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Friction stir welding of 6063 Aluminum alloy pipe with 6082 Aluminumalloy pipe

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Abstract
Many of studies are conducted in friction stir welding of plat but very little in pipes, so that,this study came in friction stir welding of 6063 aluminum alloy pipe with 6082 aluminum alloy pipe to modeling and analysis this welding by finite elements method and evaluates the mechanical properties of this joint by different tests like tensile test, microstructure test, hydrostatic test, and Microhardness test. Moreover, six parameters were used during this study included rotation speed, travel speed, axial force,rotation direction,tool geometryand tilt angle. The results show the best joint was with rotation speed 1300 rpm.

Keywords: friction stir welding, 6063 aluminum alloy pipe, 6082 aluminum alloy pipe.

Introduction:

Friction stir welding is a solid-state joining process was found first time from The Welding Institute, United Kingdom in 1991, by Wayne Thomas. This bonding method that was uses the heat of friction generated from the shoulder of the tool for make the adjacent sectors soft and the tool pin mix these sectors to get a good weld as shown in Fig. 1. [1,2].This generated heat was studied, for example Azman Ismail et al. (2015)[3] study the process parameters influence on the temperature profile of FSW aluminum 6063-t6 pipe butt joint. The microstructure of small diameters and microstructure also was studied like D. G. Hattingh et al. (2016) [4] study 38 mm OD 6082-T6 Aluminum Tubes friction stir welding process development and microstructure. The mechanical properties of FSW aluminum pipes also was studied like A.M. Khourshid et al. (2017) [5]their work presents a systematic approach to develop the mathematical model by three methods such as artificial neural networks using software, Response surface methodology (RSM) and regression Analysis for predicting the ultimate tensile strength, percentage of elongation and hardness of 6061 aluminum alloy.A M Khourshid and I Sabry (2013) [6] they were investigated in the Mechanical properties of friction stir welded joints by mechanical tests including (tensile test, hardness and microstructure) and also they studied the influence of microstructure and mechanical properties of FSW 6063 Al alloy. Qasim M Doos and Bashar Abdul Wahab (2012) [7] were investigated in the mechanical properties of welded joints by different mechanical tests. Azman Ismail et al. (2017) [8] studied the effect of welding parameters on the tensile strength of joint produced by the FSW process.Kishore prasaath. K et al. (2018) [9] studied the FSW in circular pipes and presents the optimization of friction stir welding for pipe and also highlights the influence of microstructure and mechanical properties of FSW 6063 Al alloy.Azman

Ismail et al. (2014) [10] studied the FSW external surface hardness of aluminum 6063 pipe joint.

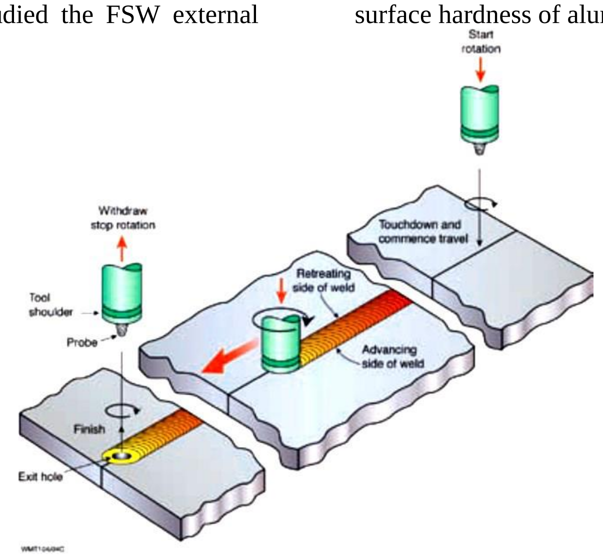

FIGURE1. The method principle for FSW. Drawing courtesy of © TWI. [11]

Experimental Work

Pipes Materials

6063 aluminumalloypipe, and 6082 aluminumalloy pipe were used for the friction stir welding process in this study as a materials joint together. The dimensions for pipes were same for both pipes, the out-side diameter of the pipe (89 mm) and the wall thickness (5 mm) as shown in Fig. 2.The chemical compositionand mechanical properties of AL6063and AL6082 are shownin tables 1 and 2 respectively.

