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Evaluation of Mechanical Properties and Finite Element Modeling in Friction Stir Welding of C12200 Copper Alloy to C36000 High-Leaded Brass Pipe

Ahmed A. Akber [a], Ali A. Khleif [b], Abbas N. Hasein [c]*

[a] University of Technology, Production Engineering and Metallurgy Department-Iraq. akbarthree@yahoo.com

[b] University of Technology, Production Engineering and Metallurgy Department-Iraq. aliuot@yahoo.com

[c] Middle Technical University, Kut Technical Institute, Production Department, Wassit, Iraq. abbas133eng.an@gmail.com

***Corresponding author**

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K E Y W O R D S

Copper alloys, friction welding, finite element modelling, mechanical properties, systems transport fluids.

A B S T R A C T

In systems transporting fluids like petrol, water, or any fluids. Copper and brass pipes are used because of the capability to resist corrosion. The copper alloys can be welded by several methods like arc, resistance, friction welding, and gas methods and they can be readily soldered and brazed. In the present study, mechanical properties and finite element modeling evaluation for friction stir welding of two dissimilar pipes (C12200 copper alloy pipe with C36000 copper alloy pipe). During this study six parameters were used where rotation speed of (775,1000,1300 and1525rpm), welding speed of 1.7 mm/min, axial force of 8.5KN, with a CW direction of rotation, and zero degree of tilt angle, using a threaded cone geometry of the tool. The results showed that the best weld quality was in case when the speed of rotation was 1525 rpm.

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1. Introduction

Copper and copper alloys considered one of the major sets of tradable metals. Furthermore, because of their excellent resistance to corrosion, good strength and fatigue resistance, exceptional thermal and electrical conductivities, and easiness of fabrication they are extensively used. [1]. Moreover, because of the good corrosion resistance of copper alloy they used for pipe. Friction stir welding of pipe joining presented very difficult challenges because of its tubular shape. [2]. FSW a solid state hopeful and developing welding technique for joining similar and dissimilar metals and alloys, in previous studies have been effectively applied to create welds of similar and dissimilar metals with respectable mechanical properties. Though, nearly all studies concentrated on friction stir butt welding of sheets and a few studies of pipes [3]. Roldo, and Vulić [4] have examined the engagement between the morphological constructions and mechanical performance of FSW Al-Mg-Si (Cu) alloy plates in two temper situations; Tensile tests and Microhardness were conducted. Moreover, using optical microscopy and scanning electron microscopy morphology were examined. Samples were exposed to post weld heat treatment to have the greatest properties due to the creation of an important number of hardening atoms which, supplementary to the nugget grain improvement, caused in the rise of the strength of material. Luo et al. [5]. FSW Finite element model was made, depending on the real size parameters. In a sensible welding method parameter range the 2A14-T6 aluminum alloy friction stir welding was simulated, and were calculate the parameters of welding method with good simulation influence. They were determined the work piece calculating point temperature and axial load of the friction stir welding tool. Is it reasonable to make a comparison between the experimental information and the simulated information, showing the precision of the finite element modeling? They were find out that can be done an aerospace application degree after analyzing the weld joint mechanical properties. The test of welding was accomplished on the rocket fuel tank upper cover in this parameter. Zhang, et al. [6]. In this study, they were used the 1060-H24 aluminum ultra-thin sheets friction stir welding butt joints to analysis and compare the effect of the traditional tool and tool without shoulder on microstructure, weld forming, and mechanical properties. Moreover, by determining the axial load, transverse load and weld temperature in friction stir welding method. They were studied the effect of these dissimilar tools on mechanism of material flow and the heat input of the joint. From the results they observed that the weld produced by the tool without shoulder has lesser HAZ, fewer heat input and thinner size. Clearly the stir region hardness is greater than before related to the base metal. 78.6% the tensile strength percentage relative to the base metal. For the tool without shoulder industrial application the welding imperfections have to be overcome. Chung, et al. [7]. They were partly joined by the gas tungsten arc welding process the C70600 alloy plate to other C70600 alloy plate. Moreover, on the C70600 alloy friction stir weld done by two stages. The results of ultimate tensile strength for C70600 joint of friction stir welding was very near to that of gas tungsten arc. Furthermore, by the welding condition the results of bending test for friction stir welding were changed. There were oxides black-arc-arrays in the SZ of friction stir welding microstructures and in the border between the SZ of friction stir welding and weld metal of gas tungsten arc welding there were micro-pores.

