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Effect of Water Level on Mechanical Properties of Underwater Friction Stir Welded Aluminum Alloys

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Abstract: **The rise of unconventional means of joining metals has given way to Friction stir welding and underwater friction stir welding (UFSW). Underwater friction stir welding is a modern technique of welding metals together that does not involve excessive amounts of heat, filler rods and shielding gases and is considered an effective 'Green Technology '. It is an upgrade on Friction stir welding in the way it uses water as a cooling medium. In this project, experiments have been conducted to determine the effect of the water level on mechanical properties of underwater friction stir welded aluminum alloys. Three sets of Aluminum slabs are welded using underwater friction Stir welding at three different water levels and then attempt to compare the variation of mechanical properties of the weld under different water levels. It is observed that the tensile strength of welded joints varies with the water level in proportion.**

Index Terms: **Friction stir welding, filler rods, Aluminum Slabs, Mechanical Properties**

I. INTRODUCTION

Welding of aluminum alloys requires different techniques and process parameters. Improper selection of welding technique and process parameters produces defective welds [1]. The conventional welding techniques are not effective to produce sound aluminum joints due to many reasons like hot cracking, porosity and distortion [2]. An advanced and innovative welding technique Friction Stir Welding was invented by The Welding Institute of UK in 1991 to produce defective free aluminum joints. This method also can be used not only for various metals but also for different materials like polymers and composites [3]. It is a solid-state joining technique which uses non consumable rotating tool. The strength of the welded joint depends on various process parameters like rotational speed, weld speed, tool pin profile, plunge depth [5]. In recent years underwater friction stir welding has come into existence which is carried out at temperatures below the melting point temperature of the material. During UFSW, the high heat absorption capacity of water reduces the transmission of heat flow to the thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) which results in the low heat existence in the TMAZ and HAZ. Due to less heat input, the TMAZ and HAZ width is narrowed. UFSW gives improved mechanical properties by minimizing several welding defects like porosity, shrinkage, and solidification cracking. It also provides well defined variation in grain size in different zones along the joint and therefore, a high-quality weld joint is produced. This process is suitable for alloys that are sensitive to overheating during the welding process and it is widely used for aluminum alloys. It is also proved that the underwater friction stir welding improves the tensile strength of the weld joint than in air [6]. This process also requires less energy compared to conventional techniques and does not require any consumable or filler materials and shielding gases which makes this process cheaper. It is widely used in shipbuilding, submarines, oil and fuel tanks and various offshore structures involving fabrication and repair.

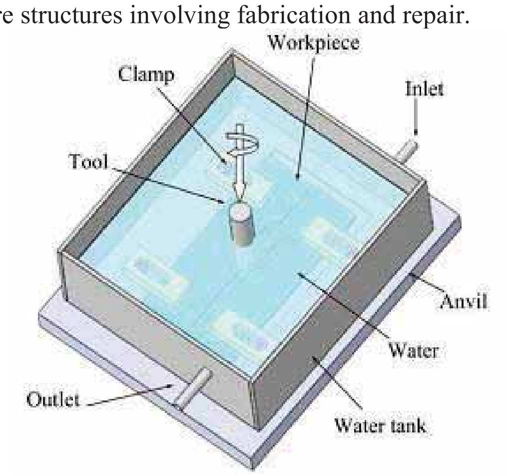

Figure 1. Under water FSW Technology

II. LITERATURE SURVEY

Nandan et.al. (2008) explained the influence of different FSW process parameters on the principle of heat flow, material flow during friction stir welding of different materials.

Yong Zhao et.al. (2016) worked on underwater friction stir welding of Aluminum and Magnesium alloys and compared the tensile strength and hardness results when the same materials were welded in air. He concluded that the tensile strength of the welded joint was improved by underwater welding.

Anil Kumar et.al (2016) concluded that the rotational speed is the most significant process parameter which has the highest influence on tensile strength and hardness, followed by the weld speed or feed.

Sagar et.al. (2016) focused on the effect of tool pin length, rotational speed and feed on the mechanical

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properties of friction stir welded dissimilar Aluminum joints. The relation between the thickness of the workpiece and plunge depth was also determined.

Saravana kumar. R (2016) derived the optimum rotational speed of the FSW tool to control the rise in temperature during welding of dissimilar Aluminum alloys.

Tulika Garg and others (2014) stated that little work is done on under water friction stir welding. It is an innovative and novel technique which can be effectively used in welding of marine ships.

Lui et. al. (2010) concluded that mechanical properties of aluminum joints can be improved by cooling effect.

III. Problem Definition

From the above literature survey, it is observed that the underwater friction stir welding produces efficient joints with proper selection of process parameters like rotational speed, feed, axial force [7]. But the previous studies focused only on cooling effect and did not study the effect of depth of water level. Therefore, it is also necessary to study effect of exact depth of water level on heat flow and mechanical properties of welded joints.