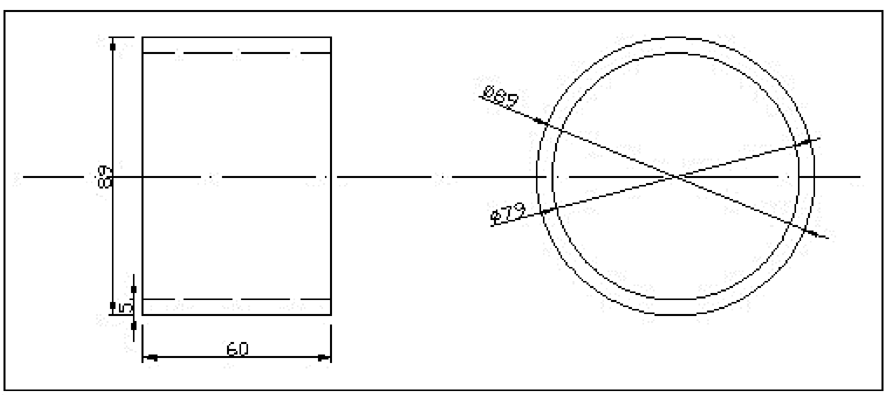

FIGURE2. Size and Dimensions of the Pipes that Used in the Study (all dimensions in mm)

Welding Parameters

Six parameters were used during this process, those parameters included rotation speed, travel speed, axial force,rotation direction, tilt angleand tool geometryas shown in table 3. With those parameters, four specimens were welded and investigated with different tests, such as Hydrostatic test, the microstructure test, Micro-hardness test, the tensile test. The comparison was conducted by changing one of the parameters (rotation speed) and keeping the others as constants.

TABLE 1. Chemical Composition of AL6063 alloy and AL6082 alloy

Type of examination	Material	Composition, wt. %										
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Specified other elements	Unspecified other elements		AL
										Each	Total	
Standard examination	AL 6063	0.20-0.6	0.35	0.10	0.10	0.45-0.9	0.10	0.10	0.10 Ti	0.05	0.15	Rem.
Actual examination	AL 6063	0.680	0.297	0.227	0.0285	0.906	0.108	0.0542	0.0826 (Ti+Ni+P+Pb+Sn)			Rem.
Standard examination	AL 6082	0.7-1.3	0.50	0.10	0.40-0.10	0.6-1.2	0.25	0.20	0.10 Ti	0.05	0.15	Rem.
Actual examination	AL 6082	1.08	0.244	0.0079	0.558	0.572	0.0008	0.0117	0.01959(Ti+Ni+P+Pb+Sn)			Rem.

TABLE 2. Mechanical Properties of Al 6063 and Al 6082

Material	Tensile strength	Yield strength	Elongation %	Hardness

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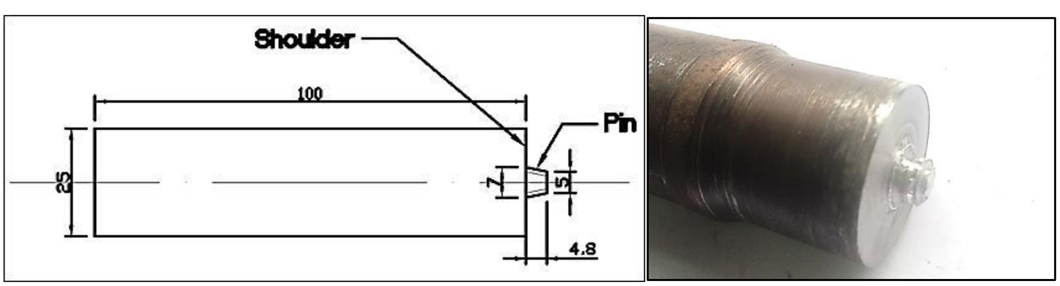
	MPa	ksi	MPa	ksi		HB
AL 6063	90	13	48	7	7.3 - 21	25
AL 6082	140	20.3	85	12.3	6.3 - 18	40

