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Authors: Zafer BARLAS, Uğur ÖZSARAÇ

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The Role of Vertical Tool Load on the Joint Properties of Friction Stir Spot Welded Brass Alloy

Zafer BARLAS*[1], Uğur ÖZSARAÇ[2]

Abstract

This study consisted of the effects of vertical tool load on failure value in FSSW of CuZn30. Tensile-shear test, microstructural examination, microhardness, vertical tool load, and temperature measurements were utilized to reveal the influence of FSSW process. According to the results, the tool load plays a key role on the features of joint. Not only low tool load, but also excessive load used leads to drop in the tensile-shear values. The spot weld region was characterized by stir and heat-affected zones and these have various microhardness values ranging from 108.2 HV to 150.2 HV. The temperature measurements show that the peak temperature increased with increasing tool load value.

Keywords: FSSW, brass alloy, vertical tool load, tensile-shear failure load

1. INTRODUCTION

Friction stir spot welding (FSSW), which is a solid-state joining method firstly adapted to joints in hood and rear door in Mazda RX-8 car in 2003. FSSW process eliminates the certain problems such as electrode overheating, electrode sticking to work-piece and short electrode life associated with the conventional resistance spot welding process. FSSW also presents significant advantages such as excellent mechanical properties, low distortion, ease of handling, 40 % saving in equipment costs, 90 % saving in energy and clean working environment comparing to resistance spot welding [1-4]. Although it has had the benefits mentioned above, the experimental studies have been commonly focused on tool rotation speed (TRS), tool geometry, and plunge depth for aluminum and steel materials [3-8]. Jonckheere et al. [5] examined the influence of the tool size, tool rotation speed (TRS), and plunge depth on the properties of friction stir spot welded (FSSWed) Al-6063-T6 alloy. The authors reported that using a larger tool leads to a larger weld region and resulted in a higher lap-shear force. Tozaki et al. [6] studied the influence of pin

* Corresponding Author: barlas@subu.edu.tr
[1] Sakarya University of Applied Sciences, Faculty of Technology
ORCID: https://orcid.org/0000-0001-9063-6501
[2] Sakarya University of Applied Sciences, Faculty of Technology, E-Mail: ozsarac@subu.edu.tr
ORCID: https://orcid.org/0000-0002-4806-1609

length, TRS, and dwell time on static strength in 6061 aluminum alloy. According to researchers, the tensile-shear load increased with increasing TRS, dwell time and pin length. The using of advanced tool materials such as polycrystalline boron nitride, WC-Co for FSSW has paved the way to apply FSSW for steels, especially for DP and TRIP steels commonly used in automotive industry. A minimum nugget size should be obtained by the optimum combination of TRS and plunge speed in FSSW of DP590 dual phase steel sheets, according to the report by Sarkar et al. [7]. Mazzaferro et al. [8] investigated TRS and dwell time on the microstructures and mechanical properties of galvanized TRIP800 steel. They found that the highest lap-shear strength could be produced under the lowest TRS with highest dwell time condition. Lakshminarayanan et al. [9] looked at the effects of TRS, plunge depth and dwell time in FSSW of low carbon automotive steels and according to them, dwell time have a great influence on tensile-shear fracture load. Barlas [10] studied on the weldability of DP600 steel to CuZn30 brass by using different axial load and dwell time of the tool by FSSW. According to the researcher, tensile-strength failure load (TSFL) increased with the increasing of the tool load and dwell time, in addition the tool load has a great role in obtaining a favorable joint. Also Barlas [11] focused on the effect of TRS, dwell time and to be welded sheets position on the quality of FSSWed copper / brass bimetal sheets. The author revealed that the failure load increased with increasing TRS and / or dwell time, as the brass sheet was in upper position during the process. Recently, Garcia-Castillo et al. [12] aimed to understand the role of TRS, axial feed rate in the joints of thin Ti6Al4V sheets by experimental study and finite element modelling. According to authors, TRS and feed rate determined the temperature distribution during the process and using a higher axial feed rate lead to reduce the peak temperature and heat input, whereas the temperature increased with increment the TRS. Obtained temperatures affected the microstructural features such as α-β phase transformation, evolution of microstructural zones and hardness values of the titanium alloy joints. Shen et al. [3] reviewed the advances about FSSW. They pointed out that there is a lack of experimental results about the brass materials joined by FSSW. Therefore, the present study interested in the role of vertical tool load (VTL) on joint properties of CuZn30 brass sheet in FSSW process.

