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Friction Stir Welded Joint Aluminum Alloy H20-H20 with Different Type of Tools Mechanical Properties

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***Abstract*—**In this project three type of tools, straight cylindrical, taper cylindrical and triangular tool all made of High speed steel (Wc-Co) used for the friction stir welding (FSW) aluminum alloy H20–H20 and the mechanical properties of the welded joint tested by tensile test and vicker hardness test. Besides, mentioned mechanical properties compared with each other to make conclusion. The result helped design of welding parameter optimization for different types of friction stir process like rotational speed, depth of welding, travel speed, type of material, type of joint, work piece dimension, joint dimension, tool material and tool geometry. Previous investigations in different types of materials work pieces; joint type, machining parameter and preheating temperature take placed. In this investigation 3 mentioned tool types that are popular in FSW tested and the results completed other aspects of the process. Hope this paper can open a new horizon in experimental investigation of mechanical properties for friction stir welded joint with other different type of tools like oval shape probe, paddle shape probe, three flat sided probe, and three sided re-entrant probe and other materials and alloys like titanium or steel in near future.

***Keywords*—**Friction stir welding (FSW), tool, CNC milling machine, aluminum alloy H20, Vickers hardness test, tensile test, straight cylindrical tool, taper cylindrical tool, triangular tool.

I. INTRODUCTION

FRICTION stir welding is a welding process recently developed in 1991 using for Al, Mg, Cu, Ti, for work pieces that could not welded by conventional types of welding and recently developed too much in different application because of economical and quality consideration [1]. Modern types of tools developed recently for harder type of material work pieces like different type of steels [2]. Besides, different types of machines developed for this purpose. FSW can done by an ordinary CNC milling machine for small work pieces to professional single purpose robotic machine in orbital FSW in steel pipes for oil industries [3].The schematic of friction stir process shown in Fig. 1. In addition, the FSW process can be modeled as a metalworking process in terms of five conventional metal working zones like preheat, initial deformation, extrusion, forging and post heating or cooling down. Furthermore, preheating generally increase hardness and Tensile strength qualification therefore preheating recommended both when the friction stir welded joint under horizontal or vertical high loads [4].Several process parameter optimizations developed for friction stir welding in recent years.

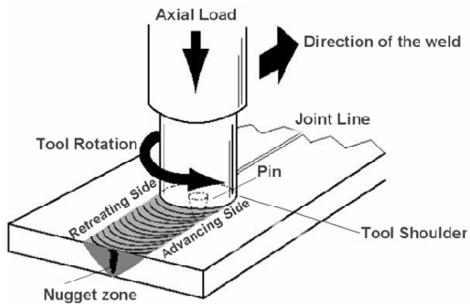

Fig. 1 Schematic of friction stir process

Base these modeling techniques the tool geometry have dominate effects in friction stir welding processes. The effect of bonding time and homogenization treatment on microstructure development and improvement is also considerable. Post bond heat treatment on mechanical Properties, micro hardness and shear strength of joints were also considered as important factors in any welding, joining or metal forming processes [5]. However, preheating preferred in friction stir welding processes and that is because of the nature of the process that based on heat generated by friction existence between tool and work pieces materials.

II. LITERATURE REVIEW AND FUTURE INVESTIGATIONS

Three main types of research take placed in previous investigations on friction stir welding first are mathematical and computer base modeling of the process. There are too many investigation area in FSW modeling and the number of areas are increasing every day some of the previous investigations are, Prediction of Friction Stir Welding Characteristic Using Neural Network, Numerical Simulation of the Friction Stir Welding Process, Heat Transfer Analysis during Friction Stir Welding, 3D numerical simulation of the three stages of Friction Stir Welding based on friction parameters calibration, 3D numerical simulation of the three stages of Friction Stir Welding based on friction parameters calibration, Numerical Simulation of Transient Temperature in Friction Stir Welding, Finite element modeling and failure prediction of friction stir welded blanks and Optimizing the Process Parameters of FSW. The ANOVA (Analysis of