2.Experimental Work

I. Materials

In this study C12200 and C36000 copper alloy pipes were used and joined together by the friction stir welding method. The mechanical properties and chemical composition of the pipes are presented in Tables 1 and 2 consecutively. Furthermore, the pipes dimensions were the same for both. Outside diameter for each pipe was (89 mm) with a thickness of (5 mm) as illustrate in Figure 1.

II. Welding Parameters

The six parameters used in this study are rotation speed, speed of welding, axial force, direction of rotation, tilt angle, and geometry of the tool. All the parameters were kept constant except the speed of rotation was changed each case as presented in Table 3.

Table 1: Mechanical properties of C12200 and C36000 pipes

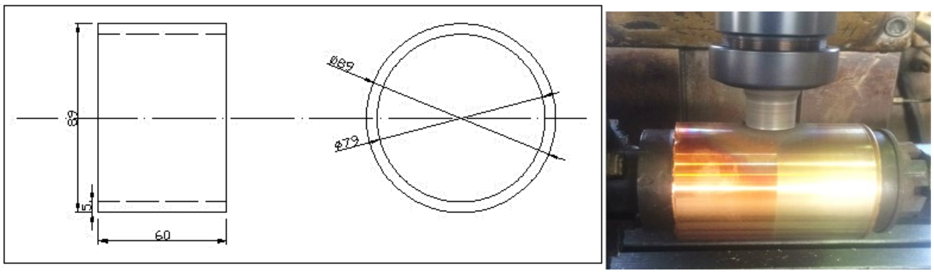
Material	Yield strength				Elongation	Hardnes
	MPa	Ksi	MPa	Ksi	%	s HB
C12200 Cooper alloy	220	32	69	10	45	50
C36000 high-leaded brass	340	49	115	17	53	135

Table 2: Chemical composition of C12200 and C36000 copper alloy pipes

Type of examination	Material	Composition, wt. %							
		Cu	Fe	Sn	Pb	P	Zn	S	Other
Standard examination	C12200	99.90	---	---	---	0.02	---	---	---
Actual examination	C12200	99.89	0.05	0.02	---	0.018	0.002	---	0.02 Al
Standard examination	C36000	60.0 - 63.0	0.35 max	---	2.5 - 3.7	---	Bal.	---	0.5 max
Actual examination	C36000	Rem.	0.196	3.59	12.4	0.0052	11.3	0.160	0.0146

Table 3: The parameters used in FSW method

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

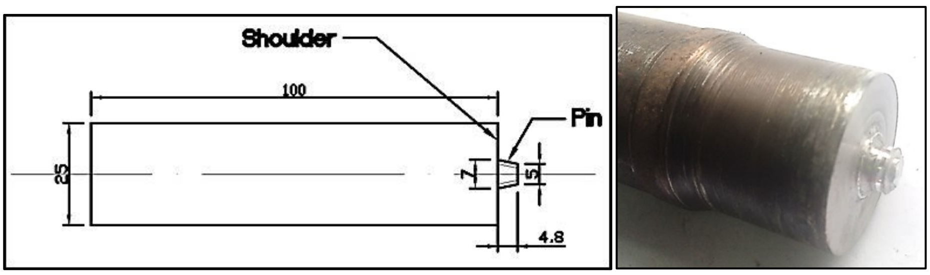


(a) (b)

Figure 1: (a) Dimensions of the pipes used in the Study (all dimensions in mm), and (b) Study samples photographical images

III. Tool geometry and material

Figure 2 shows, the tool geometry, which is involve two portion, shoulder and pin. The shoulder with a rod-shaped that makes a combination of frictional heating and forging pressure, most of the produced heat generate as a result of the tool shoulder, though the pin creates the frictional heating when it descends to contacts the surface of the joined pipe, then softens a small column of metal. Shoulder diameter is 25 mm and it is appropriate to the holder of milling machine. Pin shape is conical with thread, and it has two variants diameter, the root diameter of the pin is (7 mm) and the top diameter of the pin is (5 mm) and the pin length is 4.8 mm. Tool material that used was cold work tool steel A681 (D2) ASTM as illustrate in Figure 2-b. Furthermore, the tool was manufactured in the workshops of the Kut Technical Institute.