2. EXPERIMENTAL DETAILS

CuZn30 (30.5 Zn and 69.1 Cu) brass with dimensions of 110 (length) × 25 (width) × 1 (thickness) was used in FSSW process in overlap joint form, in this study (chemical composition in wt. % and dimensions in mm). All spot joint trials were done with tool made by EN X40CrMoV5 steel due to its high strength at elevated temperatures consisted of a shoulder diameter of 15 mm with concave shaped with a pin length of 0.6 mm (Fig. 1). Table 1 displays the FSSW conditions. The VTL values were simultaneously collected equipped with two load-cells and data acquisition system fixed bottom the backing plate during the FSSW. The temperatures were simultaneously measured by using K-type thermocouple having a diameter of 1 mm. Measurement from lap joint was done between the upper and lower sheets at mid-width. Tensile-shear tests were performed by a Shimadzu Tester at a cross-head speed of 2.5 $mm\cdot min^{-1}$ and an average value of three specimens presented as the result. The cross-sectional samples for microstructure observation and microhardness measurement were polished and etched by a solution consisted of 100 ml of H_2O, 4 ml of saturated NaCl, 2 g of $Cr_2K_2O_7$, and 5 ml of H_2SO_4. Optical microscope (OM) inspection in weld zones was made by a Nikon Eclipse L150A equipped with an image analysis software and a JEOL JSM 6060LV scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS) apparatus was used to characterize fracture surface of the failed tensile test specimens. Vickers microhardness (HV) test was utilized on etched cross-sectional sample applying a load of 100 g and a dwell time of 10 s by using a 402 MVD Model Wilson Hardness Tester. OM and SEM observations and microhardness test were carried out on the FSSWed joint having the best performance.

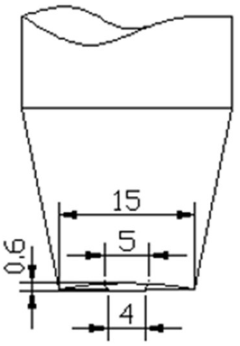


Figure 1 Tool used in FSSW processes (dimensions in mm)

Table 1
The FSSW parameters used in the process

<table>
<tr><th>VTL (kgf)</th><th>tool rotation speed (rpm)</th><th>tool tilt angle (°)</th><th>tool dwell time (s)</th><th>tool rotation direction</th></tr>
<tr><td>520</td><td rowspan="6">1100</td><td rowspan="6">0</td><td rowspan="6">7</td><td rowspan="6">Clockwise</td></tr>
<tr><td>590</td></tr>
<tr><td>660</td></tr>
<tr><td>730</td></tr>
<tr><td>800</td></tr>
<tr><td>870</td></tr>
</table>

3. RESULTS and DISCUSSION

Surfaces of FSSWed trials are presented in Fig. 2. All of them have some weld flash and keyholes. Moreover, the brownish color change because of oxidation around the outer periphery shoulder is pointed out, especially in the joints at VTLs of 730 - 870 kgf. Tool load in the process affects the temperature distribution [10, 11]. Therefore, to attain the temperatures is important during FSSW, since it plays a key role in generation of mechanical properties and material flow [3]. As can be seen in Figure 3, the temperature measurements show that the frictional heat generation between the shoulder and the upper work-piece increased with increasing the VTL. The peak temperature reached to 835 °C at VTL of 870 kgf. Increment in the peak temperature led to produce more weld flash due to increasing the deformation, so this is more distinctive for the trials at 730 - 870 kgf. All obtained values are lower than the melting point (900 - 920 °C) and zinc evaporation temperature (907 °C) of the brass alloy. Consequently, suitable FSSW parameters were carried out in order to make a solid-state welding.

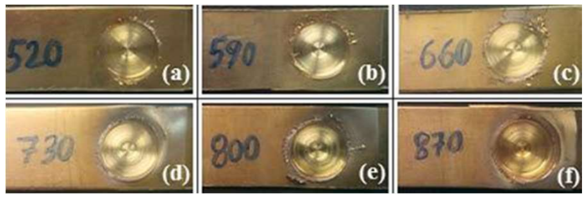


Figure 2 Joint surfaces after the FSSW process (kgf): (a) 520, (b) 590, (c) 660, (d) 730, (e) 800 and (f) 870