TABLE 3. Welding Parameters Used in FSW Process

Rotational Speed (rpm)	Welding Speed (mm/min)	Axial Force (KN)	Rotation direction ↻, ↺	Tilt Angle (Degree°)	Tool Geometry
775	1.7	8.5	CW	0°	Conic thread
1000					
1300					
1525					

The Tool Design and material

The tool used in this study was design from shoulder and pin with diameter of shoulder 25 mm and length 100 mm, moreover, the dimension of pin was (the diameter of the root of pin 7 mm, the diameter of the top of pin 5 mm) and the length of pin is 4.8 mm, and theshape of pin was conical with threadas shown in Fig. (3-a). The material of the tool used in this study was cold work tool steel A681 (D2) ASTM. Furthermore, this tool was made in the workshops of Technical Institute of Kut as shown in figure (3-b).

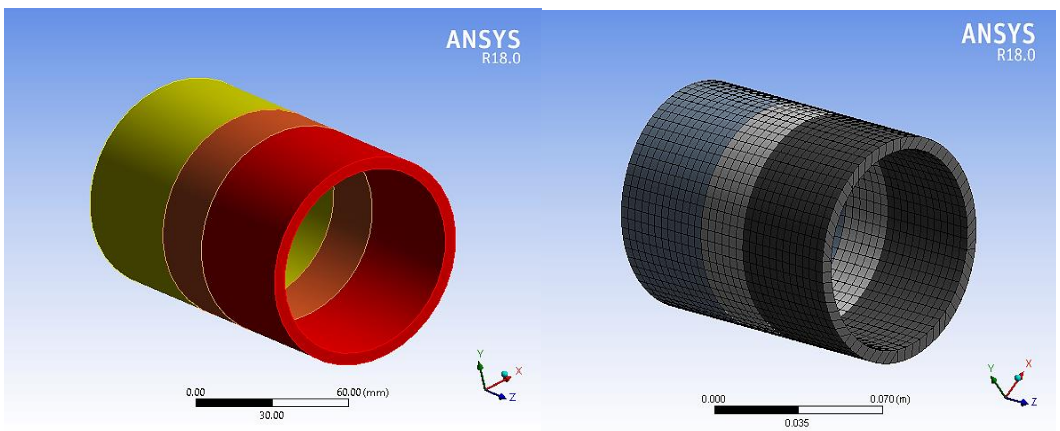


(a) (b)

FIGURE 3.FSW Tool (a). Tool geometry (all dimensions in mm), (b) ASTM A681 (D2) Friction Stir Welding Tool

Finite Element Modeling of Friction Stir Welding Pipes

The Finite Element modeling has been achieved for two pipes (Al 6063 and Al 6082) welded by friction stir welding. Moreover, this analysis has been carried out to find the effect of hydrostatic pressure on the welding area of the pipe during the working times, and this done by modeling the pipes in the Design Modeler of Ansys software version 18.0 as shown in Fig. (4-a).then open the Mechanical interface of Ansys software version 18.0 to made the analysis that start by meshing the model as shown in Fig. (4-b). After that completing the analysis setting with inserting the pressure, hydrostatic pressure, and supports to find the stress and the deformation as described in results section below.



a. Modeling b. Meshing

FIGURE 4. Modeling and Meshing the weld joint (AL6063 + AL6082) for FSW of pipe. (a). Modeling step, (b). Meshing step

Results and Discussions

The results and discussions of friction stir welding pipes reviewed in two sections:

1. The results and discussions of mechanical properties for friction stir welding pipes.

Visual Inspection

Visual inspection was conducted according to AWS D17.3 for weld joints produced by FSW (AL6063 + AL6082). The results can be seen in table (4).