(a) (b)

Figure 2: FSW tool (a). Tool geometry (all dimensions in mm), (b) ASTM A681 (D2) Friction stir welding tool

IV. Setup of the machine

Traditional universal milling machine was used as illustrated in the Figure 3 type "HECKERT" made in "German" to perform FSW process because special machine for friction stir welding process is not available in Iraqi laboratories. Moreover, enough vertical pressure this machine can apply, with various speed of spindle start from 28 rpm to 2800 rpm, and suitability of the working table to hold and fix the work piece and it's rigidly through the welding process. With little change to the arrangement by gear train setup of the milling machine an orbital movement of work piece was obtained.

Figure 3: Conventional universal milling machine used in FSW

V. The Procedure of FSW Process

The assembled work piece given in Figure 1-b was installed on the milling machine, between two jigs clamped to the machine bed firmly. The work piece was fixed to the dividing head and the other side caught by the footstock as in Figure 4.

Figure 4: Installation of work piece assembly on the machine

Before starting the welding process, a hole was made in the work piece, specifically on the interface between the two pipes. This hole represents the starting point of the welding tool so as not to consume the tool quickly, because the tool was intended to mix the metals not to make a hole. The selected parameters were set according to the experiment, where the speed of rotation was set (775 rpm, 1000 rpm, 1300 rpm, and 1525 rpm), the traveling speed at 1.7 mm/min, the tilt angle was zero degree, the direction of rotation with the clock wise, the tool geometry with threaded cone, the axial force 8.5 is chosen according to Ph.D. dissertation which was measured the axial force by Load cell unit and since the machine used in its dissertation is similar to the machine used in this study, so it was depending on the same value of axial force. [8] Then the machine was started and the tool of the welding was located above the work pieces in which the tool shall be almost perpendicular to it, after that the process started as the stages (Plunging, first dwelling, Welding, second dwelling, plunging out, and End of welding) and as shown in Figure 5-a, b, c, d, e, and f. The results of friction stir welding process for all four cases shown in the Figure 6.

