Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 30
ISSUE 2
October
2008

Microstructure and mechanical properties of friction stir butt welded dissimilar Cu/CuZn30 sheets

Z. Barlas, H. Uzun *
Department of Materials Technology, Technology Faculty,
Sakarya University, 54187 Sakarya, Turkey
* Corresponding author: E-mail address: huzun@sakarya.edu.tr

Received 24.06.2008; published in revised form 01.10.2008

Manufacturing and processing

ABSTRACT

Purpose: The aim of the study is to show the feasibility for joining of dissimilar commercial pure copper sheet to brass (CuZn30) sheet by friction stir welding (FSW).

Design/methodology/approach: In this study, dissimilar Cu and CuZn30 sheets was butt joined by FSW. It has been investigated microstructure properties, microhardness, tensile and bending tests, in order to evaluate the joint performance and the weld zone characteristics of dissimilar copper/brass (Cu/CuZn30) joints.

Findings: The tensile strength of dissimilar Cu/CuZn30 joints was found to be about same and 46% lower than that of Cu parent metal (PM) and CuZn30 PM, respectively. The root and the surface bend strengths of the joints were found to be about 47% higher and 31% lower than that of Cu PM and CuZn30 PM, respectively. The average hardness at the top and bottom lines were found to be about 92 $Hv_{0.1}$ and 102 $Hv_{0.1}$, respectively. These hardness values are higher and lower than that of Cu PM and CuZn30 PM, respectively. Different microstructure zones were determined by optical microscopy. It was illustrated that the stirred zone (SZ) exposed to the two main structures: (1) recrystallized grains of CuZn30 and (2) intercalated swirl and vortex-like structure which can be characterized both the recrystallized brass grains and copper layers.

Research limitations/implications: In this study, the limited FSW parameters were employed. Further studies are needed to evaluate the effects of welding parameters of dissimilar Cu/CuZn30 on the joining properties to establish the optimal weld parameters.

Practical implications: FSW is successfully applied to the butt joining of dissimilar Cu and CuZn30 alloy sheets.

Originality/value: This research is one of the preliminary studies on the detailed examinations of the microstructural and mechanical properties of the dissimilar Cu/CuZn joint by FSW.

Keywords: Welding; FSW; Dissimilar Cu/CuZn30 joint; Mechanical properties

1. Introduction

Copper and brass are widely used in industrial applications due to their excellent electrical and thermal conductivities, good strength, and corrosion and fatigue resistances [1]. However, welding of copper is usually difficult by conventional fusion welding techniques because of its high thermal diffusivity, which is 10–100 times higher than that of steels and nickel alloys. Hence, the heat input required for welding is much higher, resulting in quite low welding speeds [2]. Higher thermal conductivity and thermal expansion of copper result in greater weld distortion than in comparable steel welds. Major difficulty in fusion welding of brass is zinc which reduces the weldability of brass depending on proportion to the percent of zinc in the brass.

Zinc has a low boiling temperature, which results in the production of toxic vapours during the welding [1].

Friction stir welding, invented by The Welding Technology Institute in 1991 [3], is one of the most popular welding technique for joining of similar alloys such as aluminium [4-9], magnesium [10, 11], mild steel [12], stainless steel [13], titanium [14], composite [15], copper [16-18], brass [19, 20] and dissimilar materials such as aluminium to stainless steel [21], aluminium to steel [22], aluminium to copper [23], aluminium to magnesium [24], aluminium to silver [25], recently. Although, a preliminary study on the FSW for dissimilar copper to brass has been reported [26], it has been need to detailed examinations of the microstructural characterization and mechanical properties of the dissimilar Cu/CuZn weld.

The aim of the study is to show the feasibility for joining of dissimilar commercial pure copper sheet to brass (CuZn30) sheet by friction stir welding (FSW) technique. It is also evaluated the microstructure and mechanical properties of the dissimilar Cu/CuZn30 welded sheets.

2. Materials and experimental procedures

In this study, commercial pure copper (Cu) and brass (CuZn30) sheets which have 150 mm in length, 100 mm in width and 3 mm thickness were friction stir welded (FSWed) in I-type butt joint configuration. The copper and the brass sheets were located on advancing side (A.S.) and retreating side (R.S.), respectively. The butt surfaces of both Cu and CuZn30 sheets were firstly machined using milling machine then cleaned using alcohol before fixing on a stainless steel backing plate. DIN 1.3344 steel tool with the dimensions as shown in Fig. 1 was performed for FSW of dissimilar Cu/CuZn30. The tool rotational speed with the clockwise and travel speed were 800 rpm and 22 mm/min, respectively. The tool axis was tilted by 3° with respect to Z-axis of milling machine. The stirrer pin was centred at the butt line.