A. Methodology

In this experiment, we study the effects of depth of water level in underwater friction stir welding on the weld performance of joints by conducting tensile test, Vickers hardness test and optical microscopy.

B. Description of workpiece and tool material

Workpiece: Aluminum 7075 slabs
Dimensions: 100*75*6 mm
No of pieces: 3
UFSW tool: Taper turned cylindrical tool.
Tool material: H13 tool steel

C. Welding parameters

Rotational speed: 900 rpm
Welding feed: 40mm/min
Depth of water: 30mm, 40mm and 50mm

D. Work material

7075 aluminum alloy (AA7075) is an aluminum alloy, with zinc as the primary alloying element. It has excellent mechanical properties, and exhibits good ductility, high strength, toughness, and good resistance to fatigue [8,9]. It is more susceptible to embrittlement than many other aluminum alloys because of micro segregation but has significantly better corrosion resistance than the 2000 alloys. It is one of the most used aluminum alloys for highly stressed structural applications and has been extensively utilized in aircraft structural parts.

I. Chemical composition

TABLE I.
CHEMICAL COMPOSITION OF 7075 ALUMINUM ALLOY TOOL STEEL

Element	Zn	Mg	Cu	si	Fe	Mn	Ti	Cr	Al
Composition in %	6.1	2.5	1.6	0.4	0.5	0.3	0.2	0.15	Balance

II. Mechanical properties

TABLE II.
MECHANICAL PROPERTIES OF ALUMINUM ALLOY

Tensile strength	Yield Strength	Elongation	Vickers hardness
572 Mpa	503 Mpa	11%	175 HV

E. Tool material

H13 Tool Steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications. The hot hardness (hot strength) of H13 resists thermal fatigue cracking which occurs because of cyclic heating and cooling cycles in hot work tooling applications. Because of its excellent combination of high toughness and resistance to thermal fatigue cracking (also known as heat checking) H13 is used for more hot work tooling applications than any other tool steel.

I. Chemical composition

TABLE III. .
CHEMICAL COMPOSITION OF H13 TOOL STEEL

Element	C	Mn	Si	Cr	Ni	Mo	V
Composition	0.35	0.3	0.88	5	0.3	0.5	1

II. Mechanical Properties

TABLE IV.
MECHANICAL PROPERTIES OF H13 TOOL STEEL

Tensile strength	Yield Strength	Elongation	Vickers hardness	Elastic Modulus	Density
1990 Mpa	1650 Mpa	9%	549 HV	190-210 GPa	7.76 g/cm3

F. Tool Design:

Figure 2. FSW Tool

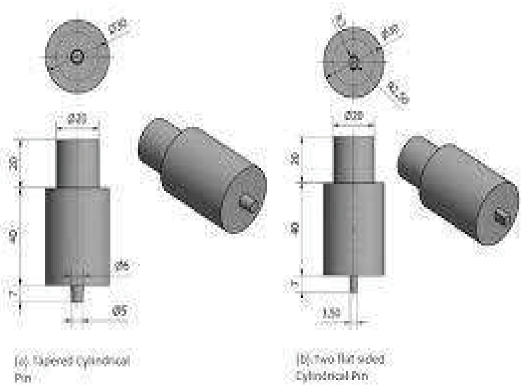

Figure 3. Design of Tool

IV. Experimental Work

In this work weld Aluminum 7075 slabs on their edges to form a butt weld. Aluminum slabs are welded by Underwater friction stir welding at a constant speed of 900 rpm. The slabs welded at 900 rpm were tested to have the best and most optimum mechanical properties such as tensile strength and hardness. H13 tool with taper threaded profile is used to weld the slabs at the feed rate of 40mm per min. Underwater friction stir welding is done at three different levels of water in the water tank. The underwater welded slabs are then tested for their strength, hardness, microstructure etc. Initially Aluminum slabs (100 * 75 mm) are made level with each other to prevent any irregularities and notches. The rough surfaces of the slabs are polished using a file to give a smoother cleaner cut. The slabs are taken together and levelled at every dimension to ease the operation of welding. Those are clamped on a surface and held against a press mechanism that levels them. Any additional metal on any of the slabs is either trimmed off by filing or cut off by a saw tooth milling cutter.

Figure 4. Aluminum slabs after levelling

Aluminum slabs after levelling are then clamped inside the water tub. The slabs are held together at one of their edges whilst the other edge is clamped by a weight that is attached to the welding board. The weights are placed on the edges of the slabs on both sides that hold the metal to the welding board. The weights are linked to the welding board by a thread screw that tightens the grip on the metal. After the process of welding, the thread screw is loosened, and the weights are removed to remove the butt-welded slab.