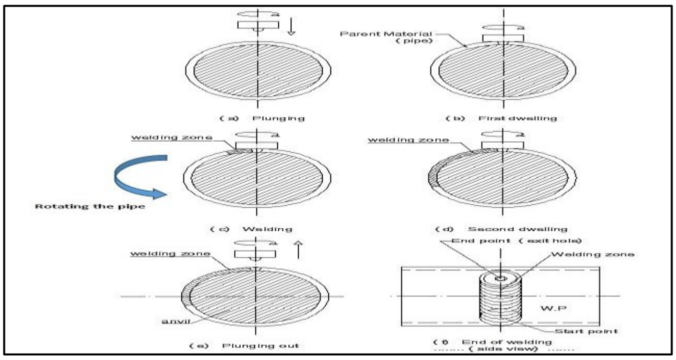


Figure 5: The stages of FSW process

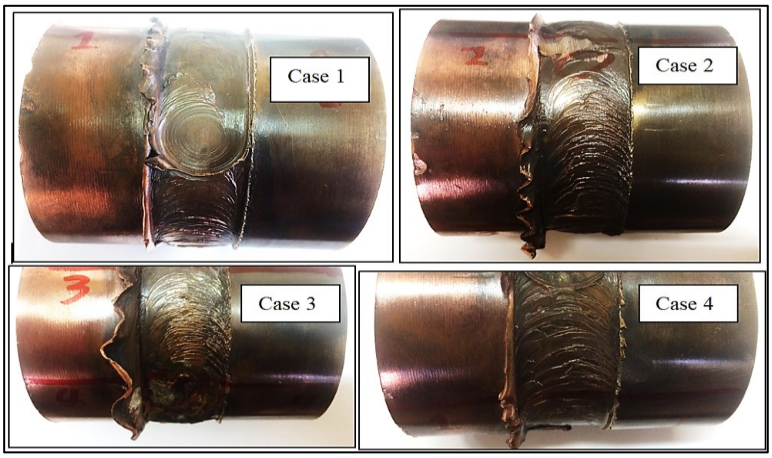
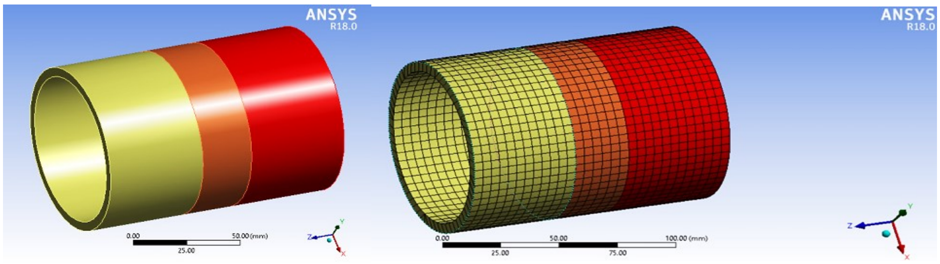


Figure 6: Friction stir welding process results for all four cases

3. Finite Element modelling of friction stir welding Pipes

The analysis of FSW process of C12200 and C36000 copper alloy pipes have been done by Finite Element modeling software called Ansys software version 18.0 to discover the deformation that occurred from the effect of hydrostatic pressure on the weld joint of welding pipes. Building the model via the Design Modeler of Ansys program was the primary step of analysis as illustrate in Figure 7-a. The next step was done of the Mechanical part of Ansys program to complete the analysis part, first by assignment of the pipes material (C12200 and C36000) before that must adding the engineering data (Density, Young's Modulus, Poisson's ratio, …etc.) for the material of the pipes in Engineering Data Sources interface, second meshing the model that was built before as is illustrated in Figure 7-b. The mesh stage is complete with 13454 nodes and 1980 elements. Then make the analysis setting of FSW pipe, the inserting of hydrostatic pressure is done. After that inserting the rest of the boundary conditions of the study (Standard Earth Gravity in Z Component -9806.6 mm/s^2, the applied pressure 35 bar, …etc).



(a) (b)

Figure 7: Modeling and meshing the weld joint (C12200 + C36000) for FSW of pipe. (a). Modeling step, (b). Meshing step

4. Results and Discussions

I. Visual Inspection

The Visual inspection was made according to AWS D17.3 for weld joints (C12200 + C36000) created by FSW. The results are shown in Table 4.

Table 4: Visual inspection results of FSW cases.

Case No.	Weld surface	Notes
(1) at 775 rpm		Average weld with appearing of flash on the boundary of the weld line (4-6 mm height), soft nature from copper side and brittle from brass side.
(2) at 1000 rpm		Average weld with appearing of flash on the boundary of the weld line (3-5 mm height), soft nature from copper side and brittle from brass side.
(3) at 1300 rpm		Average weld with appearing of flash on the boundary of the weld line (2-3 mm height), soft nature from copper side and brittle from brass side.
(4) at 1525 rpm		Good weld with appearing of flash on the boundary of the weld line (0.5-1 mm height), soft nature from copper side and brittle from brass side.

From the results of visual inspection for copper and brass cases it was observed that the flash height starts increasing with increasing the rotation speed (775, 1000, 1300 rpm) then comes down at the high rotation speed (1525 rpm) and the quality of weld increases too. So the best case sample of copper and brass weld joints was in case 4 where the rotational speed was 1525rpm. Since the temperature has not been sufficient to properly plasticize and deform the both materials at low rotational speeds and the hardness difference between brass C36000 high-leaded brass and C12200 copper alloy.

II. Microstructure Examination of Weld Zones

The microstructure examination illustrated the various areas of friction stir welding joint for (C12200 & C36000) cases as illustrate in the Figure 8-a, b, c and d below. Moreover, these areas involve of base metal (BM), heat affected zone (HAZ), thermal mechanical affected zone (TMAZ), stir zone (SZ).

