DOR: 20.1001.1.25383620.2021.5.2.10.6

Technical Article

Metallurgical Investigation of Under Water Friction Stir Welding (UWFSW) Process

M. Sadeghi*

MAPNA Boiler and Equipment Engineering and Manufacturing Co., Karaj, Iran.
Received: 10 September 2021 - Accepted: 09 December 2021

Abstract

Underwater friction stir welding (FSW) has been demonstrated to be an effective method to improve the mechanical properties of joints. To illuminate the characteristics of underwater FSW, the microstructural evolution and its effect on mechanical performance of an underwater joint were investigated in the present paper. This work compared the parameters of friction stir welding (FSW) and under water friction welding (UWFSW) on the weld joint .In this investigating Friction stir welding (FSW) used in under water environment, for this Operations research pin covered and shielded from contact water by hollow shaft spin (HSS), the HSS controlled the heat conduction of pin and disconnect with water, applying for the first time a novel under water FSW technique developed at marine structures.

The novel technique acceptance given by the experimental setup on Al X4000 series, for studied the mechanical and metallographic exams. The metallographic exams indicate that weld nugget grain size has been decreased. The mechanical testing illustrated hardness and tensile strength have been increased, on the other hand the percentage of elongation and impact energy have been decreased.

Keywords: Under Water, Friction Stir Welding, Mechanical Properties, Weld Nugget, Grain Size.

1. Introduction

Underwater friction stir welding is a latest technique which is widely acceptable in the industries like Aerospace and Shipbuilding for joining of different aluminum alloy series such as (6xxx,7xxx,8xxx) due to the light weight and high strength. It is very difficult to weld these alloys by using fusion method so, friction stir welding is introduced and it is widely taken into consideration for performing such welding process [1].Four stages during friction stir welding (FSW) have been carried out: the plunging stage, the dwelling stage, the welding stage, and the escape or retracting stage of the tool. The FSW procedure is essentially carried out by plunging a spinning FSW mechanism unit through the interface of two rigidly clamped sheets before the shoulder meets the surface of the material being welded [2]. The travel of the unit progresses along the weld line allowing the material to displace from the advancing side to the retracting side. Meanwhile, the tool shoulder consolidates the material at the back of the pin, resulting in a stable state [3]. Compared to other conventional welding processes, FSW process uses a significant amount of energy. The absence of flux or cover gas makes the process environmentally safe [4]. The key parameters in the FSW process are welding speed, tool rotational speed, penetration depth, vertical and axial force, and instrument tilt angle.

*Corresponding author
Email address: m_sadeghi@mapnaboiler.com

They are critical in producing heat generation, forging strain, the flow of material, welding appearance, and performance. As an outcome of dislocation density increase, the nugget area has high stiffness at higher speeds [5]. Furthermore, the axial forces also shift at varying rotational speeds. The softened area gets narrower as welding speed increases, and precipitate corrosion is weakened. The ultimate tensile strength (UTS) of the welded joint is boosted by lower heat generation and high volume fraction of precipitate as a result of greater travel speeds, grain boundary reinforcement [6]. Maximum penetration demands maximum plunge depth, otherwise it will lead to a decrease in loadbearing potential. The depth of penetration is seen to influence the consistency of the welds. There is a linear relationship between the shoulder force and torque and the penetration depth. FSW is recommended for maximum depth [7, 8].

The mechanical and metallurgical characteristics are depending on the environments, the base material and the consumables in general. The working environment to which the joint is exposed is often critical. There is a chance of crack expanding as the joint is exposed to high-pressure and high-temperature fluids, which stops the device itself from operating [9]. FSW is a solid state welding process in which a rotating tool is forced along the joint line, heating the abutting components by friction, and producing a weld joint by large plastic deformation (stirring) of materials from the two components. Compared to classical fusion welding techniques FSW can overcome problems such as weld porosity, use of filler metals, and cracking in the heat affected zones (HAZ) [10]. Friction Stir Welding - Process advantages such as: The process advantages result from the fact that the FSW process (as all friction welding of metals) takes place in the solid phase below the melting point of the materials to be jointed. The benefits therefore include the ability to joint materials which are difficult to fusion weld, for example 2000 and 7000 series aluminium alloys [11]. Friction stir welding can be use purpose-designed equipment or modified existing machine tool technology. The process is also suitable for automation and adaptable for robot use. Other advantages are as follows [12,13]:

- Low distortion
- Excellent mechanical properties as proven by fatigue, tensile and bend tests
- No arc
- No fume
- No porosity
- No spatter
- Can used in all positions
- Energy efficient
- Non-consumable tool
- One tool can typically be used for up to 1000m of weld length in aluminium alloys
- No filler wire
- No gas shielding for protective of weld zone
- No welder certification required
- Some tolerance to imperfect weld preparations - thin oxide layers can be accepted
- No grinding, brushing or pickling required in mass production
- Can weld aluminium and copper of >50mm thickness in one pass.

The limitations of the FSW process are being reduced by intensive research and development. However, the main limitations of the FSW process are at present [14]:

- Work pieces must be rigidly clamped
- Backing bar required (except where self-reacting tool or directly opposed tools are used)
- Keyhole at the end of each pass observe
- Cannot make joints which required metal deposition (e.g. fillet welds)

2. Materials and Methods

Different process steps invitation :
1. Simulation under water environment by glass
2. Designed special tools for FSW
3. Improved mechanical properties tools by heat treatment in order to used water environment
4. Cut weld sample for preparation of mechanical test by machining
5. Microstructure weld observed by optic microsscope and scanning electron microscop (SEM).

For Simulation the under water environment , the glassy lacuna water as show in Fig. 1. designed and fabricated.

Fig. 1. Simulation under water environment by glass.

Pin tools have alot of various form but exprimental result illustrted that dimention followes as show in Fig. 2.:

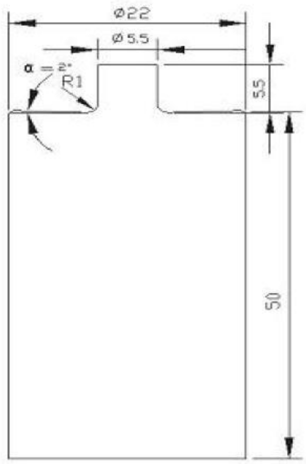

Fig. 2. Mechanical design for Pin tools.

Materials tools have a charatristics spification include wear (abrasive) resistense,shock resistense thermal resistense , mechanical power condition made of low –alloyed carbon tool steel (H_{13}) and heat treated as qunched and tempered. After machining pin tools is keeped in 1050 ˚C temperature and astenite 1h duration then quenched hardening by oil.

Temper heat treatment in 530 ˚C temperature and 20min duration and air quenched finally.

In this technology pin covered and shielded from contact water by hollow shaft spin (HSS), designed hallow shaft surface is attached by spcial embossing form with 60 ˚ degree so controled heat condition of pin and discontact with water.

Fig. 3. Isolated pin by hollow shaft.

The novel technique acceptance given by the experimental setup on Al X4000 series, ten strip used with 150×50×6 mm dimensions in butt welding position fixched. Pitch welding (v/w) is adjustment on the CNC insturment. Chemical compositions Al X4000 series given in Table. 1.:

Table. 1. Chemical composition (٪ wt) Al X4000 series [1].

Alloy	Si	Fe	Cu	Mn	Mg	Zn	Ti
4009	4.7-5.5	0.2	1-1.5	0.1	0.4-0.6	0.1	0.2

Friction stir welding (FSW) was done in two environments and two different as v/w, welding condition and environment given in Table. 2.:

Table. 2. Welding condition of different samples.

NO.	Welding Condition	Linear Velocity (V)	Angular Velocity (w)	Pitch Welding (V/w)
1	**dry**	100	150	1/15
2	**dry**	110	100	1/9
3	**wet**	100	150	1/15
4	**wet**	110	100	1/9

Mechanical test from weld is included hardness and tensile strength test was done on different samples . Tensile strength tests according to ASTM AWSB4 were carried out. The hardness test was done with Brinnel methode with 2.5 mm indentor and the force of 62.5 kg. The optical metallographic test were done by Olympus DMI3000M with image analysis and scanning electron microscop (SEM) test were done by VEGA\TESCAN-XMU.Mechanical ,furthermore polishing and aching with 1CC hydrofluoric acide , 95CC and 4CC hydrofluoric acide and distilled water.