After clamping the slabs to the welding board in the water tub, the tool H13 taper threaded steel is taken. The tool is polished and made sharp. The tool is then fixed into the tool holder that rotates at 900 rpm. The tool rotates at a very high speed underwater to melt the metal slabs and weld them together at room temperature. After the tool is clamped to the tool holder, water is filled into the tub. Water level in the tub is seen through a scale attached on its side. The scale accounts for the depth of water involved in the welding operation. Butt welds welded at different depths have different mechanical properties.

Figure 5. Water tank arrangement

Water level on the given scale is measured. Zero level is seen as 23 mm on the scale. Zero level is the level at which the surface of the slabs touches the water without submerging in them. It is the level at which there is virtually zero depth of water. The first level or first depth is taken at 30mm or 7mm above the zero level. The second level is taken at 40mm or 17 mm above the zero level. The third and the final level of water is taken at 50mm or 27mm above the zero level.

Aluminum slabs are welded at the depths of 30, 40 and 50 mm underwater consecutively.

Figure 6. Slabs at a depth of 30 mm

In the above figure, the aluminum slabs are welded at 900 rpm at the depth of 30mm or 7mm above the zero level.

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Figure 7. Slabs at a depth of 30 mm

In the above figure, the slabs are welded at depth of 40mm or 17 mm above the zero level. From the figure, we can see that welding at greater depths of water causes lower turbulence in the water.

Figure 8. Slabs at a depth of 30 mm

In the above figure, slabs are welded at the depth of 50mm or 27mm above the zero level. From the figure, we see that turbulence at this depth is almost invisible.

Another observation we can see is that at lower levels of depth of water, the uncut flash thickness is substantially greater than the flash thickness of the welds at higher levels of water. Slabs welded at a higher depth have more smoothness in appearance and precision in cut.

Figure 9. Slab welded at 30 mm

The above figure shows slabs welded at 30mm depth or 7mm over zero level. The weld is not smooth and large sharp uncut flash is seen on the edges of the circular weld.

Figure 10. Slab welded at 40 mm

The above figure shows slabs welded at depth of 40mm. The weld is smooth and there is virtually no uncut flash in this case. There is negligible difference between the uncut flash of slabs welded at 40mm and 50mm.

V. Testing of Specimen

A. Visual Inspection

In the first step of inspection of the weld, several welding defects are revealed. Open surface tunnels are found in the joint due to lack of significant downward pressure. Excessive lateral flash was also observed in the first weld (at the depth of 30mm) resulting from outward flow of plasticized material from underneath of the shoulder. For welds done at higher depths, no defects were found.

Figure 11. Inspection of welded piece

B. Mechanical Testing

UFSW produces almost defect free welds that are used in almost all the industries. They are an effective 'Green Technology' that do not require excessive heating, filler rods and shielding gases. The success of the applicability of the weld is replicated in the real world through mechanical testing.

Some of the tests are.

- Vickers Hardness Test
- Tensile test

C Tensile Test

Tensile testing, also known as tension testing, is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation, and reduction in area] From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

D. Hardness Test

Vickers hardness testing machine is used to determine the hardness of friction stir welded 7075 aluminum plates. It is an indentation hardness test which works on basic principle of indentation or depth of penetration caused on the material when minimum required amount load is applied. The hardness of the material is defined by Vickers hardness number and the unit of hardness is Vickers Pyramid Number (HV).

VI. RESULTS AND DISCUSSIONS

In this study, three sets of Aluminum slabs of 75*100 mm dimensions were welded using Underwater friction stir welding technique. The AA slabs were welded at 900 rpm tool rotation speed and 40mm/min feed of Aluminum slabs attached to the welding table. The tool used for welding is H13 taper turned tool steel. The water level has been taken as 30mm 40 mm and 50 mm on measuring scale and they are 7 mm, 17 mm and 27 mm above the base level.

Visual Inspection: In the first step of inspection of the weld, open surface tunnels are found in the joint due to lack of significant downward pressure. Excessive lateral flash was also observed in the first weld (at the depth of 30mm) resulting from outward flow of plasticized material from underneath of the shoulder. For welds done at higher depths, no defects were found.

Tensile Test Results:

The yield strength and ultimate strength of the welded specimens were determined by using ASTM D638 universal tensile testing machine.

TABLE V.
TENSILE TEST RESULTS

S.No	Absolute Water Level(mm)	Yield strength (Mpa)	Ultimate strength (Mpa)
1	30	1655	2010
2	40	1662	2035
3	50	1660	2050

From the above results it is observed that the yield strength and ultimate strength of the welded specimens have been improved with increasing of water level. The maximum value of ultimate strength of 2050 Mpa is observed at water level of 50 mm.