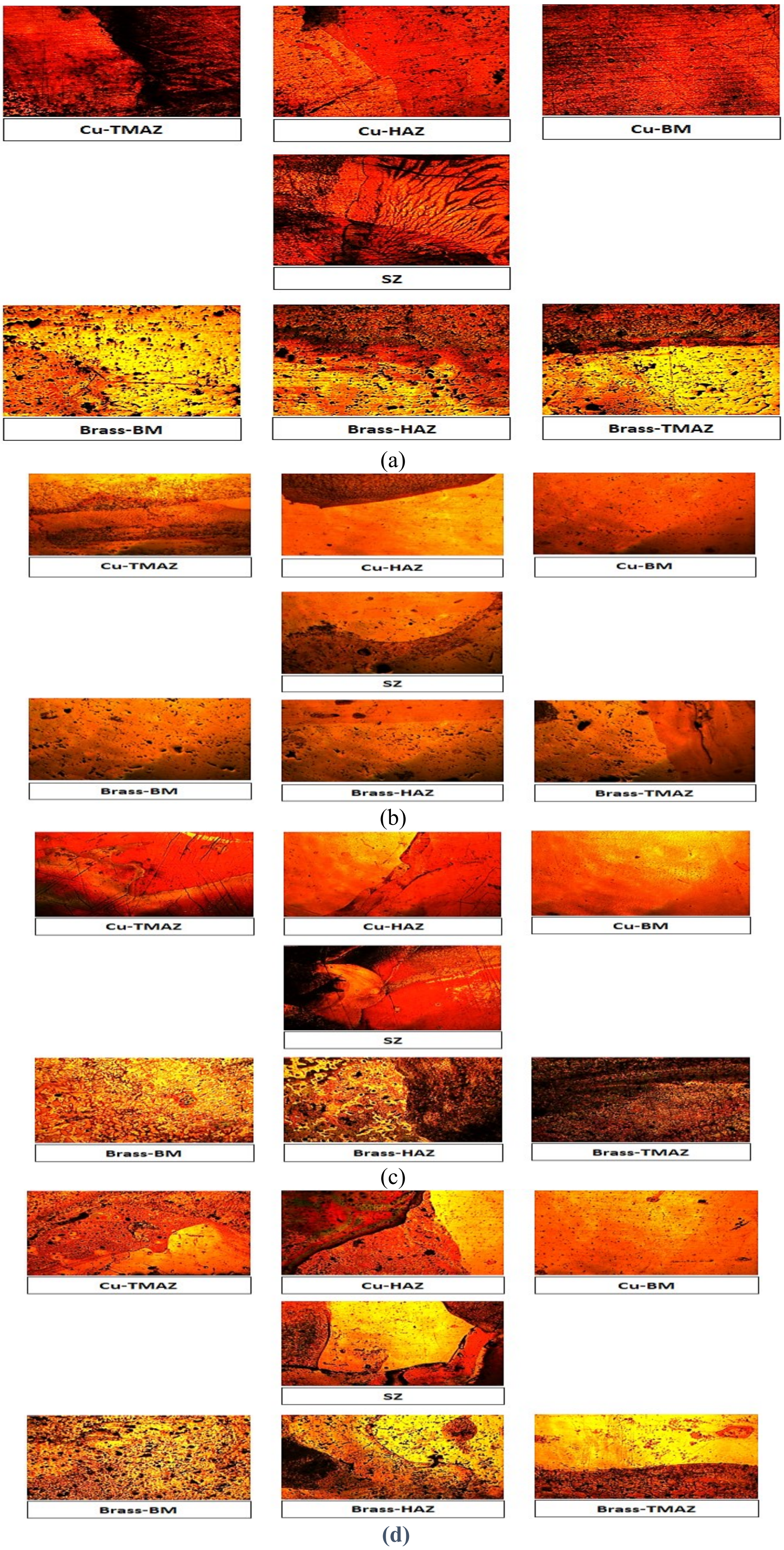


Figure 8: Microstructure test showing the areas of FSW (C12200 & C36000) weld joint at (a). 775 rpm, (b). 1000 rpm, (c). 1300 rpm, (d). 1525 rpm