3. Result and Discussions

Fig. 4. showes the picture of different samples,it can be seen that the under water sample dont have any cracks or diefects and surfacec qulity of under water sample similar as other samplethat welded in dry condition (conventional).

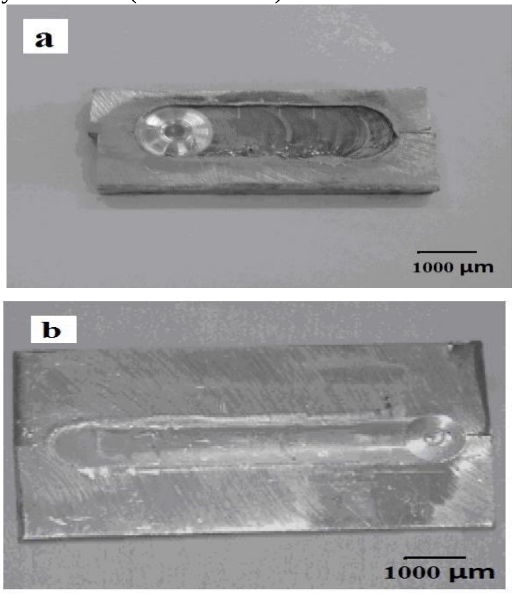

Fig. 4. Visual surface on friction stir welding (FSW) Al X4000 series (a) under water FSW (wet condition) (b) FSW (dry condition).

Tabel. 3. given the mechanical test of different samples. It can be seen that by increasing the welding pitch , the hardness ,yield and tensile stregth of weld metal in dry and wet (under water) condition increased. In addition the hardness, yield stregth and tensile stregth of weld metal in wet (under water) as higher than the dry (conventional) condition.

Table. 3. Mechanical test result FSW (dry condition) and UNFSW (wet condition).

NO.	welding Condition	Pitch Welding w/v	Hardness (HV)	Strength (Mpa)	Tensile Strength (Mpa)
1	**dry**	15	85	128	207
2	**dry**	9	101	147	241
3	**wet**	15	108	160	256
4	**wet**	9	121	172	271

Fig. 5.A more comprehensive scheme has been developed by TWI, and has been discussed with a number of appropriate people in industry and academia.

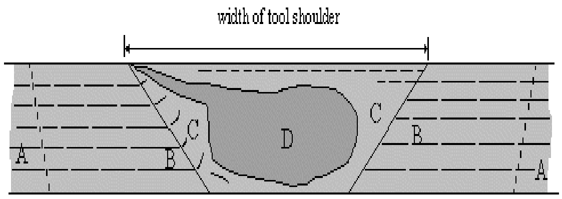

Fig. 5. The system divides the weld zone into distinct regions: A. Unaffected material B. Heat affected zone (HAZ) C. Thermo-mechanically affected zone

(TMAZ) D. Weld nugget (Part of thermo-mechanically affected zone).
This has also been accepted by the Friction Stir Welding Licensees Association. The system divides the weld zone into distinct regions.