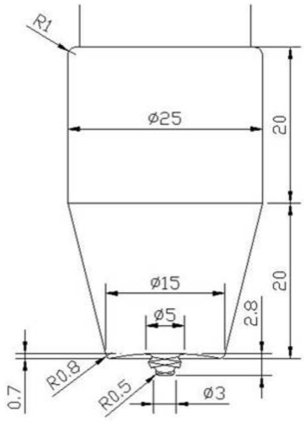

Fig. 1. Schematic views the geometry of tool (dimensions in mm)

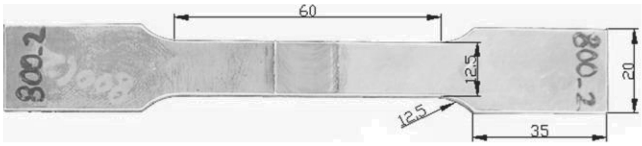

Fig. 2. The image of the tensile test sample (dimensions in mm)

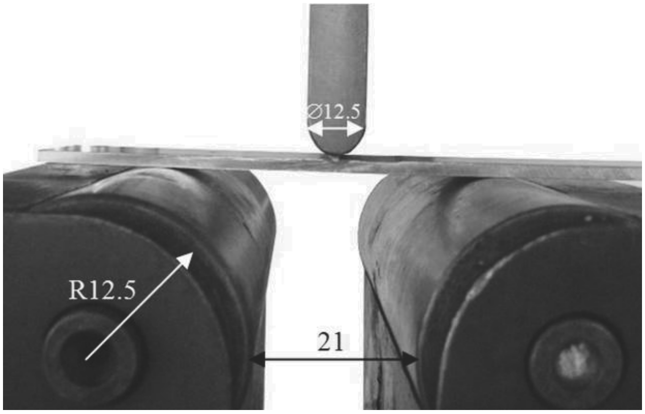

Fig. 3. Representation of the set-up for a three-point bend test (dimensions in mm)

The cross-sectional sample was prepared using standard metallographic procedure in order to determine the macrostructure and microstructure of the welding zone. Both sides of the sample was etched by a solution consisting of 100 ml of water, 4 ml of saturated sodium chloride, 2 g of potassium dichromate, and 5 ml of sulfuric acid. Etched sample was examined using optical microscope and image analyzer program. The transverse tensile and three-point bend tests were applied to evaluate the mechanical properties of the Cu/CuZn30 butt joint. The tensile test specimens and bend test specimens were cut by water jet according to EN 895 and EN 910 specifications, respectively. Fig. 2 shows the tensile test sample with dimensions and Fig. 3 illustrates the bend test configuration. The Vickers microhardness measurements were performed on top and bottom lines of the cross-section perpendicular to the weld direction using a load of 100 g and a dwell time of 10 s.

3. Results and discussion

3.1. Macro view of weld zone

Dissimilar Cu/CuZn30 sheets were successfully welded in the butt joint configuration by FSW. Fig. 4 exhibits the appearance of the upper surface and root side of the joint. Surface quality of the FSWed joint is very good. Defect-free weld was obtained from the visual inspections for the joint under the tool rotational speed of 800 rpm and travel speed of 22 mm/min. welding conditions.

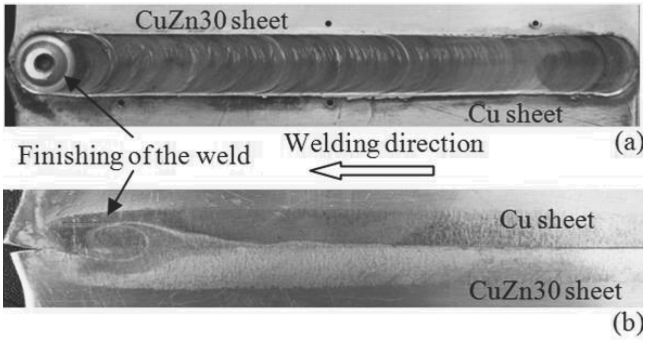

Fig. 4. The images of (a) the upper surface and (b) the root side of dissimilar Cu/CuZn30 joint

3.2. Characteristics of macro and microstructures in the weld zone

Typical macrostructure on a cross-section of the butt welded dissimilar Cu/CuZn30 is shown Fig. 5. It was no observed weld defects such as void, cavity in the macrostructure investigations. As can be seen this Figure, the weld zone is divided by six different microstructures occurred during the FSW, namely: (1) Cu PM, (2) heat affected zone (HAZ) in the copper at A.S. of the weld, (3) stirred zone (SZ), (4) thermomechanically affected zone (TMAZ) in the brass at R.S. of the weld, (5) HAZ in the brass at R.S. of the weld, and (6) CuZn30 PM.

