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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 we will using three type of tools, straight cylindrical, taper cylindrical and triangular tool all made of High speed steel (Wc-Co) for the friction stir welding (FSW) aluminum alloy H20 –H20 and test the mechanical properties of the welded joint by tensile test and vicker hardness test. Finally we will compare mentioned mechanical properties and make conclusion. The result will help welding parameter optimization in different type 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 will complete other aspects of the process. hope this paper open a new horizon in experimental investigation of mechanical properties of 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 also other materials and alloys like titanium or steel in near future.

Key words: Friction stir welding (FSW) · Tool · CNC milling machine · Aluminum alloy H20 · Vickers hardness test · Tensile test · Straight cylindrical tool · Taper cylindrical tool · Triangular tool

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 develop too much in different application because of economical and quality consideration [1]. Modern types of tool developed recently for harder typed of materials work pieces like different type of steels [2]. Also 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 welding in oil industries [3]. The schematic of friction stir process shown in Figure 1.

Alsothe FSW process can be modeled as a metal working process in terms of five conventional metal working zones: preheat, initial deformation, extrusion, forging and post heat/cool down. Beside this preheating generally increase hardness and Tesile strength qualification therefore preheating recommanded both when the friction stir welded joint under horizental or vertical high loads. [4] several process parameter optimization develop for friction stir welding in recent years. base these modeling techniques The tool geometery have dominate effects in friction stir welding processes. The effect of bonding time and homogenization treatment on microstructure development

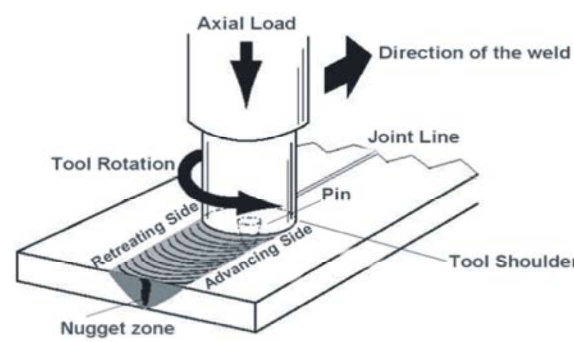

Fig. 1: Schematic of friction stir process.

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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]. But as I mentioned before preheating preferred in friction stir welding processes and that's because of the nature of the process that base on heat generated by friction existence between tool and work pieces materials.

Literature Review and Future Investigations: Three main type of research take placed in previous investigations on friction stir welding first mathematical and computer base modeling of the process. There are too many investigation area in FSW modeling and the number of areas 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 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 research in this field will have major influence on process parameter optimization. The second main category is Microstructural Study of Friction Stir Welded Joints That focus 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. 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.

FSW successfully done by similar work piece of aluminum alloy H20-H20 in both conventional and overlap joints. The vickers number 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. This results suggest that during the design process when the joint will under high vertical position load and hardness qualification required that is better to use overlap joints on the other hand when the joint is under horizontal load and tensile qualification required that is better to design conventional joint. Friction stir welding also tested with different preheating temperature and without preheating, preheating generally increase Vickers Hardness Number and therefore hardness qualification of the welding process beside this preheating increase Tesile strength of the weld joints quite considerably. therefore preheating recommanded both when the friction stir welded joint under horizental or vertical high loads in this project we disscuss different type of tools mechanical properties of aluminume alloy H20. We used three most popular tools in friction stir welding processes, straight cylindrical, taper cylindrical and triangular tool and also aluminum alloy H20 have special characteristic perfect for friction stir welding. The popularity of tools and material help the further design process more effective in any related field or industries. The result of this project will make cause to complete other previous investigations in FSW and will open a new door 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 types of investigation with different type of tools will complete the other experimental aspect like preheating and different type of joints this will help the future design process more accurate and with more mechanical consideration and will reduce the volume of try and error process and more reliable design with more safety factors we can also achieve better understanding of process parameter optimization in friction stir processes like rotational speed, travel speed and depth of welding, tool geometry and so on these optimization will help us to reduce the costs and increasing friction stir welding performance and improve welded joints quality. The results of these kinds of investigations combined with preheating and different joints type research in experimental properties of FSW will build novel and significant ideas in further researches and FSW process parameter optimization and mechanical design.