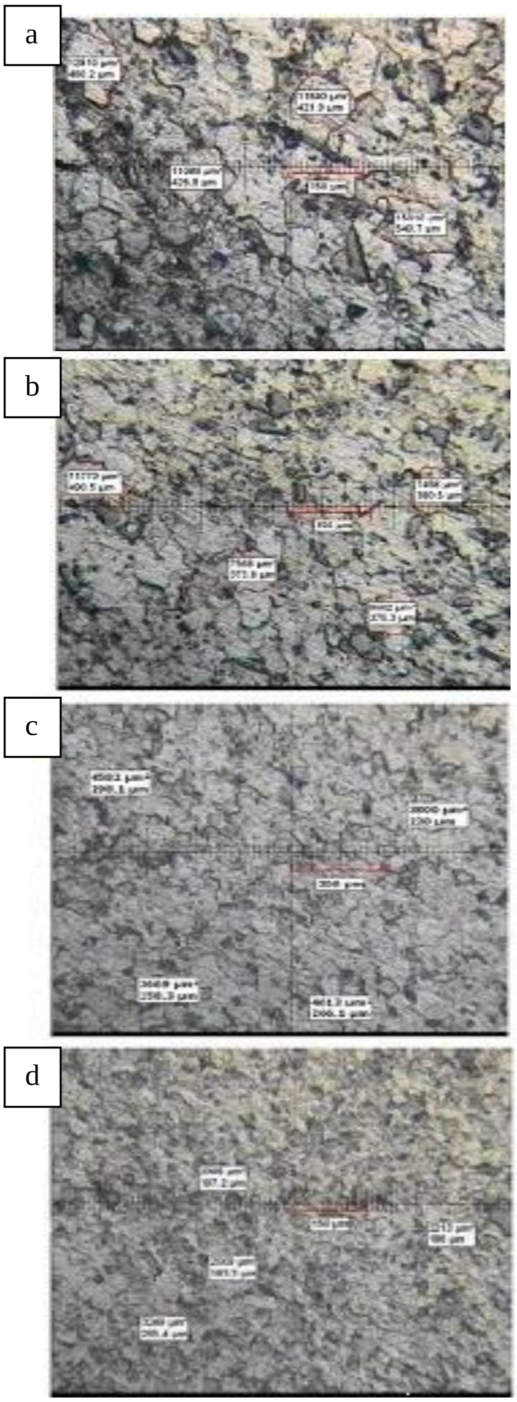

Fig. 6. Microstructure nuget weld by optic microsscope in under water (FSW) (a) FSW (dry condition) 15 Pitch welding, Grain size 142μ (b) FSW (dry condition) 9 Pitch welding, Grain size 120μ (c) Under water FSW (wet condition) 15 Pitch welding, Grain size 84μ (d) Under water FSW (wet condition) 9 Pitch welding, Grain size 61μ.

The first attempt at classifying microstructures was made by P L Threadgill (Bulletin, March 1997). This work was based solely on information available from aluminium alloys. However, it has become evident from work on other materials that the behaviour of aluminium alloys is not typical of most metallic materials, and therefore the scheme cannot be broadened to encompass all materials.

