# OVERVIEW OF UNDERWATER FRICTION STIR WELDING

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## ABSTRACT

Friction Stir Welding (FSW) is the one of the advance welding techniques in current years. It is solid state welding and efficiently can overcome the conventional fusion welding technique weaknesses. FSW involve rotational tool and move along the edge of the two workpieces. The frictional heat and plastic deformation process provide firm condition for the solid state welding to occur. Due to the advantages of solid state welding, formerly the FSW was applied to aluminium alloys rather than hard material. The developments of knowledge in tool level up the FSW application to the hard materials such as steel, stainless steel and even Inconel. Other than that, researchers found that the heat input during welding process is the one of the factor in order to enhance the quality of the joint. Therefore, in FSW areas, researches exploring Underwater Friction Stir Welding (UFSW) to control the heat input during the process and produce good quality of the joint in term of microstructure and mechanical properties. In this paper, relevant researches in UFSW will be discussed and until now, it is found that researches in UFSW are still in basic stage and not many researchers deeply explore it yet.

**Keywords:** underwater, friction stir welding, welding, and solid state welding.

## INTRODUCTION

FSW (Friction Stir Welding) was invented by TWI, United Kingdom in 1991. FSW is a solid state welding which operates below the melting point of the material [1]. The FSW involves rotation of a non-consumable tool and the workpiece. The rotational tool usually made up of harder material than workpiece. FW tool provides the frictional heat as its probe and shoulder contact with the surface of the workpiece. The heat input during the plunging, dwelling and travelling phase is sufficient to soften and weld the workpiece [2]. The low heat input keep the process operates below the melting point of the workpiece thus its properties and defect can be controlled. The advantages of the FSW compared to other types of conventional welding such as reduce internal porosity, surface cracking, and material shrinkage bring this technique as an alternative approach in manufacturing technology to weld the specific material [3]. Until now, researchers have explored the wide applications of FSW including weld metals with non-metals material.

## LITERATURE REVIEW

At early years, FSW is applied to the soft metal for example aluminium alloy. FSW at that time is the alternative way for conventional arc welding technique because aluminium alloy difficult to weld using fusion welding method. FSW is the solid state welding which operates below the melting point of the material and by applying low heat input as compared to the conventional arc welding technique, the quality of the weld especially in soft material is enhanced. The heat input is mainly from frictional heat at the rotational tool's probe and shoulder once contacting with the surface of the workpiece. The maximum temperature recorded during FSW process of 6.35mm thickness of AA6061-T6 is around 450 °C to 480 °C with 300 to 400 rpm [1].

Development of the FSW tool in term of shape, material and durability ignite researchers to explore FSW from soft material like aluminium alloy to harder metals such as carbon steel, and duplex stainless steel and even Inconel. Studies show that the FSW produce better results as compared to the conventional welding. S. Jannet *et al*. mentioned that better tensile strength and welding dimension in FSW according to their comparative studies between FSW and fusion welding of 6061-T6 and 5083-0 aluminium alloy [4]. Other than strength, FSW process also has been proven that the process is safer than conventional method to the environment. V. Balasubramaniam concluded that FSW is an eco-friendly process which not use and emit gas but yield well in mechanical and metallurgical properties as compared to the conventional welding processes [5].

Welding thermal cycles may affect the behaviour of the mechanical properties especially at Heat Affected Zone (HAZ) in FSW process. Researchers implement several methods to control overheating and enhanced the properties during the process and one of the methods is submerged the process in water or liquid environment. By that, several studies have been done in underwater FSW process. Liu *et al* indicated that the tensile strength of the underwater friction stir welding (UFSW) of Aluminium alloy 2219 has been improved from 324 MPa to 341 MPa compare to in normal condition. However, the elongation for UFSW sample is lower and the plasticity of the joint is deteriorated compared to normal FSW. The fracture area also seems different as the fracture of the UFSW occurred at the area between weld nugget zone (WNZ) and thermal mechanically affected zone (TMAZ) but for normal FSW sample it is occurred at area between TMAZ and heat affected zone. The microhardness distribution at the joint of UFSW is lower at the WNZ but higher at TMAZ and HAZ as compare to the normal FSW joint [6].