Figure 8-a, b, c, and d illustrated FSW joints of C12200 copper alloy and C36000 high-leaded brass were examined for microstructure changes at different welding conditions of rotational tool speed. Since both alloys are of high thermal conductivity and during friction stir welding and to balance the heat dissipation extra heat is required which is generated by reducing contact between tool and base alloys by increasing tool rotating thus refining grain size as observed at 1525 rpm in Figure 8-d while in cases of low tool rotating speeds coarse grains were formed due to high heat generated during stirring. The microstructure images results illustrate the stir zone area with a good mixing between the C12200 and C36000 copper alloys at 1525 rpm (case 4), and while other cases showed normal mixing with little imperfections. Figure 9 represents the microstructure of the stirred zone of FSW joint prepared at 1525 rpm where the deformation stream lines (onion lines) are clear and explains the complete mixing of C12200 with C36000 and the of interface between them. It can be seen that the copper alloy is the most severe deforming and stirred with the high-leaded brass. Pores and cavities are seen on the Brass side formed due to work hardening of the brass and the presence of the alloying elements which have low melting points while FSW temperature exceeds their melting point leading to these pores or cavities.

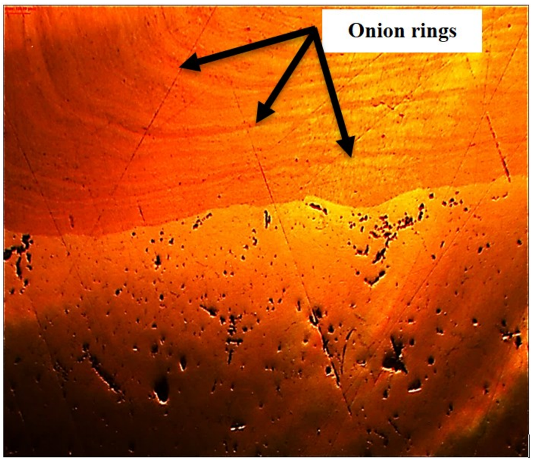


Figure 9: Microstructure examination showing the onion rings of FSW weld joint (C12200 & C36000/ case 4)

III. Microhardness Testing

Microhardness values recorded at the denoted points spaced equally as shown in Figure 10 on the cross-section of C12200 and C36000 weld joints for the various cases were represented by plots shown in Figure 11.

Figure 10: The distribution points of data for microhardness test of friction stir welding

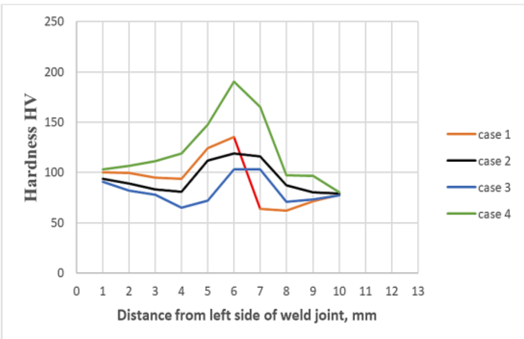


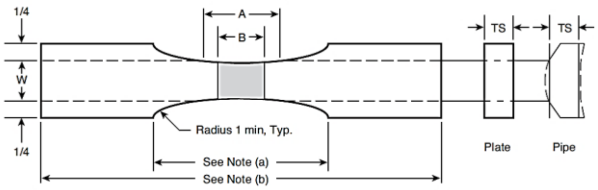
Figure 11: Microhardness values distribution through the FSW of C12200 and C36000 weld joints performed at (1). 775 rpm, (2). 1000 rpm, (3). 1300 rpm, (4). 1525 rpm

From the figure above the results show that the highest hardness value is at case 4, where the rotational speed was (1525 rpm) and on the stir zone of weld. Important rise in hardness is seen in the stir zone as a result of the existence of concentric grains with strongly refined recrystallization and the existence of intermetallic composites of CuxPb, CuxSn and CuxZn which are dispersed in the stirred zone. Figure 11 shows that as rotational speed is increased the micro hardness is increased where higher rotational speed means the tool was in contact with the was metals for a short time resulting in lowering heat input and grain size structure so highest micro hardness was obtained at rotational speed of 1525 rpm.

