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Effect of Friction Stir Processing (FSP) to the Some Properties of Pure Copper Welded by Friction Stir Welding

Abstract- *Friction stir processing (FSP) is an innovative technique of varying the metallic features by intense, local plastic deforming. Accordingly, materials are stirred with no altering the phase via melting or otherwise to produce a microstructure with equiaxed and fine grains. This method enhances the microstructural features of metals. In This study the microstructure and the mechanical features including (tensile strength and microhardness), and radiographic inspection results are studied. All specimens of pure copper use in the (FSW) and (FSP) have variable rotating speed (900, 1200, and 1600 rpm) with constant feed speed (40 mm/min). The most remarkable results, the ultimate tensile strength for FSW and FSP at (1200 RPM and 40 mm/min) with the values of 250.4 MPa for FSW and 261..2 MPa for FSP and the efficiency reached 92.7% and 96.3% for FSP and FSW, respectively. The high hardness in the same sample was 118 HV for FSW and 135 HV for FSP. The microstructure at welding zones, specially nugget zone, is improved by the friction stir processing. Radiographic examination showed incomplete fusion of welding joint without defect.*

Keywords: *friction stir processing, microstructure, efficiency, rotating speed, microhardness, friction stir welding, radiographic test.*

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1.Introduction

Friction stir processing (FSP) is a novel technique for microstructural alterations, and it has been an effective method for refining and homogenizing metal sheet grain structures. FSP exhibits considerable potential in endowing super plasticity to pure copper [1]. FSP is a solid state method, that is, it allows any material to be in the solid-state condition at any instant of the processing. This process requires a rotating cylindrical tool that includes a pin-shoulder assembly whose dimension is proportional to the sheet thickness. The pin in rotary tool is directly charged into the surface of metal sheet, the shoulder face comes into contact directly with the metal sheets surfaces, and then the pin crosses in preferred direction [2].The process and tools of FSP and FSW are comparable, however, in place of producing FSW joint, the FSP purpose is in the neighborhood changing the base material microstructure to acquire necessary features. Materials by FSP are feasibly to be handled selectively at particular settings, with no varying the whole structure features. FSP is possibly employed to tailor the microstructure of materials to be appropriate for many uses, influencing both the material surface and thickness [3]In [4], copper plates FSW with the thickness of 5 mm in the 1/2H state has been investigated. Dual changed investigational experiments have been performed. One of them in the constant traverse speed of 50 mm/min with changed rotating velocities of 400, 600, and 800 rpm while the latter has fixed rotating speed of 800 rpm and diverse traverse velocities of 50, 100, and 200 mm/min. The outcomes exhibited that growing rotating speed as well as lessening the traverse speed causes the augmented heat response, and subsequently rise the grain size of the nugget area.FSW of the copper plates with the thickness of 5 mm under the 1/2H state and fixed welding speediness of 50 mm/min and diverse rotating velocities of 400, 600, and 800 rpm has been conducted in [5]. The defect-free copper welds have been realized under reasonably low heat input circumstances with a satisfactory grained microstructure of 3.5–9 μm produced at a rotating speediness of 400 rpm for a traversed

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

speediness of 50 mm/min. In that study, a relationship amid the mechanical featurs and grain size was detectedas in Hall-Petch relationship. Nevertheless, the testers with coarse-grained copper weren't fit with the Hall-Petch correlation.FSW on the copper plates of 4 mm thickness with the traverse speediness of 61 mm/min and the rotating speediness of 1250 rpm has been performed in [6]. Even if fine grain structure in the nugget zone was obtained unlike base metal, the rigidity of the nugget zone has been a smaller amount than that of the base metal. Hardness spreading in the welded samples were not agree with the Hall-Patch rule, and additionally the factors of 2nd phase and the dislocation density motivated for weld hardness. The goal mouth of this study, is to focus on the studying the consequence of friction stir welding and friction stir processing on the features of pure copper.