Other than that, Hosseini *et al* studied the differences in mechanical and microstructure properties of FSW and UFSW of ultrafine grained aluminium 1050

(AA1050) that produced by accumulative roll-bonding (ARB) technique. The parameters used for the both experiment are 630 rpm and 50 mm/min of rotational and travel speed. They concluded that the UFSW samples produced better tensile strength and smaller grain size as compared to FSW. Therefore, UFSW is preferred to be used for surface hardening [7].

Rui-dong *et al* carried out an FSW experiment of aluminium 7050 in air, hot and cold water condition. They measured the weld thermal cycles and transverse distributions of the microhardness in the experiment. They also tested the tensile properties of the welded plate and analysed the microstructure properties at the fracture area. The highest temperature in the experiment was recorded when carried in air which about 380 ºC while in hot and cold water condition at 300 ºC and 220 ºC respectively. The FSW carried out in hot water produced better tensile properties compare to in cold water and air condition which is 92% as compared to the base material [8].

Yong *et al*. investigated the normal FSW (in air) with UFSW of ultra-high strength spray formed 7055 aluminium alloy in order to decrease the heat supply and enhance the joint. They fix the rotational speed and feedrate at 1000 rpm and 100 mm/min respectively. Results from the experiment shows that the Ultimate Tensile Strength (UTS) for UFSW specimen is 495 MPa while normal FSW is 430 MPa. UFSW perform better for percentage of elongation which is 7.2% and normal FSW is 4.1%. Nevertheless, the microhardness of UFSW is higher as compare to normal FSW. Due to lower thermal cycle in the water environment, the UFSW specimen experienced lower residual stress as compare to normal FSW [9].

Philip *et al*. studied the comparison of double sided FSW and UFSW for S275 structural steel plate. They setup the experiment by applied rotational force at 4.8 mm depth on the both, top and bottom surface of the specimens and continuously run 100 mm/min of feedrate. The FSW and UFSW specimens were analysed the distortion profile together with the submerged arc welded (SAW) of DH36 steel plate. UFSW specimens show smallest and SAW highest deviation pattern. This is because heat inputs between processes are different. For tensile strength, there is no significant different between FSW and UFSW specimens which are around 509 MPa and the fracture occur at the parent material. FSW shows finer grains than UFSW as huge amount of heat were loss during UFSW operation [10].

Abbas *et al*. develop a study on feasibility of the underwater friction stir welding (UFSW) of aluminium 6061-T6 using conventional CM milling machine. According to the study, the small amount of porosity exists and no existence of void and crack at the joint. Tensile strength of the UFSW is 347.68 MPa while normal FSW is 267.57 MPa. The percentage of elongation and hardness also show the better results in UFSW. They have concluded that the parameters to obtain optimum results of tensile properties as well as percentage of elongation and hardness are 1300 rpm for tool rotational speed and 4º for tilt angle [11]. Most of the studies are focusing on the differences in microstructure and strength of the FSW and underwater FSW samples.

**GAPS in literature review**

Based on the survey through literature reviews, researchers start to explore the UFSW in term of mechanical and microstructure properties on aluminium and some other alloys. Most of the researchers concluded that UFSW can improve strength and microstructure properties at the joint region as compare to normal FSW. It is an innovative technique to produce high quality joint. But the studies of UFSW are still lack of knowledge on the non-metal material, tools, energy consumption, thermal cycle, corrosion, and the effect of depth and high pressure in underwater condition.

## CONCLUSIONS

UFSW is an innovative and alternative method to produce high quality joint in term of strength and microstructure properties. It can be applied in the offshore and marine applications in order to overcome the weaknesses of conventional underwater welding method such as submerged arc welding and also conventional friction stir welding.

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