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TABLE 4. The results of Visual inspection test for fourcases of FSW.

Case No.	Weld surface	Notes
(1) AL6063 + AL6082		Medium appearance weld with appearing of flash on the boundary of weld (0.5 mm height), and little crack on the surface. (775 rpm, 1.7 mm\min).
(2) AL6063 + AL6082		Good appearance weld with appearing of flash on the boundary of weld (0.5-1 mm height). (1000 rpm, 1.7 mm\min).
(3) AL6063 + AL6082		Good appearance weld with appearing of flash on the boundary of weld (0.5-1 mm height). (1300 rpm, 1.7 mm\min).
(4) AL6063 + AL6082		Medium quality weld with appearing of flash on the boundary of weld (0.5 mm height), and little burned area appear in stir zone. (1525 rpm, 1.7 mm\min).

From the results above of visual inspection for (AL6063 + AL6082) cases it was observed that the flash height was starting to increase with increasing the rotation speed (775, 1000, 1300 rpm) then decreasing at high rotation speed of (1525 rpm) with a reduction in the weld quality. So the best quality sample of AL6063 to AL6082 weld joints case was in cases 2, and 3 where the rotational speed is 1000 rpm and 1300 rpm respectively.

Hydrostatic Test

Hydrostatic Test was made for four cases of FSW, and the results were as follows in the table (5) below.

TABLE 5.the results of hydrostatic test for four cases of FSW.

Case No.	Joint materials	Max. Pressure Value in bar	Notes
1	AL6063 + AL6082	23	Leak on the stir zone at 24 bars.

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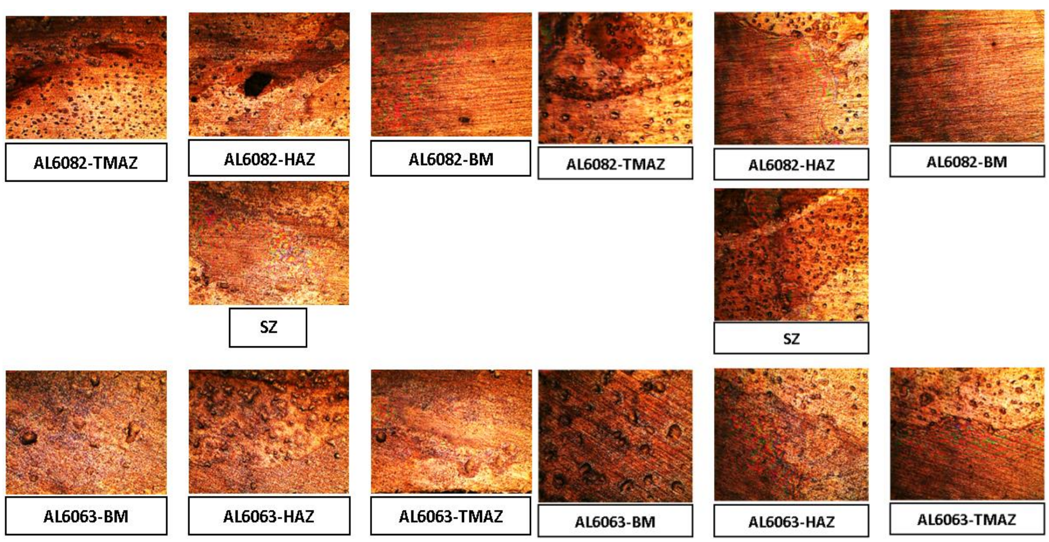
2	AL6063 + AL6082	27	Leak on the stir zone at 28 bars.
3	AL6063 + AL6082	30	No leak
4	AL6063 + AL6082	29	Leak on the stir zone at 30 bars.