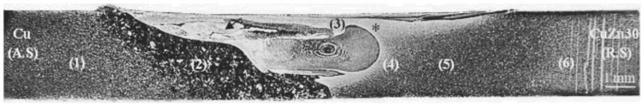

Fig. 5. The image of typical macrostructure of the joint

Fig. 6a shows the transition from the Cu PM to Cu HAZ at the A.S. The grain size of Cu HAZ compared with the Cu PM was significantly increased by the annealing effect of weld heat. No distinct TMAZ, which is characterized by the elongated grains, was seen at the A.S. It is reported [16] the similar result of FSW copper. As can be seen Fig.6c, the grain size of CuZn30 HAZ compared with the CuZn30 PM (Fig.6b) was slightly increased. The difference of the coarse grain sizes of both Cu HAZ and CuZn30 HAZ can be attributed different thermal conductivities of Cu and CuZn30 parent metals and tool rotational direction. In addition, TMAZ adjacent to HAZ and recrystallized CuZn30 grains observed in the brass at the R.S. by the frictional heat and mechanical effect of the tool act (Fig. 6.c).

The SZ was macroscopically exhibited the basin-shaped appearance (indicated by 3 number in Fig. 5). While brass material moved toward to copper material which is located on A.S., the particles with various sizes of the copper material are stirred into the SZ with effect of the stirrer pin act (indicated by arrow in Fig. 5). The stirred zone composed of the mixing of the Cu and CuZn30 materials. It was observed that the SZ contained to the two main structures: (1) recrystallized grains of CuZn30 (indicated by asterisk in Fig. 5) and (2) intercalated swirl and vortex-like structure which can be characterized the recrystallized brass grains and copper layers (Fig. 6d). Fig. 6e shows that magnified view of the recrystallized CuZn30 grains shown by asterisk in Fig. 5. The onion rings, which are consist of copper and brass particles-rich bands are obviously seen in centre of the SZ (Fig. 6f). The spacing of the onion rings tends to decreasing toward to outside.

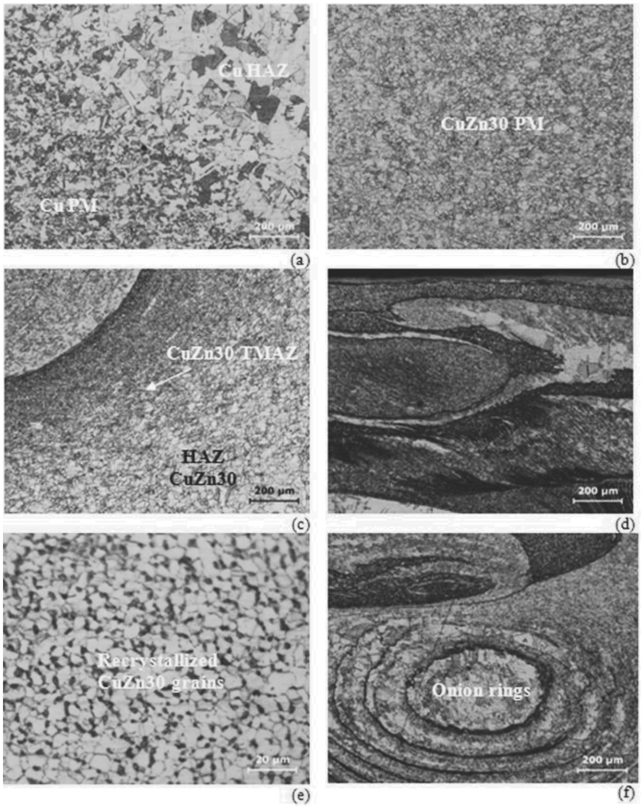

Fig. 6. Optical microstructures of the parent metals and the typical weld zones

3.3. Mechanical properties of the weld

Fig. 7 shows the tensile test results of the as-welded Cu/CuZn30 joint, Cu and CuZn30 parent metals. The average tensile strength, yield strength and percentage of elongation of the dissimilar Cu/CuZn30 joints are 235 MPa, 167 MPa and 22%, respectively. The tensile strength of the joint is the same as Cu PM and 46% lower than that of the CuZn30 PM. The yield strength of the joint is 17% higher and 54% lower than that of the Cu PM and CuZn30 PM, respectively. The FSWed specimens fractured at the copper parent metal region (A.S.) quite far from the weld centre, as shown in Fig. 8.