MATERIALS AND METHODS

We are using the CNC milling machine BMV 45 with aluminum alloy work piece H20 and rotational speed 1000RPM feed 20 mm and travel speed 20mm/m in this project the CNC milling machine specification as following:

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 [12]. Also we used aluminum alloy H20 successfully in previous investigations with the same CNC milling machine BMV45.

Type of Tools: A wide variety of tools can use by friction stir process(FSP) in different geometry and different materials some of the most common type of tools are triangular, square and cylindrical that could be threaded or taper like threaded cylindrical (TH) and taper cylindrical (TC)also we have straight cylindrical (SC) that all consider as conventional tool types we have oval shape, paddle shape and many others that developed recently for different application and the displacement between threaded can be adjusted sometimes for different applications like changing spiral form and flared probe [13]. by the way the material also can be change from some conventional types like High speed steel (Wc-Co) in aluminum work piece in ordinary application to some tool made of cemented tungsten carbide with nickel and a AL2O3 surface coating made of cemented carbide comprising WC grains that is a kind of super abrasive tools suitable for hard steel work pieces friction stir welding (FSW) recently developed in Sweden. we will use straight cylindrical, taper cylindrical and triangular tools in this investigation for the mentioned work piece (mention dimension and materials)the tool material is High speed steel (Wc-Co).and the tool dimension are as following:

Effect of welding parameters on the microstructure of welded joint and welded product quality is one of the most important consideration in process parameter optimization among these parameter tool geometry have the most important effect on the welding joint quality. some of the aluminum alloys plates are under rolling to reduce the thickness specially cold rolling process the mechanical and metallurgical behavior of welded joints vary by the direction of friction stir welding for example in the same direction with rolling process or perpendicular

Table 1: 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

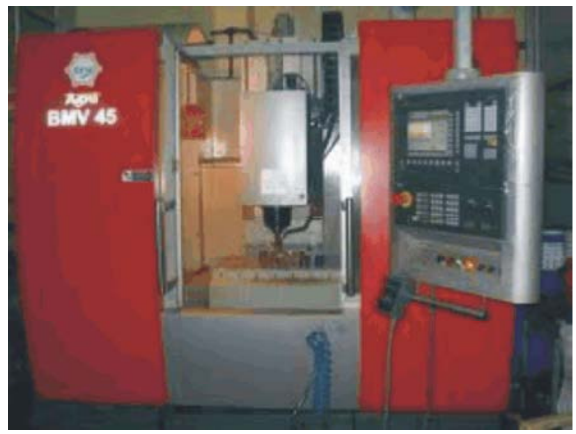

Fig. 2: CNC milling machine BMV 45


Fig. 3: Aluminum alloy H20 work piece

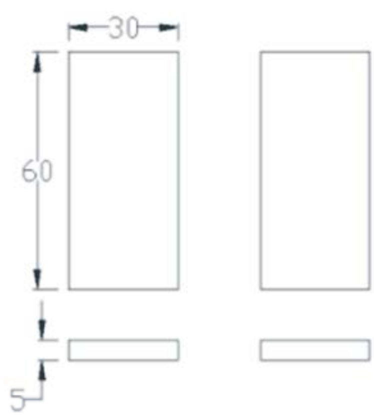

Fig. 4: Work piece Dimension (conventional joint)

Fig. 5: Friction stir welding straight cylindrical tool.

Fig. 6: Friction stir welding taper cylindrical tool.

Fig. 7: Friction stir welding triangular tool.


Fig. 8: Torque Wrench and Adapter Tool

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 or 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 [14].

E.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 [15].

Particular torque wrench has an accuracy of ±2% from 20% to 100% of full scale, or 7.6 to 27.10 N-m. Below this range it has an accuracy of ±3%. The torque wrench and adapter tool are shown in Figure 8.