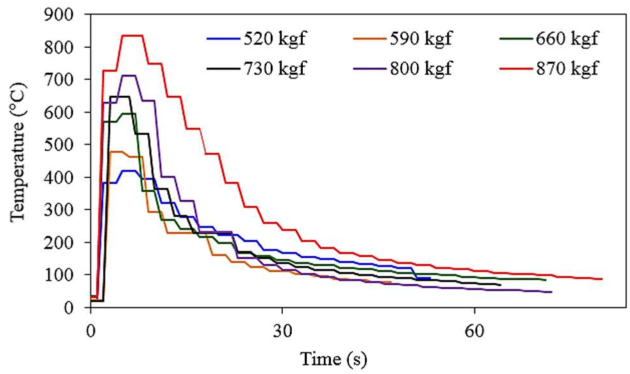


Figure 3 Temperature distributions dependence on VTL values

TSFL and images of the failed samples are given in Figures 4 and 5, respectively. TSFL increased with the increasing the VTL from 520 kgf to 800 kgf and decreased in the highest TL of 870 kgf. The highest TSFL value of approximately 6.5 kN was achieved when VTL of 800 kgf was applied and then it dropped to 4.5 kN which close to that of VTLs of 660 kgf and 730 kgf. In addition, a satisfying metallurgical bonding not occurred between the upper and lower sheets for the trials at 520-660 kgf, as can be obviously seen in Figures 5a-c. Even if just a bit deformation on the surface of the lower sheets clarified with increasing VTL, it did not adequate to bonding in the used conditions. Therefore, it might be said that deformation amount on the lower material is characteristic reagent to an acceptable bonding. On the other hand, a suitable bonding could be produced beginning from 730 to 870 kgf (Fig. 5d). Figure 5 also depicts that the metallurgical bonding mainly happened between bottom and around of the pin and it might probably be developed to the outwards. It is believed that the joints at 730, 800 and 870 kgf confirm this assessment, since they failed away from the pin around. The best joint failed with button pull out mode and a button with diameter of almost 5 mm from the lower sheet remained after completed the tearing by the test machine (Fig. 5e), whereas the sheets at 730 kgf separated with interfacial fracture mode (Fig. 5d). Furthermore, the joint at 870 kgf fractured at the outer periphery shoulder on the upper sheet. It was revealed in the OM observation that the thickness of the upper sheet after used the highest VTL of 870 kgf lower than that of 800 kgf, as obviously seen in the presented measurements in Fig. 6. The upper sheet in the weld region was thinned down to approximately 50 % according to its beginning due to excessive heat input and mechanical deformation. Therefore, the dropping in the TSFL value of the joint at 870 kgf can be attributed to the thinning of upper sheet. From this point of view, it should be noticed that not only insufficient VTL, but also excessive load leads to reducing of the weld performance due to excessive deformation on the upper material. SEM image denoting the presence of elongated dimples (Fig. 7) on the fracture surface for 800 kgf indicates the typical tensile-shear fracture mode. In addition, it is exhibited that there is no remarkably altering in the composition in the bonded zone for the best joint with regard to EDS analysis result.

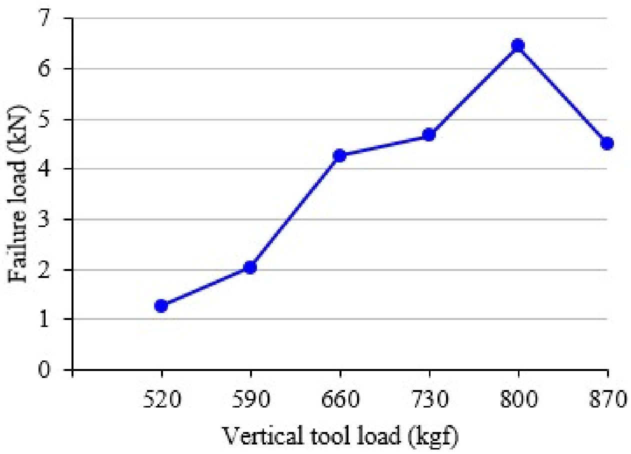


Figure 4 TSFL variation of the test samples according to VTL

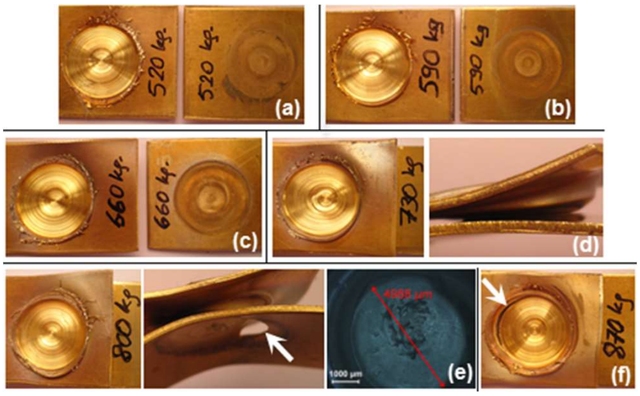


Figure 5 Images of failed FSSW samples (a) 520 kgf, (b) 590 kgf, (c) 660 kgf, (d) 730 kgf, (e) 800 kgf, (f) 870 kgf