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Variance) results emphasis that parameter pin length contribution was 45.09% and has more influence on quality performance of weld [6]. That is why this investigation and future researches in this field could have significant influence on process parameter optimization. The second main category is Microstructural Study of Friction Stir Welded Joints that focused on metallurgical concepts of friction stir welding like, flaws in friction stir welds, Creep testing and creep loading experiments on friction stir welds and Prediction and Measurement of Weld Dilution. Weld dilution is an important feature of weld bead geometry that determines the mechanical and chemical properties of a welded joint [7].The third main category is about experimental investigation of mechanical properties of different types of joints, different material and methods of friction stir welding [8].The investigation take placed with different types of joints are widely developed recently like overlap and conventional joints or overlap with different depth mechanical properties [9]. FSW successfully done by similar work piece of aluminum alloy H20-H20 in both conventional and overlap joints. The vickers numbers varied by position of the joint (distance from weld center) and the hardness number is about 75 percent of aluminum alloy H20 (parent material). Conventional joint weld have the better tensile strength properties than overlap joint also Tensile Strength in MPa decreasing by lap distances MM increased in overlap joints[9]. FSW also could be applied in rail industries because of its programmability and its automation capabilities [10]. FSW of heavy metals like steel alloys usually needed some special tools that usually manufactured in standard shapes and dimensions [11]. For light metals such as aluminum, FSW tools could be manufactured by ordinary machining processes. The material, shape and dimension of FSW considered as critical process parameter that could affected directly on product mechanical properties and microstructure [12]. Results mentioned in previous projects suggested that during the design process when the joints are under high vertical position load and hardness qualification required that is better to use overlap joints on the other hand when the joints are under horizontal load and tensile qualification required that is better to design conventional joint. Friction stir welding also tested with different preheating temperature. Preheating generally increase Vickers Hardness Numbers and therefore hardness qualification of the welding process. Besides, preheating increase tensile strength of the weld joints quite considerably. Therefore preheating recommended either when the friction stir welded joint under horizontal or vertical high loads [4]. In this project different type of tools mechanical properties discussed for aluminum alloy H20. Three most popular tools in friction stir welding processes straight cylindrical, taper cylindrical and triangular tool used in this project. Aluminum alloy H20 is perfect for friction stir welding [4], [9]. The popularity of tools and material can help the further design processes more effectively in any related field or industries. The result of this project will make cause to complete other previous investigations in FSW and could open new doors for further investigations with other different types of tool for other popular materials in friction stir welding like titanium or different type of steel alloys. Novelty and significance of this research is to opening a new horizon in experimental investigation of mechanical properties of friction stir processes and new investigations with different type of tools could complete the other experimental aspect like preheating and different type of joints [4], [9].This could help the future design process more accurate, with more mechanical considerations and will reduce the volume of try and error process with more reliable design and more safety factors. The results can cause Better understanding of process parameter optimization in friction stir processes like rotational speed, travel speed, and depth of welding, tool geometry and so on in upcoming investigations. This optimization could cause reducing costs, increasing friction stir welding performance and improving welded joints quality. The results of these kinds of investigations combined with preheating and different joints type researches in experimental properties of FSW could build novel and significant ideas in further researches, FSW process parameter optimization and mechanical designs.

III. Material and Methods

The CNC milling machine BMV 45, aluminum alloy work piece H20, rotational speed 1000RPM, feed 20 mm and travel speed 20mm/m are used in this project. The CNC milling machine specifications are as following.

Fig. 2 CNC milling machine BMV 45

TABLE I
Specification of CNC Milling Machine BMV 45

No	Part name	Specification
1	3-axis machine center	Spinner
2	Model	BFW45
3	Spindle driver	Servo motor
4	Spindle range	10-6000 RPM
5	Tool holder	ISO 40
6	Cutting fluid	NR
7	Tool	HSS
8	Work piece	Aluminum Alloy H20
9	Movement	610*450
10	Bed size	800*500

IV. Aluminum Alloy H20 and H20

Because of suitable corrosion Resistance, strength properties, machinability and control in grain structure aluminum alloy H20 is a good material in friction stir welding [13]. In addition, Aluminum alloy H20 successfully used in previous investigations with the same CNC milling machine BMV45 [4], [9].