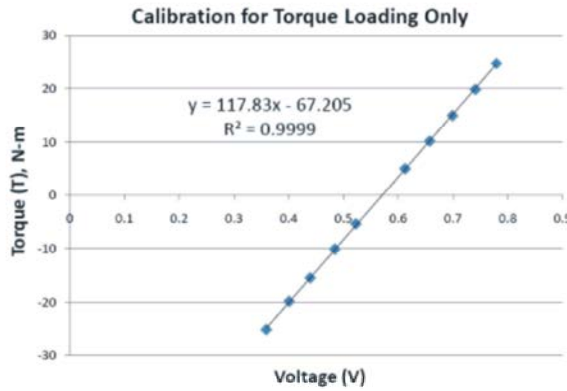

Fig. 9: Torque Calibration Curve

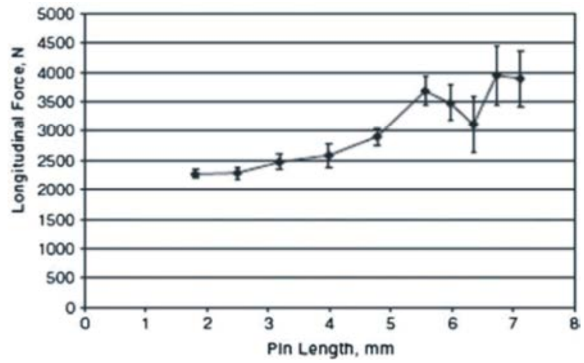

Fig. 10: Pin length (mm) via longitudinal force (N) different type of tools [17]

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. Figure 9 displays the calibration curve resulting from the compiled torque and voltage data.

The calibration was highly linear and the signal to noise ratio documented in the raw data file in technical documents was also 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 [16]. Figure 10 considering as a typical diagram that represent pin length via force apply to FSW by increasing the pin length the longitudinal force increase and 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 increase and also the tool temperature increase. 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.

Weld Testing Procedures

A.Vickers Hardness Test: Diamond pyramid shape tool apply to the welded part, changing dimension parameter h and d will measure by a microscopic method and finally the Vickers hardness number (VHN) will calculate by following formula [18]:

If P is applied load by Pyramid shape diamond per KgF that is adjust by testing process between 1 to 120 kgF for different type of work piece materials. that we performed 1kgF in this investigation more suit for aluminum alloy H20 and L is area of indentation per mm, that will calculated by microscopic method available in the testing machine form D and h shown in the Figure 8 and α is angle between opposite faces of diamond equal to 136° in this investigation testing machineThen DPHcalculate with following formula.And testing machine can represented related vicker hardness number respect to distance from the center of the weld or weld position accurately.

$DPH=2P\sin(\alpha/2)/L^2=1.854P/L^2$ [19]

Procedure of Vicker's Hardness Testing:

- The indenter is pressed into the sample by an accurately controlled test force.
- The force is maintained for a specific dwell time, normally 10 – 15 seconds.
- After the dwell time is complete, the indenter is removed leaving an indent in the sample that appears square shaped on the surface.
- The size of the indent is determined optically by measuring the two diagonals of the square indent.
- The Vickers hardness number is a function of the test force divided by the surface area of the indent. The average of the two diagonals is used in the mentioned formula to calculate the Vickers hardness.

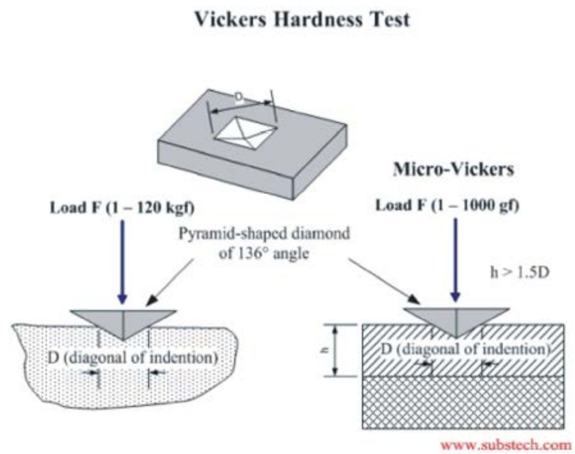

Fig. 11: Vickers Hardness Test Terminology

Fig. 12: Vickers Hardness Testing Machine.

Vickers hardness numbers are reported as e.g. 440HV30, where:

- 440 is the hardness number,
- HV gives the hardness scale (Vickers),
- 30 indicates the load used in kg.