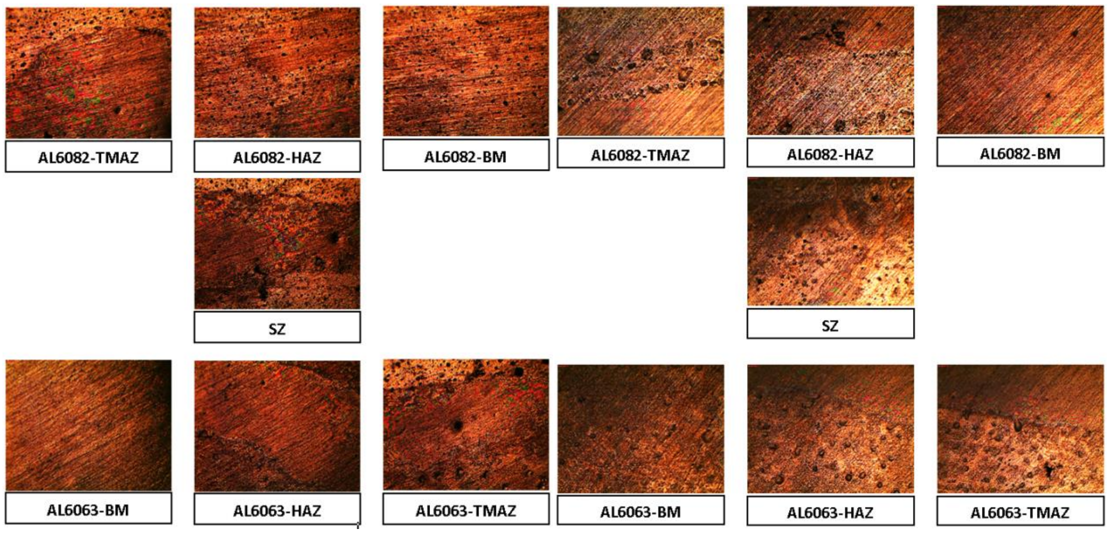
From the results above of hydrostatic test for AL6063 to AL6082 welded cases, the best result (No leakage) was when welding conditions were 1300 rpm rotational speed and 1.7 mm/min travelling speed (welding speed) while increasing rotational speed of the tool resulted in defected stirred zone due to high heat generation and as a result coarse grained structure formation.

Microscopic Examination

The microstructure examination images showing the various regions for FSW weld joints of (AL6063 & AL6082) with it cases. Moreover, these regions consist of the base metal (BM), heat affected zone (HAZ), thermal mechanical affected zone (TMAZ), and stir zone (SZ) as shown in figures below.



(a) (b)



(c) (d)

FIGURE5.microstructure test showing the regions of FSW (AL6063 & AL6082) weld joint at (a). 775 rpm, (b). 1000 rpm, (c). 1300 rpm, (d). 1525 rpm.

Over the weld line the physical welding involves of thick mixture the base metal. Actual plastic deformations directly below the tool surface offer fine grained structure and a good weld quality of pipe joints for AL6063 with AL6082 at FSW condition of 1300 rpm rotational speed where a SZ with excellent mixing is achieved shown in Fig. (5-c). Compared to other microstructures oxidized spots and pores are experienced at low speeds as in Figs. (5-a), (5-b). Increasing the tool rotation also caused non homogenous mixing related to the properties of the aluminum alloys in case at high welding temperature shown in Fig. (5-d).

Microhardness Testing

The data of Microhardness distributedaccording to points shown in Fig. (6) on the transverse cross-section of weld joints AL6063 & AL6082 and all of this are summarized in Fig.(7).