Fig. 3 Aluminum alloy H20 work piece

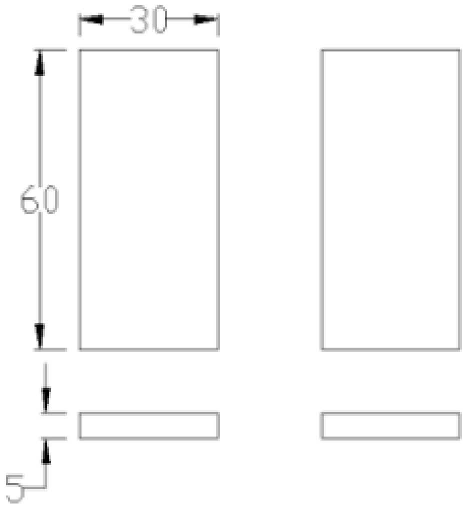

Fig. 4 Work piece Dimension (conventional joint)

V. Type of Tools

A wide variety of tools used for friction stir process (FSP) and friction stir welding (FSW) in different geometry and different materials. Some of the most common types of tools are triangular, square and cylindrical that could be threaded or tapered like threaded cylindrical (TH), taper cylindrical (TC) and straight cylindrical (SC) that all considered as conventional tools. Besides, oval shape, paddle shape developed too much recently for different applications and the displacement between threaded can be adjusted for different applications like changing spiral form and flared probe [14]. In addition, The tool material can be changed from some conventional types like High speed steel (Wc-Co) in aluminum work pieces in ordinary application to some tools that made of cemented tungsten carbide with nickel and a Al_2O_3 surface coating made of cemented carbide comprising WC grains that is a kind of super abrasive tools suitable for hard steel work pieces recently developed in Sweden [11]. Straight cylindrical, taper cylindrical and triangular tools used in this investigation for the mentioned work piece (mentioned dimension and materials). The tool material is High speed steel (Wc-Co) and the tools dimension are as following.

Fig. 5 Friction stir welding straight cylindrical tool

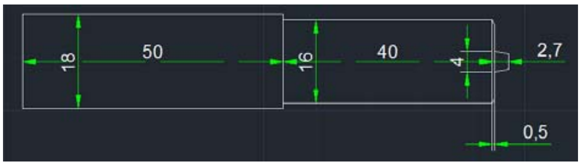

Fig. 6 Friction stir welding taper cylindrical tool

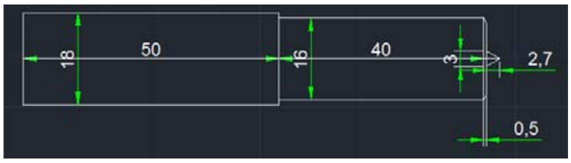

Fig. 7 Friction stir welding triangular tool

Effect of welding parameters on the microstructure of welded joint and welded product quality is one of the most important considerations in FSW process parameter optimization. Tool geometry has the most important effects on the welding joint quality. Some of the aluminum alloys plates are under rolling to reduce the thickness especially cold rolling process. The mechanical and metallurgical behavior of welded joints varied by the direction of friction stir welding for example in the same direction with rolling process or perpendicular with the direction of rolling process or angular with the direction of rolling process therefore the direction of friction stir welding is one of the important process parameter beside the rotational speed, travel speed, depth of welding, feed, tool geometry, work piece geometry, tool material and work piece material. The previous investigations shows superior mechanical properties for the weldments with weld direction parallel to the rolling direction as compared with the joints with weld direction perpendicular to the rolling direction [15].

Thomas found that the addition of flat features can change material movement around a probe. This is due to the increased local deformation and turbulent flow of the plasticized material by the flats acting as paddles demonstrated that a reduction in transverse force and tool torque was directly proportional to the number of the flats placed on a tapered shoulder [16].

Particular torque wrench has an accuracy of ± 2percentages from 20% to 100% of full scale or 7.6 to 27.10 Nm. Below this range; it has an accuracy of ± 3 percentage. The torque wrench and adapter tool are shown in Fig. 8.

Fig. 8 Torque Wrench and Adapter Tool

The torque wrench also features audible tones and LEDs to inform the user when 90% of the desired torque is reached, when 100% of the desired torque is reached and if the desired torque is exceeded. The wrench also displays the maximum torque experienced after any single load is applied. This was convenient for calibration purposes. The torque calibration was performed by first establishing wireless communication and then applying torques of 5, 10, 15, 20, and 25 N-m in first the CW 85 and then the CCW directions. The actual, maximum torque reached at each interval was recorded and these values were then matched to the corresponding peak voltages that were recorded. The raw voltage data along with the table of peak values can be found in technical documents. Fig. 9 displays the calibration curve resulting from the compiled torque and voltage data.

