel. *Science and Technology of Welding and Joining*. 2011; Available at: DOI:10.1179/1362171811Y.0000000035
10. Oyyaravelu R., Kuppan P., Arivazhagan N. Comparative study on metallurgical and mechanical properties of laser and laser-arc-hybrid welding of HSLA steel. *Materials Today: Proceedings*. 2018. Available at: DOI:10.1016/j.matpr.2018.02.253
11. Wahba M., Mizutani M., Katayama S. Microstructure and Mechanical Properties of Hybrid Welded Joints with Laser and CO₂-Shielded Arc. *Journal of Materials Engineering and Performance*. 2016; Available at: DOI:10.1007/s11665-016-2137-x
12. Liu W., Ma J., Yang G., Kovacevic R. Hybrid laser-arc welding of advanced high-strength steel. *Journal of Materials Processing Technology*. 2014; Available at: DOI:10.1016/j.jmatprotec.2014.06.018
13. Yamamoto M., Kadoi K., Phaoniam R., Todo M., Shinozaki K., Yamamoto M., et al. Hot-wire Laser Welding Process Using Laser Diode for Large-Diameter Pipe with Narrow Gap Joint Article in *QUARTERLY JOURNAL OF THE JAPAN WELDING SOCIETY*. 2015; Available at: DOI:10.2207/qjwjs.33.107s