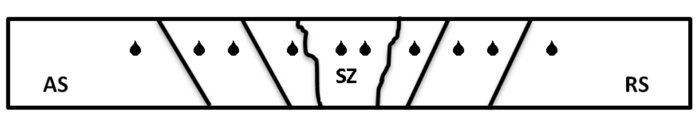


FIGURE 6.data distribution points of Microhardness test for FSW(AL6063 & AL6082) weld joint

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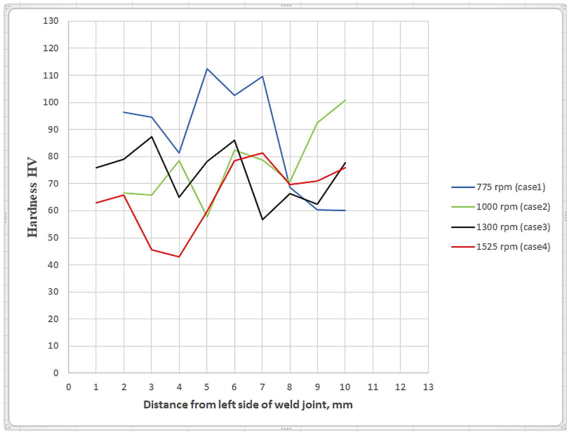


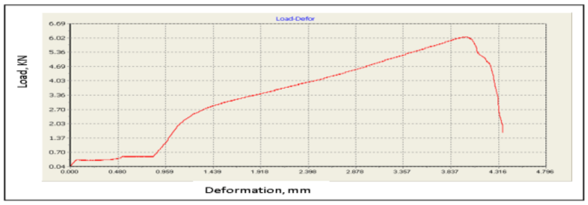
FIGURE 7. Hardness profile across the FSW weld joint of AL6063 & AL6082

From
the figure above the results show that the highest hardness value is at case 1 where the rotational speed was (775 rpm) and at the stir zone of weld and this is related to the refining process of the stirred zone microstructure with the severe plastic deformation of mixed alloys (AL6063 and AL6082).

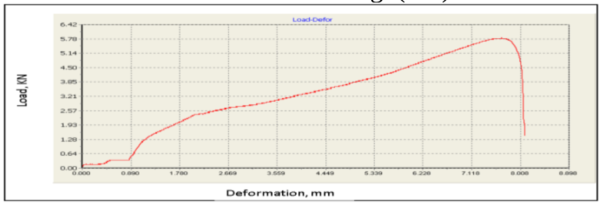
Tensile Test

The Load-Deformation Effect of Tensile Test

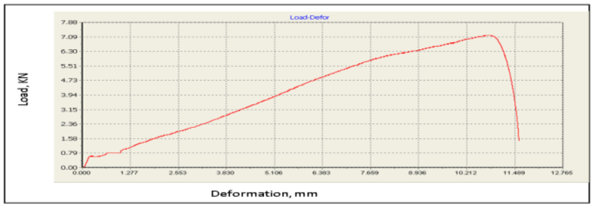
The Load-Deformation curves for weld joints (AL6063 & AL6082) are shown in figures below.FSW joints made at welding conditions of rotational speeds of 775, 100, 1300 and 1525 rpm with a travelling welding speed of 1.7 mm/min, were tested for tensile strength measuring of welded zone. Figure (8-a) reveals a fracture tensile load of about 6020N (100Mpa) when joints were produced at 775 rpm and those welded at 1000 rpm showed a tensile fracture load of 5780N (96Mpa) as shown in Fig. (8-b). In Fig. (8-c) where the joint was friction stir welded at 1300rpm, the fracture tensile load obtained was more than 7090N (about 120Mpa) while at 1525 rpm a tensile fracture load of 6450N (107Mpa) was observed as indicated in Fig. (8-d).