Fig. 9 shows the three-point bend test results of the as-welded Cu/CuZn30 joint, Cu and CuZn30 parent metals. The root side and upper surface bend strengths of dissimilar Cu/CuZn30 joint are 228 MPa and 234 MPa, respectively. The bend strengths of the joint were found to be about 47% higher and 31% lower than that of Cu PM and CuZn30 PM, respectively. It can be seen the root side and upper surface specimens of the joint have very good bend properties. There are no visible cracks in the cross section of weld region, as shown in Fig. 10.

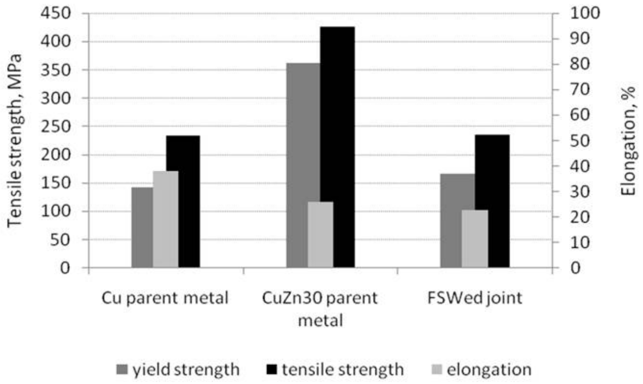

Fig. 7. Transverse tensile properties of dissimilar Cu/CuZn30 joint and parent metals

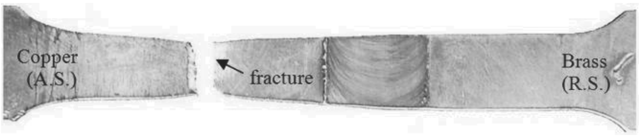

Fig. 8. The image of the fractured tensile specimen of the joint after the tensile testing

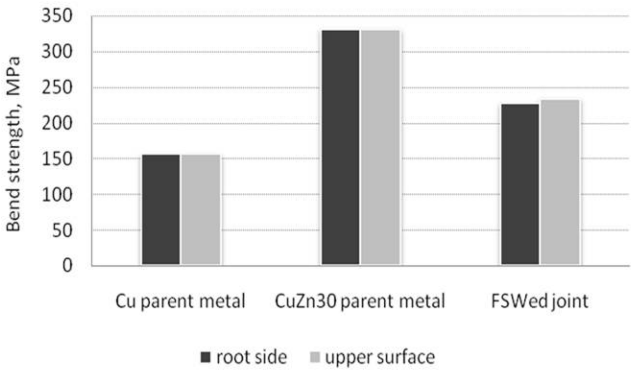

Fig. 9. Bend test results of the joint and parent metals

Fig. 11 shows the hardness profiles along the top and bottom sides of the cross-section perpendicular to the weld direction. The lowest hardness values were found in Cu PM and Cu HAZ at the top and bottom, approximately 63 Hv0.1. Although the highest hardness value was found about 137 Hv0.1 for CuZn30 PM at the top, the average hardness of CuZn30 PM is same, 117 Hv0.1, at the top and bottom.

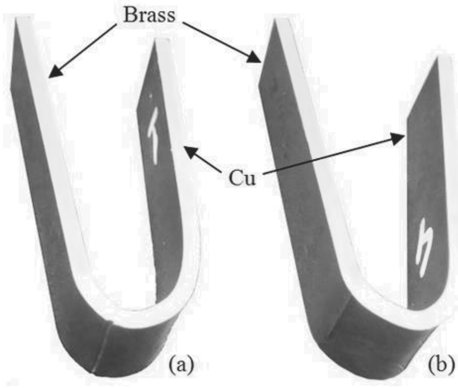

Fig. 10. The images of (a) root bend and (b) upper surface bend samples of the joint after the bend testing