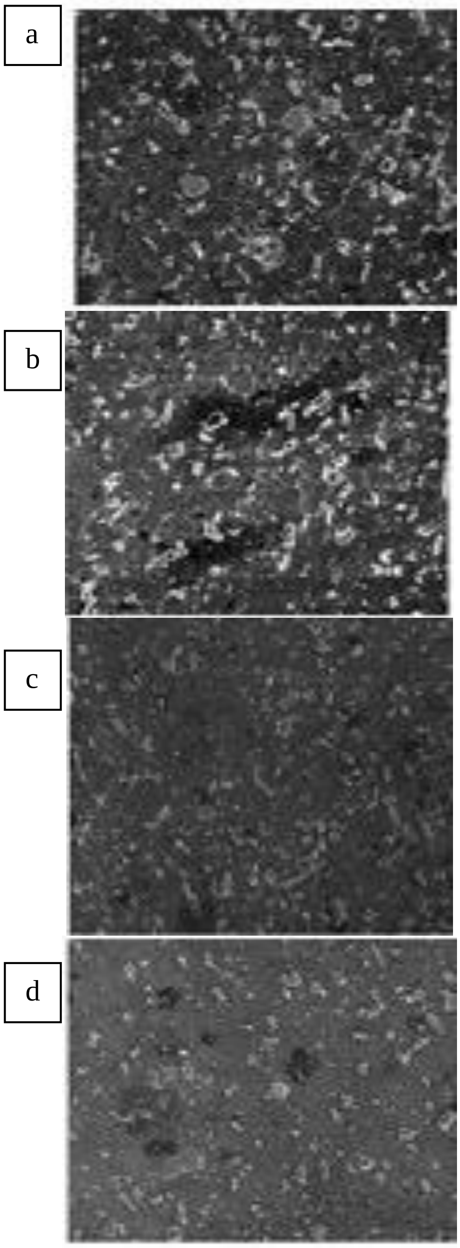

Fig. 7. Microstructure weld by scanning electron microscop (SEM).(a) FSW (dry condition) 15 Pitch welding, Grain size 142μ (b) FSW (dry condition) 9 Pitch welding, Grain size 120μ, (c) Under water FSW (wet condition) 15 Pitch welding, Grain size 84μ (d) Under water FSW (wet condition) 9 Pitch welding, Grain size 61μ.

The microstructure weld metal by optic microsscope in under water friction stir welding (FSW) shown in

Fig. 6. In dry condition with 1/15 and 1/9 Pitch welding Grain size 142μ and 120μ Fig. (2.a,b) was gained when two microstructure nuget comared in wet condition with 1/15 and 1/9 Pitch welding Grain size 84μ and 61μ Fig. (2.c,d) therefore grain size in wet condition is half of dry conventional as same case state. The microstructure of weld metal result illustrted that by scanning electron microscop (SEM) approved. Fig. 7. The underwater FSW microstructure grain size has been decreased.

4. Conclusion

The results of this research have shown that parameter effect pitch welding on the microstructure and mechanical properties:

1. The UWFSW microstructure grain size has been decreased so mechanical properties improved.
2. Increasing heat input treatment so that minimum residual stress and minimum change mechanical properties compare other welding method.
3. This process is without flux or filler material and heating the abutting components by friction.
4. This method is used various joint, especially non-congener joint material and composite is easy carried out.

Acknowledgement

The author wishes to acknowledge to the MAPNA Boiler Engineering & Manufacturing Co. and Islamic Azad University, Karaj Branch for their support.

References

[1] S,Shahabuddin, V. K. Dwivedi, A. Sharma, Int. J. Eng. Adv. Technol. (IJEAT), Volume-8 Issue-4, April 2019.

[2] I. Sabry and A. M. El-Kassas, Int. J. Eng. Tech., 11, 2019, 78.

[3] A. W. Mohd, A. K. Zahid and A. N. Siddiquee, Trans. Nonferrous Met. Soc. China, 28, 2018, 193.

[4] A. M. El-Kassas, J. Adv. Eng. Tech., 4, 2017, 158.

[5] I. Sabry, I. Mourad and D. T Thekkuden, Joints Inter. Rev. Aerosp. Eng. 14, 2020, 64.

[6] H. Papahn, Int. J. Adv. Manuf. Tech., 78, 2015, 1101.

[7] M. Sadeghi and H. Sabet, Effect of The Under Water (FSW) Parameters on Microstructure and Mechanical Properties of the Al-Si Alloy, 1st International Conference on Welding and Non Destructive Testing (ICWNDT 2014), Islamic Azad University Karaj Branch, Karaj, Iran, pp.30, 2014.

[8] H. J. Liu, H. J. Zhang and L. Yu, Mat. des., 32, 2011, 1548.

[9] S. K. Maiti, S. Namdeo and I. Mourad, Eng. Des., 238, 2008, 787.

[10] Aaron L. Stahl, Experimental measurements of longitudinal load distributions on friction stir weld pin tool, department of Mech. Eng. Brigham Young University, December 2005.

[11] R. S. Mishra and Z. Y. Ma, A Rev. J. Chinese Accademy Sci., Shenyang 110016, China, 18 August 2005.

[12] T. S. Srivatsan and S. Vasudevan, Dept Mech. Eng., Cin, Ohio, Usa, October 15-19, 2006.

[13] V. Balasubramanian, Dept. Manuf. Eng., Annamalai University, Annamalainagar 608002, Tamil Nadu, India, 6 July 2007.

[14] T. R. McNelley, S. Swaminathan and J. Q. Su, Recrystallization mechanisms during friction stir welding/processing of aluminum alloys, Department of Mechanical and Astronautical Engineering, Naval Postgraduate School, Monterey, CA 93943-5146, USA, 28 September 2007.