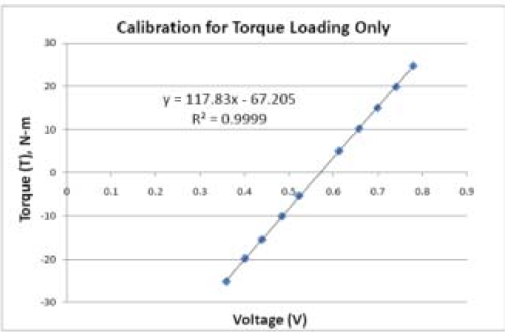

Fig. 9 Torque Calibration Curve

The calibration was linear and the signal to noise ratio documented in the raw data file in technical documents was impressive. The calibration also marked the end of the first stage of development for the force transducer. The system is completely implemented for one force measurement and is readily upgradable to measure additional forces and temperature [17]. Fig. 10 considered as a typical diagram that represent pin length via force applied to FSW. The longitudinal force increase by increasing the pin length because of that pin pressure increasing sharply and this process will have direct effect to torque adjustment of different type of tools. Triangular tool have more pin length that directly in touch with work piece materials than two others then the pin pressure and the tool temperature increased significantly. Straight cylindrical tool have less pin length that directly in touch with work piece materials then the pin pressure and temperature is minimum compare to two others.

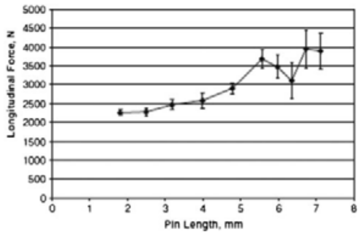

Fig. 10 Pin length (mm) via longitudinal force (N) different type of tools [18]

VI. Mechanical Properties Friction Stir Welded Joint Results

Mentioned dimension aluminum alloy H20-H20 conventional joint with the mentioned process parameter welded by CNC milling machine three times first with triangular tool after that with taper cylindrical tool and finally with straight cylindrical tool. Besides, both vicker hardness and tensile strength test performed to the welded joints. The results compared and made conclusion.

Fig. 11 Friction stir welded aluminum alloy H20 triangular tool

The Vickers hardness numbers of the welded joint varied by distance from the weld center. The surface quality of the welded joint by triangular tool is better than the surface quality of welded joint by taper cylindrical tool. Besides, the surface equality of welded joint by straight cylindrical tool was not satisfactory. On the other hand the hardness characteristic of welded joint by straight cylindrical tool was the best. In addition, the hardness characteristic of welded joint by taper cylindrical tool is better than welded joint by triangular tool.

Fig. 12 Friction stir welded aluminum alloy H20 taper cylindrical tool

Fig. 13 Friction stir welded aluminum alloy H20 straight cylindrical tool

TABLE II
FRICTION STIR WELDED JOINT ALUMINUM ALLOY H20-H20 VICKERS HARDNESS NUMBER (VHN)

Friction stir welded joint with triangular tool	S.No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Distance from the weld start position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Vickers Hardness Number (VHN)	57.9	62.2	56.8	55.3	51.7	50.6	49.4	44.8	51.1	49.8	53.5	51.5	51	53.5	57.5
Friction stir welded joint with taper cylindrical tool	S.No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Distance from the weld start position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Vickers Hardness Number (VHN)	64.7	57.6	66.6	62.9	63.2	67.1	67.1	59.3	62.1	64.3	54.2	59.4	60.1	64.3	67.9
Friction stir welded joint with straight cylindrical tool	S.No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Distance from the weld start position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Vickers Hardness Number (VHN)	73.6	72.4	69.3	68.4	77.2	73.6	72.2	74.3	78.4	68.6	73.2	70.9	71.4	76.1	69.8

The vicker hardness testing results obtained by transformation the data from Table II to Fig. 14 in a compact graph to have better understanding of different welded joints behavior in a glance and making conclusion more easily.

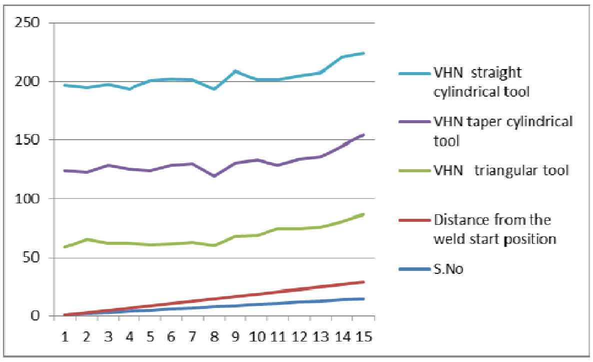

Fig 14 Vicker hardness numbers

In addition, Table III represented the results of the tensile testing.