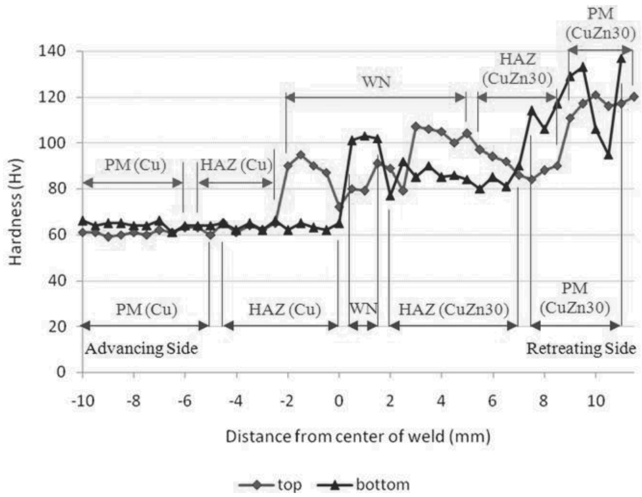

Fig. 11. Hardness profiles along the top and bottom in cross-section of the FSWed joint

The hardness distribution region at the top of SZ is wider than that of the hardness distribution of the bottom side of SZ. As can be seen in Fig.11, the hardness distribution in the SZ fluctuated at the top side due to the various microstructures and material flow patterns. The hardness values in this zone (SZ) varying between 72-107 Hv0.1. The other hand, the hardness distribution at the bottom side of SZ is not different each other varying between 101-103 Hv0.1 because of consist of the recrystallized CuZn30 grains.

4. Conclusions

Friction stir welding method was successfully applied to the butt joining of dissimilar Cu and CuZn30 alloy sheets. The microstructure, microhardness, tensile and bend properties of FSWed dissimilar Cu/CuZn30 joints have been studied in the present work. Following conclusions are drawn:

1) The present study has demonstrated that commercial pure copper can be successfully joined to dissimilar CuZn30 alloy by FSW.
2) The microstructure welding zone in the FSWed dissimilar Cu/CuZn30 was divided into six zones: (1) Cu PM, (2) HAZ in the copper at A.S. of the weld, (3) stirred zone (SZ), (4) TMAZ in the brass at R.S. of the weld, (5) HAZ in the brass at R.S. of the weld, and (6) CuZn30 PM.
3) The microhardness distribution in the SZ fluctuated at the top side (72-107 Hv0.1) due to the various microstructures and material flow patterns. The microhardness distribution at the bottom side of SZ is not different each other varying between 101-103 Hv0.1 because of consist of the recrystallized CuZn30 grains.
4) The tensile test results show that the tensile strength of dissimilar Cu/CuZn30 joints was found to be about same and 46% lower than that of the Cu PM and CuZn30 PM, respectively. In addition, the root and the surface bend strengths of the joints were found to be about 47% higher and 31% lower than that of the Cu PM and CuZn30 PM, respectively.

Further studies are needed to evaluate the effects of welding parameters of dissimilar Cu/CuZn30 on the joining properties to establish the optimal weld parameters.