2. Experimental work

I. FSW and FSP procedures

FSW and FSP were applied to pure copper plates (2 mm thickness, 200 mm length, and 100 mm width), as shown in Figure 1. The specimens that to be welded is fixed by a clamping fixture on a MITSUBISHI CNC M70V milling machine. Nevertheless, the mechanical properties and chemical compositions of the pure copper used in this work are presented in Tables 1 and 2, respectively.The initial FSW and friction stir processing tool designed was a cylindrical tool, with a shoulder and pin diameter of 16 mm and 4.5 mm respectively. The pin height was 1.9 mm, which equivalent to the plunged distance in the surface of copper plate sheets. Consequently, the length was same as welding depth. The FSW and FSP has been done by stirrer rotation at the surface of copper at different welding and rotational speeds under the effect of constant amount of friction force, as shown in Figure 2.The welding instrument in this research was from tool steel code X38. The tooling pin was in contact with the upper surface of the copper sheet work piece, and the tool was rotated by a digital control part, where welding speed was accurately determined by the manual spindle to develop the looked-for welds to accomplish FSW [7]. At the equivalent traverse and rotation (feed) speed in Table 3, the tool went into the opposite direction till the starting point of welding was reached to generate friction stir processing, as shown in Figure 3. The specimens for testing in FSW and FSP were cut by using a CNC milling machine (CE-TIK milling machine). Figure 4 shows the position of samples from welded plate.

	Ultimate strength(MP	Yield strength(MP	Modulus of elasticity(GP
Measured	270	208	23

Tabel 1:machanical properties of pure copper

Table 2: chemical composition of pure copper

Chemical composition	Content %
Zn%	0.004
Pb%	0.0003
Sn%	0.001
P%	0.005
S%	0.002
Mn%	0.004
Fe%	0.017
Ni%	0.0002
Cr%	0.001
Sb %	0.004
Al%	0.011
Cu	Bal

Welding category	Rotation speed (RPM)
FSW1	900
FSW2	1200
FSW3	1600
FSP1	900
FSP2	1200
FSP3	1600

Table3:FSW and FSP process at adjustable rotation speed at 40 mm/min feed speed

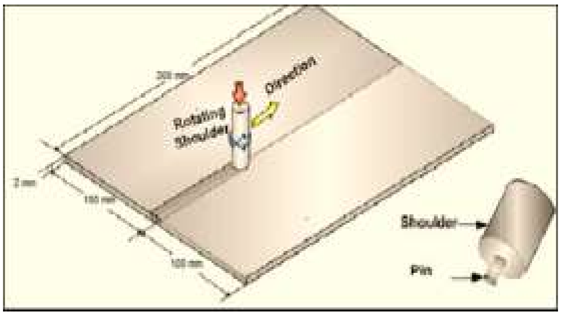


Figure 1: FSW representation for plate

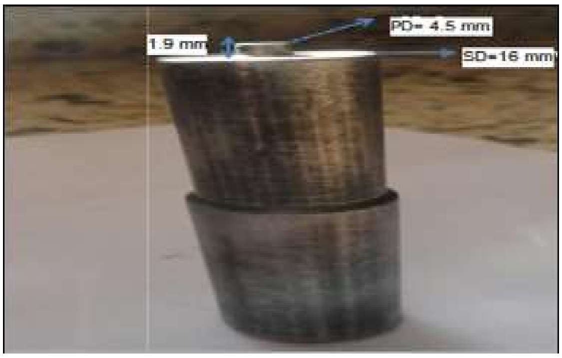


Figure 2: FSW&FSP tool

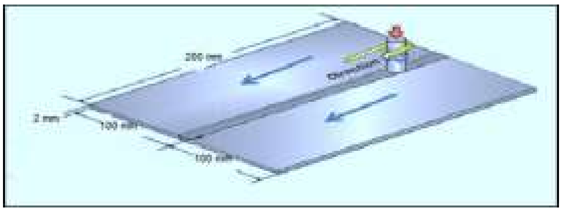


Figure 3: FSP process for pure copper plates

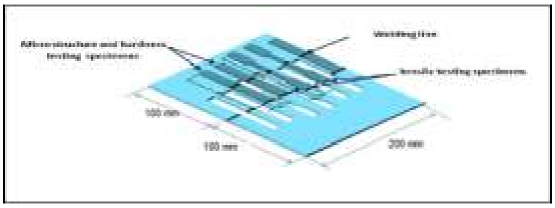


Figure 4:Dividing welded plate into testing specimens[8]

II. Tensile test

This test has performed by a tensile testing device (H300kU from tinius olsen company) in Al-Mustansiryiah University / Faculty of Engineering / Materials Engineering Department at a cross head speed of 10 mm/min. Pure copper test samples have organized based on the ASTM E8M [9] standard. The specimen geometry is shown in Figure 5.