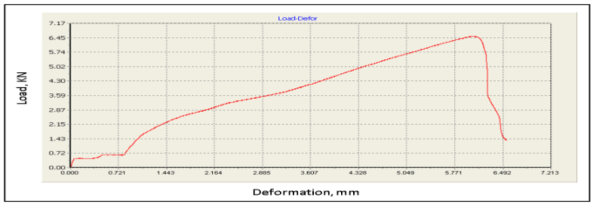
(a)



(b)



(c)



(d)

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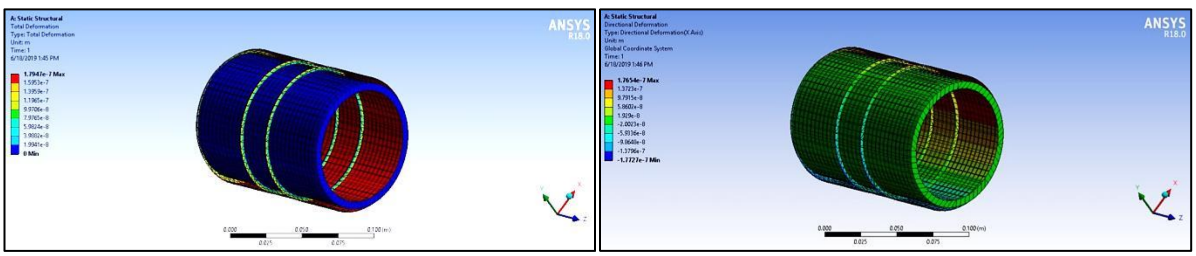
FIGURE 8. Load-Deformation of tensile test curve for FSW weld joints AL6063 & AL6082 at (a). 775 rpm, (b). 1000 rpm, (c). 1300 rpm, (d). 1525 rpm.

From the result of Load-Deformation curves above for FSW joint of AL6063 to AL6082 the best result is when the rotational speed was 1300 rpm where the highest microhardness was achieved due to the fine grained structure of the stirred zone with the formation of intermetallic compounds of MgxSi and AlxMg at FSW temperature, moreover the tensile strength of two aluminum alloys (Al6063 and AL6082) ranges between 130 to 380 Mpa that means accepted efficiency of FSW of those couple of pipe alloys was achieved.

2. The results and discussions of finite element modeling for friction stir welding pipes.

FEMof The Load-Deformation Effect welded pipe joints

The Load-deformation effect of weld joints (AL6063 & AL6082) studied by Finite Element Modeling using ANSYS 18.0 as shown in Figs. (9-a), (9-b).



(a)

(b)

FIGURE 9. (a). Total deformation model for FSW weld joints AL6063 and AL6082, (b) Directional Deformation model for FSW weld joints AL6063 and AL6082

The results above of finite element modeling were done by ANSYS 18.0 software which showed that the pipe joint area capable to stand (35 bar) practical pressure at the process time.

CONCLUSION

The following conclusions can be made by depending on the this studyas follows:

1. From the results of visual inspection for (AL6063 + AL6082) cases it was observed that the flash height starts increases with increasing the rotation speed (775, 1000, 1300 rpm) then come down at the high rotation speed (1525 rpm) but the quality of weld reduces too. So the best case sample of (AL6063 + AL6082) weld joints was in cases 2, case 3where the rotational speed is 1000 rpm and 1300 rpm respectively.
2. From the results above of hydrostatic test for AL6063 + AL6082 cases can be conclude that the good result (No leak) was where the rotational speed is 1300 rpm (case 3).
3. The results of microstructure images show that the stir zone region has a good mixing between the AL6063 and AL6082 alloys was at 1300 rpm (case 3).
4. From the Microhardness test results can be conclude that the highest value of hardness is at case 1, where the rotational speed was (775 rpm).
5. Highest tensile strength load of (7090N) for AL6063 with AL6082 weld joint cases the greatest result is where the rotational speed is 1300 rpm (case 3).
6. From the analysis results of Ansys software version 18, can be conclude that the welding

joint be able to withstand pressure more than 35 bar during the working time.

7. Through all the tests performed and the results that were obtained, can be conclude that the case 3, in which Al 6063 and Al 6082 was weld with rotating speed 1300 rpm and welding speed 1.7 mm/min, is the best case.

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