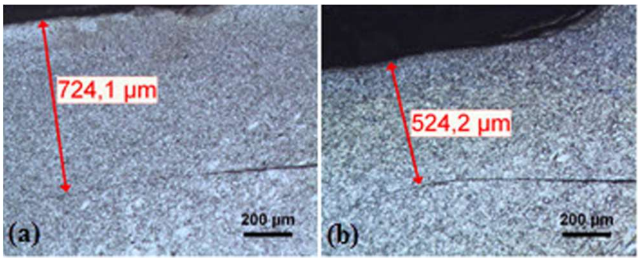
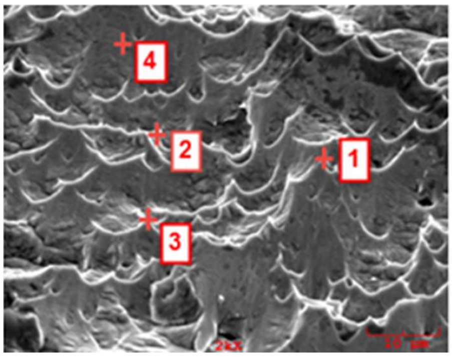


Figure 6 Cross-sectional measurements of the shorter area at the upper sheets (a) 800 kgf and (b) 870 kgf



	Elt.	Line	Intensity (c/s)	Error 2-sig	Conc	Units
1	Cu	Ka	130.79	7.232	71.768	wt.%
	Zn	Ka	42.18	4.107	28.232	wt.%
2	Cu	Ka	132.26	7.271	71.759	wt.%
	Zn	Ka	42.67	4.130	28.241	wt.%
3	Cu	Ka	126.41	7.110	72.588	wt.%
	Zn	Ka	39.15	3.957	27.412	wt.%
4	Cu	Ka	139.40	7.467	71.959	wt.%
	Zn	Ka	44.54	4.221	28.041	wt.%

kV 20.0
Takeoff Angle 35.0°
Elapsed Livetime 10.0

Figure 7 SEM image and EDS analysis results on the fractured surface of the best joints

Figure 8 displays the macro-image of FSSWed joint at 800 kgf. Weld defect such as porosity, crack etc. could not be determined in the weld region and also the cross-section comprised of the shoulder and pin geometry is distinctive. Moreover, the keyhole depth is considerably less than that of common applications, since a very short pin was used in this study. Nevertheless, a keyholeless weld region could be nearly accomplished by the used tool geometry. It is believed that suchlike keyhole formation or keyholeless zone contributes to TSFL value, if a sufficient bonding is produced. As presented in Figure 9, a stir zone (SZ) and the heat-affected zone (HAZ) as well as the base metal (BM) have been developed in the weld region. The grains in the BM contain large deformation twins. The HAZ consisted of increased grains with less twins in comparison with that of the BM. However, a thermo-mechanically affected zone which characterized with elongated and / or rotated grains was not clearly stated in the FSSW process, alike in the result of previous study [10]. The reached temperatures in this joint are enough to recrystallization. Hence, recrystallized fine brass grains formed in the SZ were caused by the combination of intense plastic deformation and raised temperature. Furthermore, the grain size from the top to the bottom within SZ slightly decreased around the pin center, since the bottom side of weld region exposed to a shorter cycle. It was also recognized that the grains within both area where the bottom of periphery of the shoulder is relatively finer than that of the other areas in the SZ. It is considered that the circumference of shoulder with concave shaped brought about a more forging effect rather than heat dissipation for the areas.