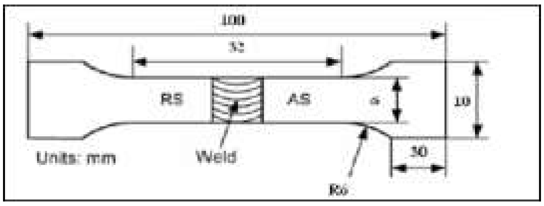


Figure 5: standard tensile sample [9]

III. Microhardness test

Hardness genarallry at microscopic level is a measure of material resistance toward cracking and indentation. In general, microhardness testing can provide useful information about the variation in hardness at varied different surface regions of FSP and FSW plates. Hardness profiles are considerably useful in interpreting the microstructure and mechanical properties of a weld. Each specimen was divided into areas. Every indentation point require 10 s in Vickers hardness (HV), and the reading was documented. This procedure was repeated to other indentation points. The distance between any two indentation points was 1.5 mm. The outlines of hardness were measured lengthwise of the centerline cross-section of the welds at approximately eleven points are distributed as (five points on both sides of the weld and last one in the centerline of the weld) with different rotational and translational welding speeds using microhardness apparatus.

IV. Macrostructure Examination

Metallographic tests at 20× magnification were accomplished by using (OPTIKA microscopes Model B600.POL-I) in University of Technology / Materials Engineering Department. The Macrostructure examination affected the surface analysis of the weld mid area (nugget zone), where the HAZ was present. In addition, the area deformed TMAZ was also included in the examination. The surface was etched in accordance with ASTM E-340 by using a solution of 15 mL, 100 mL HCl and distilled water respectively, with 2.5 mg $FeCl_3$.

V .Radiographic test

It is a nondestructive method of analyzing assemblies and components. This test is established as a result of different absorption due to differences in part thickness, density, or absorption characteristics spcially that produced by composition variation. Consequently, different amounts of penetrating radiation are absorbed by dissimilar portions of a piece. The unabsorbed radiation passing a cross the test piece can be recorded on a photosensitive paper and observed by numerous types of radiation electronic detectors or observed on a florescent screen. Radiography testing refers to a radiographic method that yields an image on paper or film. Nonetheless, this term widely, indicates all systems of radiographic testing .

3. Results and discussion

Experimental results of pure copper welded by FSW and FSP are presented. The highly joint measure of FSP and FSW quality beyond welding have been performed; these methods included (tensile, microhardness, microstructure, and radiographic) tests.

I. FSW and FSP study

The FSW joints are shown in Figure 6. The higher surface of the welding beads of pure copper plates produced by FSP is shown in Figure 7. As shown in Figures 6 and 7, all welding lines showed a worthy look by pictorial examination.

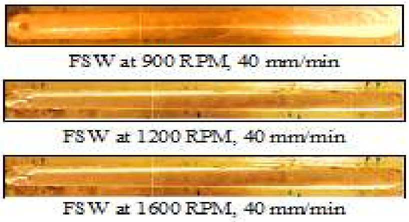


Figure 6: Welding beads of upper surface for pure copper plates produced by FSW

Figure7: The appearance of upper surface of welding beads of pure copper plates produced by FSP

II. Tensile test results

Tensile test consequences of specimens have been presented in figure (8). The optimum value has gotten at 1200 rpm and 40 mm/min of rotating speed and welding speed respectively for both FSP and FSW. The final strength of FSW was 250.4 MPa, and the efficiency of welding line was 92.7% compared with that of base metal. Moreover, the ultimate tensile strength of FSP was 261.2 MPa, and the welding efficiency was 96.3% of the base metal. These results indicate that the ultimate tensile strength of samples was augmented with risen rotating speed to 900rpm and afterward reduced with an additional intensification of rotating speed. FSP is effective in extending weld life. Consequently, FSP modifies the microstructure to increase and enhance the tensile properties of the weld.