Vickers Hardness Testing Machine Specifications:
Model: SHIMADZU HSV 20
Test Conditions: One Kg load, 10 Seconds Loading

- Force: 8 Types: 1.96, 2.94, 4.9, 9.8, 29.4, 49, 98, 294 N (HV 0.2 to HV 20).
- Force duration: 5 to 999 seconds
- Indenter: Squared-based pyramidal diamond indenter with face angle of 136°.
- Optical Monitor: Monitor Objective lens x 20, Eyepiece x 10, Optical path can be selected for observation and filming.
- Optical head: Measurement range 500 µm at x20, resolution 0.02 µm at x20.
- Sample geometries: Maximum height 200 mm and Maximum depth 170 mm.

Tensile Test Procedure: Tensile strength measured by UTM machine

- The test should be carried out at a temperature between 10°C and 35°C and prepare a piece in required dimensions i.e., as shown in diagram.
- Calculate the original cross sectional area (S_o) from the measurements of the appropriate dimension of the test piece.
- Mark each end of the original gauge length (L_o) by means of fine marks or scribed lines, but not by notches which may cause a premature fracture. If parallel length (L_c) is much longer than the original gauge length, draw a series of overlapping gauge lengths.
- Clamp the test piece in a suitable gripping device that the force is applied as axially as possible. Attach the extensometer to the test piece.
- Apply a tensile force on the test piece so as to strain the test piece in a non-decreasing Manner, without shock or vibration. Maintain the speed of testing within the limits specified. Record the force and the corresponding extension. Accurately plot the Force/extension diagram
- Calculate the tensile strength (Rm) by dividing the maximum force (F_m) by the original Cross-sectional area (S_o) of the test piece.

$$R_m=F_m/S_o$$

- Construct a line parallel to the linear portion of the force/extension diagram at a distance equal to the specified non-proportional percentage, for example 0.2%.record the force corresponding to the point at which this line intersects the curve (Fig). Calculate the proof strength by dividing this force by the original cross-sectional area of the test piece.

Load the test piece to beyond the presumed proof strength and then reduce the force to a value equal to about 10% of the force obtained. Once again increase the force on the test piece until it exceeds the value obtained originally. Plot the force/extension diagram and draw a line through the hysteresis loop. Construct another line, at a distance from the origin of the curve, measured along the abscissa, equal to the specified non-proportional percentage. Record the force corresponding to the point at which this line intersects the curve. Calculate the proof strength by dividing this force by original cross-section of the test piece [19-23].

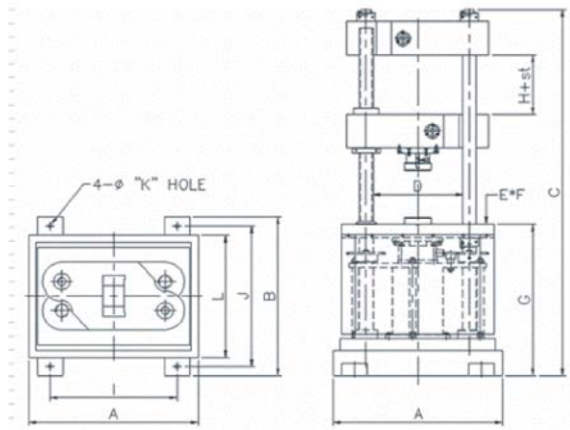

Fig. 13: Typical universal testing machine technical plot


Fig. 14: Universal testing machine DTU-9000HCA

We use universal testing machine model DTU-9000HCA in this investigation.

RESULTS AND DISCUSSION

Mechanical Properties Friction Stir Welded Joint Results: We weld the mention dimension aluminum alloy H20-H20 conventional joint with the mentioned process parameter and CNC milling machine three times first with triangular tool after that with taper cylindrical tool and finally with straight cylindrical tool and then perform both vicker hardness and tensile strength test to the welded joints compare the results and make conclusion.

The Vickers hardness number 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 welded joint by taper cylindrical tool and the surface quality of welded joint by straight cylindrical tool was not satisfactory. On the other hand the hardness characteristic of welded joint by straight cylindrical tool

Fig. 15: Friction stir welded aluminum alloy H20 triangular tool

Fig. 16: Friction stir welded aluminum alloy H20 taper cylindrical tool.