Hardness Test Results:

The hardness test is conducted by using VM50 Vickers's hardness testing machine to determine the hardness of welded joints.

TABLE VI.
HARDNESS TEST RESULTS

S. No	Absolute Water Level(mm)	Vickers's Hardness (HV))
1	30	551
2	40	558
3	50	562

From the above results it is observed that there is slight increase in the hardness of aluminum joints with the increase in water level. The maximum value of 562 HV is observed at water level of 50 mm.

A. Graphs

Graphs showing Tensile test results

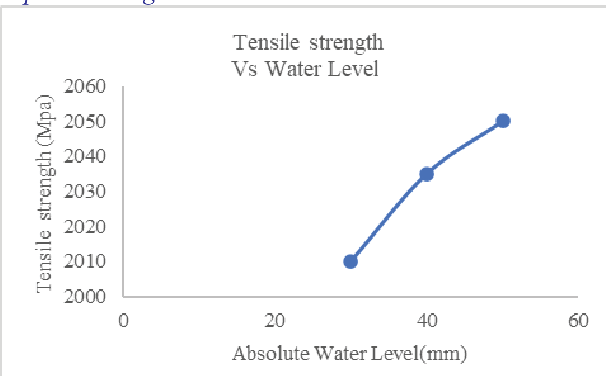

Figure 12. Variation of tensile strenth with water level

Graph showing Vickers Hardness results

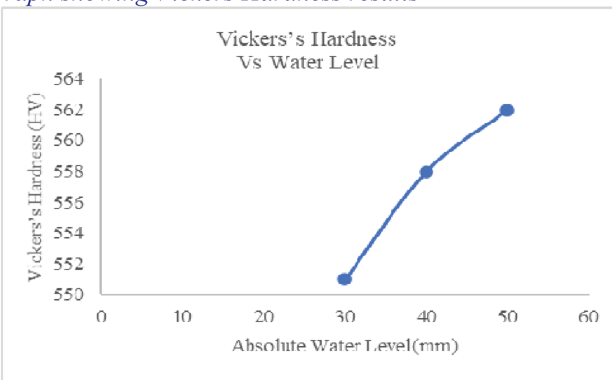

Figure 13. Variation of hardness with water level

Graph showing Yield Strength results

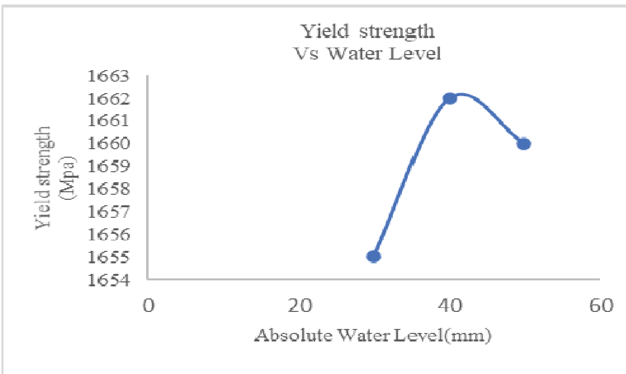

Figure 14. Variation of yield strength with water level

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VII. Conclusions

The present work focused on finding out the effect of water level on tensile strength and hardness of underwater friction stir welded aluminum joints.

From the above experiment, it is observed that the effect of water level plays a prominent role on the mechanical properties of welded joints. Aluminum slabs welded at 900 rpm by H13 tool steel at different depths of water were analyzed thoroughly in detail. From the investigation, following conclusions were obtained.

UFSW uses water as a cooling medium which reduces temperature and restricts the coarsening or dissolution of the precipitates leading to enhanced mechanical properties of the joint.

The tensile strength of the welded joint increases with increase in the depth of water. The yield Strength of the welded joint increases with increase in the depth of water. The highest yield Strength is obtained at 27 mm depth as 1662 MPa and the highest ultimate tensile strength is obtained at a depth of 27 mm (50mm from the base) as 2050 MPa.

The Hardness of the welded joint increases with increase in the depth of water. The highest Vickers hardness is obtained at 27 mm depth as 562 HV.

Limitations: There are limitations like large down forces are required with heavy duty clamping, leaves a keyhole in welded specimen, high cost of initial set up and difficult to weld forgeable materials.

Applications: Underwater friction stir welding can be used successfully to weld wide variety of metals and materials. This is mainly used to produce defect free welds of aluminum alloys used for industrial, aerospace, and marine applications.

Future Scope: The metallurgical characteristics can be determined at welded zone, heat affected zone and thermo mechanically affected zone.

It is also necessary to study and understand the thermal flow of material during welding as the water is acting as cooling medium and the mechanical and metallurgical results can be compared with the results when the welding is done in air.

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