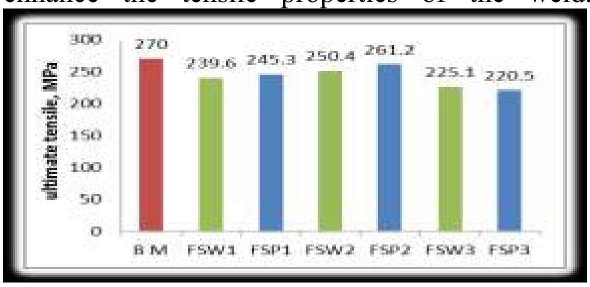


Figure 8: Tensile test results

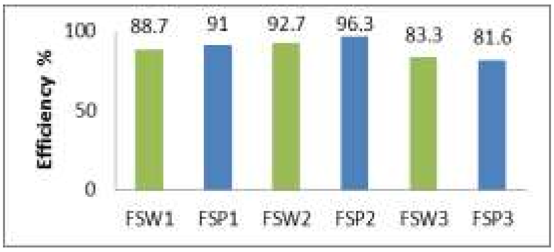


Figure 9: the efficiency for every case in accordance with with base metal

III. Microhardness study

The results of microhardness for FSW and FSP of pure copper are presented in Figures 10 and 11, respectively. Figure 10 shows the hardness of the nugget region is bigger than the base metal, that indicates the hardness does not relate with the grain size in this specific variety of rotating speed. Therefore, these outcomes point to that the hardness distribution in the NZ does not go along with the Hall-Petch relation. This relation can be useable in the case of grains have free dislocation. Consequently, other determinants must influence the microstructure featurs of the nugget region like subboundaries, subgrains, dislocations, and second phases [5, 6,10]. As before, the expansion in rotating speed and deformation degree caused the increased dislocation densities in recrystallized grains. By an extra intensification of the rotating speed, the temperature goes up and the recrystallized grains are annealed, and so the hardness drops down. Additional growth in the rotating rate to 1200 rpm can make the annealing tool more central, and so the hardness can be reduced. The lowermost hardness magnitudes on the proceeding side have been usually less than those lowermost magnitudes on the receding sideways. It is because of an upper temperature on the advancing side that is familiar for the FSW process [2].Fgure 11 displays the augmented hardness for FSP, since it associated with the microstructure filtering and improvement of mechanical features when FSP has been employed.

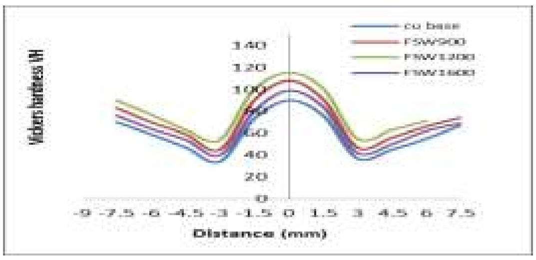


Figure 10: Hardness result of FSW

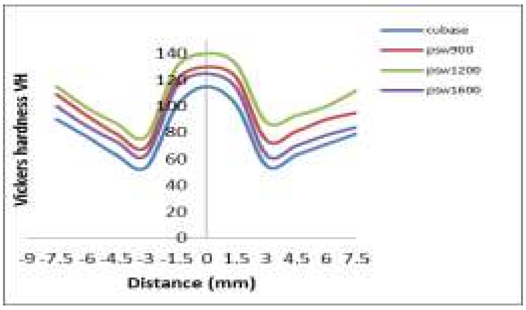


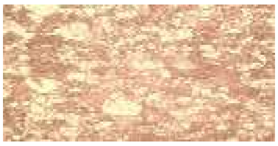
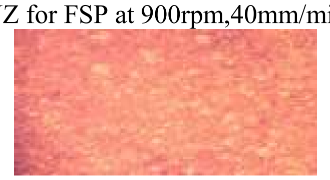
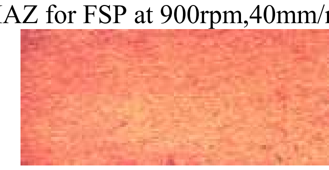
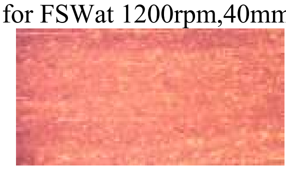
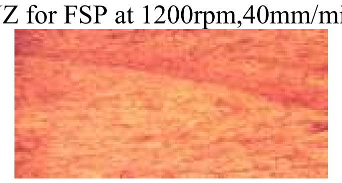
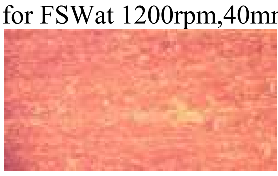
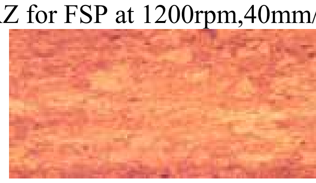
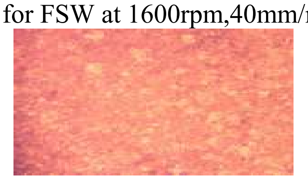
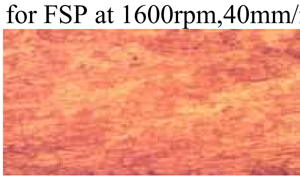
Figure 11: Hardness result of PFS