IV. Tensile Test

The Load-Deformation Effect of Tensile Test

C12200 Copper alloy pipe welded to C36000 high-leaded brass pipe were tested also to determine the tensile strength and according to (AWS B2.1:2000) the tension test specimens are illustrated in Figure 12 all the specimens of the test in this study are sectioned as shown in the Figure 13. This test done in the University of Technology lap of the production and metallurgy department.



in	mm
1/4	6.4
1/2	13
3/4	19
1	25
3	76

Test Weldment			
		Pipe	
		Outside Diameter	
Dimensions	Plate	<3	>3
B	← See Note (c) →		
A	← See Note (d) →		
W	3/4	1/2	3/4
TS	TS[e]	← See Note (e) →	

All Dimensions in Inches

a This section shall be cut by machining or grinding.

b The specimen length shall be as required by the tension testing equipment.

c B shall be equal to the greater dimension of the weld metal in the direction of the specimen's longitudinal axis.

d The length of the reduced section A shall be equal to B plus 1/2 in [13 mm] with a minimum of 2-1/4 in [57 mm]. The ends shall not differ in width from the ends to the center, but the width at either end shall not be more than 0.015 in [0.38 mm] greater than the width at the center. The weld shall be in the center of the reduced section.

e The amount removed shall be the minimum needed to obtain plane parallel surfaces across the width of the reduced section.

Source: Adapted from AWS B2.1:2000, Specification for Welding Procedure and Performance Qualification, Figure II3A.

Figure 12: Tension test specimen standard

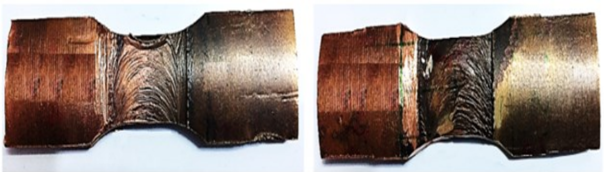
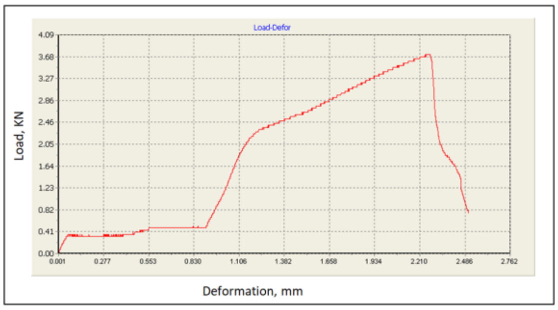
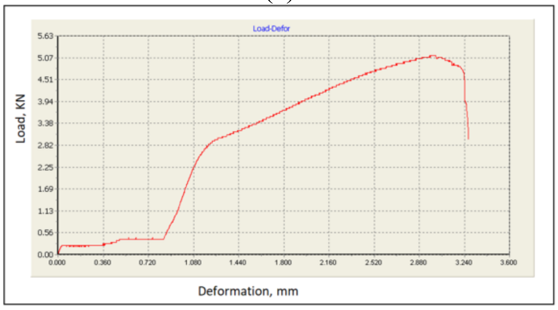


Figure 13: Sectioned of tension test specimens

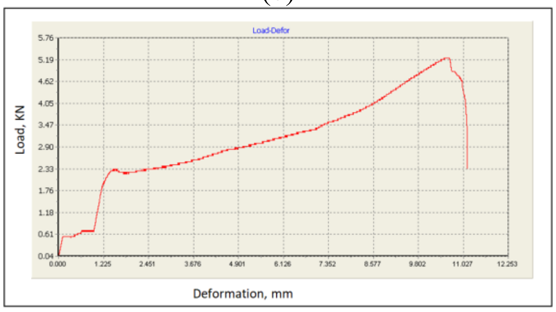
The plots shown in Figure 14 show that increasing rotational tool speed increases tensile joint strength. Lowest tensile strength load value of 3680 N was at 775 rpm and increased by increasing rotational speed to 8920N (148.66Mpa) at 1525rpm. The chemical composition of C36000 in Table 2 outlines high percentages of lead up to 12.4% and zinc up to 11.3% with a 3.6% Sn. These low melting elements are the main causes of obtaining low strength FSW joints compared to both copper and brass pipes. At low rotating tool speed 775 and 1000 rpm the heat generated is too much compared to high speeds (1300 and 1525 rpm) where short duration contact of the tool with the base pipe copper alloys so the presence of these low temperature elements (Pb, Zn and Sn) resulting in weak layers specially of pure lead or its intermetallic compounds of CuxPb and CuxZn. In Table 1 the tensile strength of copper C12200 and C36000 are 220 and 320 MPa respectively and at 1525rpm, the highest value was achieved (148.66Mpa) which may be due to no more low temperature layers were agglomerated compared to low rotating speeds.