TABLE III
FRICTION STIR WELDED JOINT ALUMINUM ALLOY H20-H20 TENSILE STRENGTH IN MPA

Type of Joint	Tensile Strength in MPa
Friction stir welded joint with triangular tool	138
Friction stir welded joint with taper cylindrical tool	122
Friction stir welded joint with straight cylindrical tool	113

The tensile strength testing results obtained by transformation the data from Table III and Fig. 15 in a compact graph to have better understanding of different welded joints behavior in a glance and making conclusion more easily.

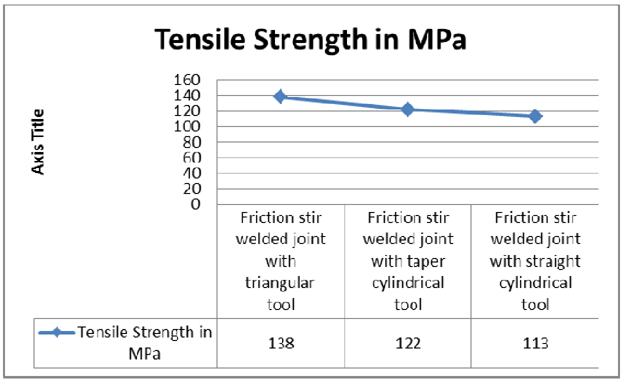

Fig. 15 Tensile strength in MPa

VII. Mechanical Properties Friction Stir Welded Joint Discussion

The tensile strength characteristic of Friction stir welded joint with triangular tool is the best and the tensile strength of friction stir welded joint with taper cylindrical tool is better than tensile strength of friction stir welded joint with straight cylindrical tool. In addition, previous investigation done in this area show that from Real tension and tensile curves were obtained and tensile tests applied to the samples of welded-joints, it was found that rotating speed of the pin, feed rate and the profile of the pin had significant effects on the strength of the welded-joints. When the real strain and tensile curves of the welded samples connected by increasing the rotating speed of the mixer pin and feed rate were examined, high heat generation was observed. Besides, grain growth took place due to the increase in the intensity of extrusion caused by the increase in the material viscosity in the weld zone [19].

VIII. Mechanical Behavior of the Three Type of Tools Analysis

For analyzing mechanical properties of mentioned tools types (straight cylindrical, taper cylindrical and triangular tool) Vickers hardness numbers (VHN) should reviewed in Fig. 14. VHN increasing by distance from the start weld position but taper cylindrical have significantly increased by approximately 90 units. On the other hand straight cylindrical and triangular tools have just 30 units increased. This phenomena shows that taper cylindrical is not generally suitable for design joints under high vertical loads or significant pressures like marine industries. Straight cylindrical tools have more significant overall VHN approximately 200 units. Therefore it is more suitable for such industries. On the other hand Fig. 15 represented that friction stir welded joint with triangular tools have the best tensile strength among two others 138 MPA and this kind of tools are more suitable for joints under horizontal or tensile loaded, like piping industries [20].

IX. Current and Future Development

Friction stir welding applied successfully for aluminum alloy H20-H20 by CNC milling machine BMV 45. Friction stir welded joints with triangular tool have a good surface quality and tensile strength. On the other hand Friction stir welded joints with straight cylindrical tool have excellent hardness characteristics but the surface quality is not satisfactory and the welded joints usually need some surface treatments processes. In conclusion when the work pieces are under hard vertical loads that are better to choose friction stir welded joints with straight cylindrical tool but when the work pieces are under hard horizontal loads the friction stir welded joints with triangular tool preferred in choosing FSW process parameter.

Appendix

This CNC program is used in our CNC milling machine (BMV45).

```
00010(DIA 16.0EM 45 DEGEREE TIP CUTTER)
N01 (FRICTION STIR WELDING)
N02 (DATE 11-01-2010 TIME 20:15:08)
N03 G0G17G40G49G53G80G90
N04 G5.1Q1R10
N05 G91G28Z0
N06 M03S950
N07 G90G54X0.0Y0.0
N08 G43H6Z50
N09 G1Z2F800
N10 G1Z-3.8F16
N11 X170
N12 G0Z50.0M09
N13 M05
N14 G91G28Z0
N15 G5.1Q0
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