References

[1] ASM Handbook, vol.6-CD, 1872-1876, USA, 1993.
[2] C.G. Andersson, R.E. Andrews, B.G.I. Dance, M.J. Russell, E.J. Olden, R.M. Samderson, A comparison of copper canister fabrication by the electron beam and friction stir processes, Proceedings of the 2nd International Symposium "Friction Stir Welding", Gothenburg, 2000, CD-ROM.
[3] W.M. Thomas, E.D. Nicholas, J.C. Needham, M.G. Murch, P. Templesmith, C.J. Dawes, G.B. Patent Application No. 9125978.8, December 1991.
[4] G. Biallas, G. Braun, C.D. Donne, G. Staniek, W. Kaysser, Mechanical properties and corrosion behaviour of friction stir welded 2024-T4, Proceedings of the 1st International Symposium "Friction Stir Welding", TWI, 1999, CD-ROM.
[5] J. Adamowski, M. Szkodo, Friction Stir Welds (FSW) of aluminium alloy AW6082-T6, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 403-406.
[6] M. Vural, A. Ogur, G. Cam, C. Ozarpa, On the friction stir welding of aluminium alloys EN AW 2024-0 and EN AW 5754-H22, Archives of Materials Science and Engineering 28/1 (2007) 49-54.
[7] P. Cavaliere, F. Panella, Effect of tool position on the fatigue properties of dissimilar 2024-7075 sheets joined by friction stir welding, Journal of Materials Processing Technology 206 (2008) 249-255.
[8] A. Barcellona, G. Buffa, L. Fratini, D. Palmeri, On microstructural phenomena occurring in friction stir welding of aluminium alloys, Journal of Materials Processing Technology 177 (2006) 340-343.
[9] S.T. Amancio-Filho, S. Sheikhi, J.F. dos Santos, C. Bolfarini, Preliminary study on the microstructure and mechanical properties of dissimilar friction stir welds in aircraft aluminium alloys 2024-T351 and 6056-T4, Journal of Materials Processing Technology 206 (2008) 132-142.
[10] J.A. Esparza, W.C. Davis, E.A. Trillo, L.E. Murr, Friction-stir welding of magnesium alloy AZ31B, Journal of Materials Science Letters 21 (2002) 917-920.
[11] B.M. Darras, M.K. Khraisheh, F.K. Abu-Farha, M.A. Omar, Friction stir processing of commercial AZ31 magnesium alloy, Journal of Materials Processing Technology 191 (2007) 77-81.
[12] T.J. Lienert, W.L. Stellwag, B.B. Grimmett, R.W. Warke, Friction Stir Welding Studies on Mild Steel, Welding Journal, Research Supplement 82/1 (2003) 1-9.
[13] A.P. Reynolds, W. Tang, T. Gnaupel-Herold, H. Prask, Structure, properties, and residual stress of 304L stainless steel friction stir welds, Scripta Materialia 48 (2003) 1289-1294.
[14] W.B. Lee, C.Y. Lee, W.S. Chang, Y.M. Yeon, S.B. Jung, Microstructural investigation of friction stir welded pure titanium, Materials Letters 59 (2005) 3315-3318.
[15] H. Uzun, Friction stir welding of SiC particulate reinforced AA2124 aluminium alloy matrix composite, Materials and Design 28 (2007) 1440-1446.
[16] W.B. Lee, S.B. Jung, The joint properties of copper by friction stir welding, Materials Letters 58 (2004) 1041-1046.
[17] G.M. Xie, Z.Y. Maa, L. Geng, Development of a fine-grained microstructure and the properties of a nugget zone in friction stir welded pure copper, Scripta Materialia 57 (2007) 73-76.
[18] T. Sakthivel, J. Mukhopadhyay, Microstructure and mechanical properties of friction stir welded copper, Journal of Materials Science 42 (2007) 8126-8129.
[19] H.S. Park, T. Kimura, T. Murakamic, Y. Naganod, K. Nakata, M. Ushio, Microstructures and mechanical properties of friction stir welds of 60% Cu–40% Zn copper alloy, Materials Science and Engineering A 371 (2004) 160-169.
[20] C. Meran, The joint properties of brass plates by friction stir welding, Materials and Design 27 (2006) 719-726.
[21] H. Uzun, C.D. Donne, A. Argagnotto, T. Ghidini, C. Gambaro, Friction stir welding of dissimilar Al 6013-T4 To X5CrNi18-10 stainless steel, Materials and Design 26 (2005) 41-46.
[22] K. Kimapong, T. Watanabe, Friction Stir Welding of aluminum alloy to steel, Welding Journal 83/10 (2004) 277-282.
[23] J. Ouyang, E. Yarrapareddy, R. Kovacevic, Microstructural evolution in the friction stir welded 6061aluminum alloy (T6-temper condition) to copper, Journal of Materials Processing Technology 172 (2006) 110-122.
[24] A.C. Somasekharan, L.E. Murr, Microstructures in friction-stir welded dissimilar magnesium alloys and magnesium alloys to 6061-T6 aluminum alloy, Materials Characterization 52 (2004) 49-64.
[25] Y. Li, E.A. Trillo, L.E. Murr, Friction-stir welding of aluminum alloy 2024 to silver, Journal of Materials Science Letters 19 (2000) 1047-1051.
[26] L.E. Murr, G. Sharma, F. Contreras, M. Guerra, S.H. Kazi, M. Siddique, R.D. Flores, D.J. Shindo, K.F. Soto, E.A. Trillo, C. Schmidt, J.C. Mcclure, J.G. Kaufman, T.J. Lienert, Joining Dissimilar Aluminum Alloys and Other Metals and Alloys by Friction Stir Welding, Proceedings of the TMS 2001 Annual Meeting "Aluminum Automotive and Joining Symposia" Aluminum 2001, New Orleans, 2001, 197-211.