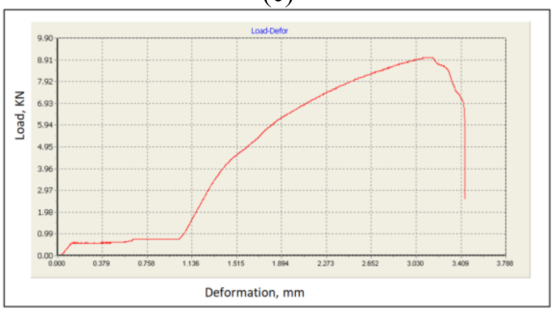
(a)



(b)



(c)

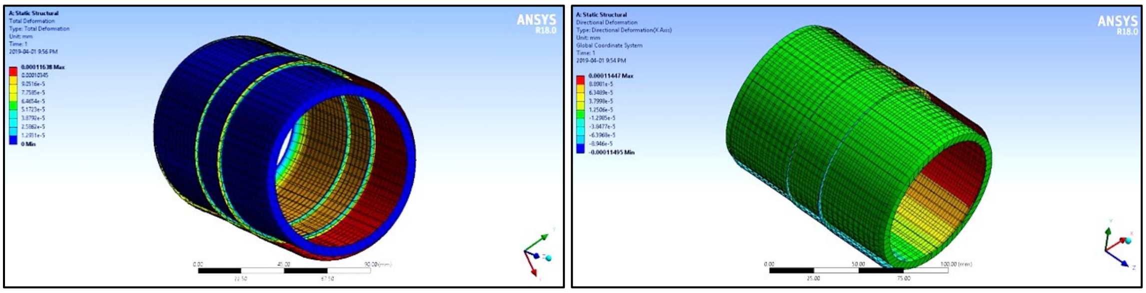


(d)

Figure 14: Load-deformation of tensile test curve for FSW C12200 and C36000 weld joints at (a). 775 rpm, (b). 1000 rpm, (c). 1300 rpm, (d). 1525 rpm.

V. Finite Element Modeling of FSW pipes: The load-deformation effect of FEM

From the results of finite element modeling using Ansys 18.0 software indicated that the weld joint area of C12200 and C36000 pipe can withstand (35 bar) applied pressure at the job time as illustrated in Figure 15.



(a) (b)

Figure 15: (a). Total deformation model for FSW C12200 and C36000 weld joints, (b) Directional deformation model for FSW C12200 and C36000 weld joints

4. Conclusions

From the results of the present study, several conclusions can be drawn:

1. Visual inspection of C12200 and C36000 stir welded joints showed that the flash height starts increasing with increasing the rotation speed (775, 1000, 1300 rpm) then comes down at high rotation speed (1525 rpm) and the quality of weld was improved. So the best property of copper and brass weld joints was in case 4 where the rotational speed is 1525 rpm.
2. The highest hardness value was at achieved at rotational speed of (1525 rpm) in the stir zone of weld.
3. Highest tensile load for C12200 and C36000 weld joint was in case 4 where the rotational speed is 1525 rpm.
4. Finite element modeling based Ansys 18.0 software showed that the weld joint area of C12200 and C36000 pipe can withstand (35 bar) applied pressure at the job time.
5. It was concluded that in case 4, where rotational speed of 1525 rpm to weld C12200 and C36000 was with traveling speed 1.7 mm/min to give the best case.

Acknowledgement

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