Fig. 17: Friction stir welded aluminum alloy H20 straight cylindrical tool.

was the best.Beside this the hardness characteristic of welded joint by taper cylindrical tool is better than welded joint by triangular tool.

By transformation the data from Table 2 to Chart 1 we can see the vicker hardness testing results in a compact graph to have better understanding of different welded joint type behavior in a glance it also will help us to make conclusion more easily.

Also The results of the tensile testing shown in Table 3.

By transformation the data from Table 3 to chart 2 we can see the tensile strength testing results in a compact graph to have better understanding of different welded joint type behavior in a glance. it also will help us to make conclusion more easily.

Mechanical Properties Friction Stir Welded Joint Discussion: The tensile strenght charecteristic of Friction stir welded joint with triangular tool is the best and The tensile strenght of Friction stir welded joint with taper cylindrical tool is better than tensile strenght of Friction stir welded joint with straight cylindrical tool**.**Also 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. Also 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 [20].

Mechanical Behavior of the Three Type of Tools Analysis: For analyzing mechanical properties of mentioned tools types straight cylindrical, taper cylindrical and triangular tool we should first review Vickers hardness numbers (VHN) in Chart 1. VHN

Table 2: 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

Table 3: 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

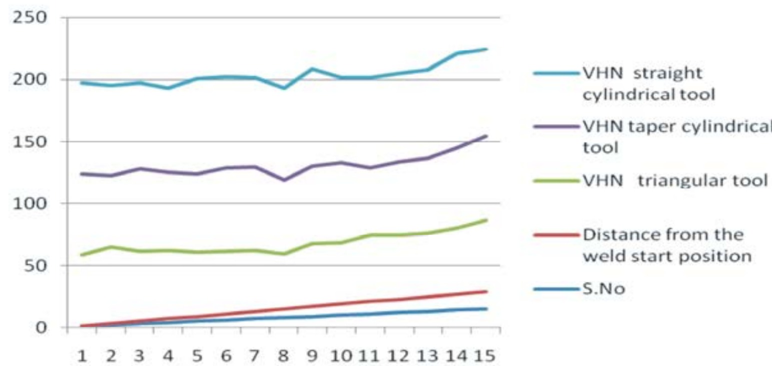

Chart 1: Vickers hardness numbers.

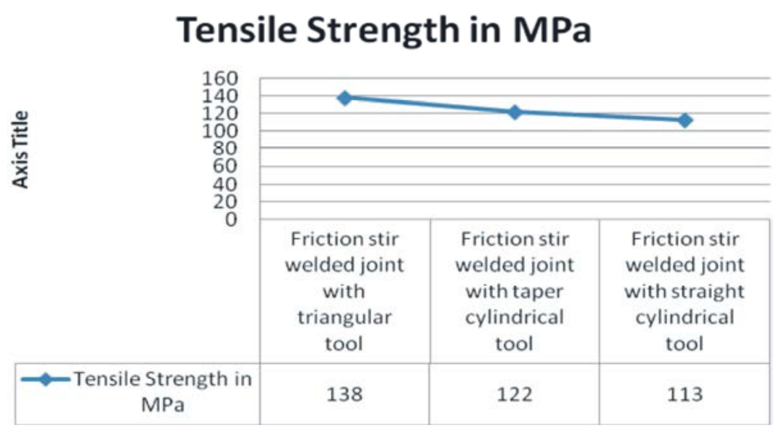

Chart 2: Tensile strength in Mpa

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 load or significant pressure like marine industries. Straight cylindrical tools have more significant overall VHN approximately 200 units. Therefore it will more suitable for such industries. On the other hand the tensile strengths in MPA chart 2 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 welding applications in piping industries.

CONCLUSION

Friction stir welding can apply successfully for aluminum alloy H20-H20 by CNC milling machine Friction stir welded joint with triangular tool have a good surface quality after welding also have a good tensile strength. on the other hand Friction stir welded joint with straight cylindrical tool have an excellent hardness characteristic but the surface quality is not satisfactory after welding and the welded joint usually need to some surface treatments process in conclusion when the work piece is under hard vertical load that is better to choose Friction stir welded joint with straight cylindrical tool but when the work piece is under hard horizontal load the Friction stir welded joint with triangular tool will prefer in choosing FSW process parameter.

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