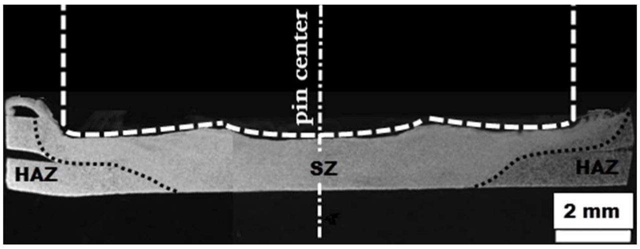


Figure 8 Cross-sectional macro-view of the FSSWed joint at VTL of 800 kgf

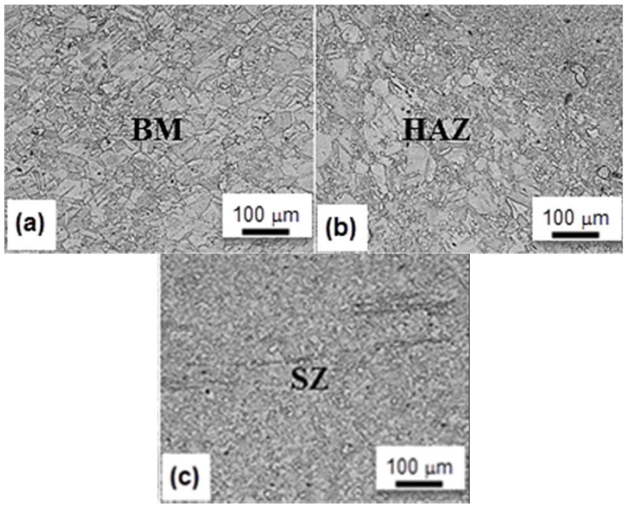


Figure 9 Microstructure zones of the best joint (a) CuZn30 BM, (b) HAZ, and (c) SZ

The hardness values in the weld region were affected by the change in the microstructures. It is understood that the hardness in the weld region was governed by three factors in the FSSW study of CuZn30; softening of annealing effect, grain refinement and deformation twins. On the other hand, it is supposed that there is no influence of zinc content on the hardness, since it is similar to the beginning material condition, taken account of the temperature measurement together with EDS analysis. The CuZn30 BM and the SZ have average hardness of 144.5 HV ± 4.6 and 114.2 HV ± 6.1, respectively, in addition an inhomogeneous distribution was seen in the hardness values in the SZ, viz., the SZ softened according to BM even though decreasing in its grains, since the dominant mechanism was the annealing effect. Besides, the hardness increased from the top (108.2 HV) to bottom (116.5 HV) around the centerline of the SZ due to the presence of slightly finer grains at the bottom side. However, the different hardness values from 135.8 to 150.2 HV were measured on the areas where around the bottom of the shoulder peripheries (namely, almost around the weld flashes) due to presence of the finest grains in the weld region. It might be ascribed to a rapid cooling in the area after the squeeze by the shoulder. As for the HAZ, it has between hardness of 121.3 HV and 127.7 HV (average value 124.8 HV ± 2.6), even though its larger grains according to the SZ. It can be said that the hardness in here was affected by together the deformation twins and coarse grains. As well known, dislocation movement is difficult in fine grained and twinned microstructures. Eventually, it has taken into account the overall changing of the hardness values in the weld region, it is believed that the grain refinement in this study has a little bit decisive effect than the others. On the other hand, the fracture zone for this type overlap joint was affected by the combination of the hardness distribution and the thinning of the upper sheet. Briefly, the cross-section of the SZ will be thickened due to a good metallurgical bonding, thus required failure load in order to fracture will increase by properly chosen the FSSW parameters. All in all, the fracture experienced relatively weaker section where between the SZ and HAZ in the present work.

4. CONCLUSIONS

The influences of vertical tool load on the features of FSSWed CuZn30 brass joint were investigated and the following conclusions were drawn: VTL level has important role to provide a metallurgical bonding between the work-pieces, as the other parameters were constant. The peak temperature induced by friction between the tool and sheets increased with increasing the vertical tool load and it reached to 835 °C at the highest VTL of 870 kgf. TSFL also increased with increasing VTL from 520 kgf to 800 kgf and then dropped in the highest VTL of 870 kgf due to the material loss in the upper sheet. A defect-free weld could be done in VTL of 800 kgf and it has the highest TSFL of almost 6.5 kN. The weld region comprised of the stir and the heat-affected zones with the brass base metal. Annealing, grain refining and twinning mechanisms affected the microhardness properties of these zones.

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The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

Z.B: Making of the experimental study plan including determining of the materials, parameters and etc., Literature survey, Conducting of the tests, Data collection, Evaluation of the test results, Writing of the paper.

U.O: Literature survey, Conducting of the tests, Data collection, Evaluation of the test results, Writing of the paper.

The Declaration of Ethics Committee Approval

The authors declare that this document does not require an ethics committee approval or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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