IV. Microstructure study

The finest results from the tensile investigation of FSW and FSP were tested in the microstructure test. Figure 12 illustrates the microstructure of the welding zones in FSW and FSP processes. According to Figure 12, the microstructures of the nugget (welding) zone and other welding zones in FSP were modified and ultrafine. This refining increased the tensile properties of the weld. The best result is found in 1200 rpm and 40 mm/min of rotating speed and welding speed respectively for both FSP and FSW, the grain size is refine than other. For 1600 rpm and 40 mm/min for both FSW and FSP the increase grain size with increased rotating speed up to 1200 rpm and risen topmost of temperature generates coarser recrystallized grain and lower the tensile strength. The modified microstructure showed no defect or porosity in the welding nugget zone in both cases.

V. Radiographic results

The results of the radiographic inspection are accomplished on all the welds produced at feed rate 40 mm\min and rotation speed of (900, 1200, and 1600 rpm) as shown in figures 13, 14. all samples are examined through visual inspection on the surface of the welds, no defect was found , because that defects are formed when rotational speed is either too low or too high.

Base Metal 	
NZ for FSWat 900rpm,40mm/min 	NZ for FSP at 900rpm,40mm/min 
HAZ for FSWat 900rpm,40mm/min 	HAZ for FSP at 900rpm,40mm/min 
NZ for FSWat 1200rpm,40mm/min 	NZ for FSP at 1200rpm,40mm/min 
HAZ for FSWat 1200rpm,40mm/min 	HAZ for FSP at 1200rpm,40mm/min 
NZ for FSW at 1600rpm,40mm/min 	NZ for FSP at 1600rpm,40mm/min 

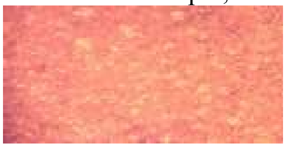
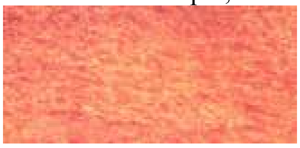
HAZ for FSW at 1600rpm,40mm/min	HAZ for FSP at 1600rpm,40mm/min
	

Figure 12: microstructure of base metal &all samples

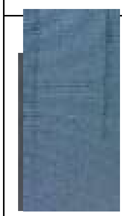
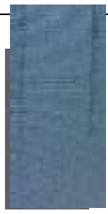
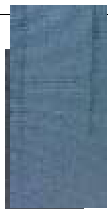
 FSP at 900 Rpm 40mm/mim FSW at 900 Rpm 40mm/mim	 FSP at 1200 Rpm 40mm/mim FSW at 1200 Rpm 40mm/mim	 FSP at 1600 Rpm 40mm/mim FSW at 1600 Rpm 40mm/mim

Figure 13: radiographic inspection result of FSW

Figure 14: radiographic inspection result of FSP

4. Conclusion

1-The ultimate tensile strength of pure copper for FSW and FSP at (1200 RPM and 40 mm/min) with the values of 250.4 MPa for FSW and 261.2.7 MPa for FSP and the percentage of efficiency improvement by using FSP is (4.4 %) from FSW.

2-The hardness values of samples were upper than base metal ($85H_V$) at every limitation and the hardness increase from (102-118 H_V) for FSW and from (111-135 H_V) for FSP.

3- The microstructure of nugget zone is improved by the friction stir processing because the grain size is refined compared with friction stir welding and base metal.

4- Radiographic examination showed incomplete fusion of welding joined without defect.

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