# PIN DIAMETER EFFECT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF DISSIMILAR FRICTION STIR LAP WELDING ALUMINUM ALLOY 6061-T6 TO DUAL PHASE STEEL

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## Abstract
In this work, the effect of the pin diameter on the microstructure, hardness, and strength of friction stir welded 6061-T6 aluminum alloy to dual phase steel has been investigated. Microhardness measurements, tensile shear tests, optical microscopy, scanning electron microscopy with energy dispersive spectroscope (EDS), and X-ray diffraction were the main techniques used. The results showed that friction stir welding can be used for the joining of dissimilar 6061-T6 aluminum alloy to dual phase steel. We have found that the maximum strength is obtained after welding with the highest pin diameter.

## 1   Introduction
Joining of dissimilar materials is of increasing interest for a wide range of industrial applications. The main reasons for dissimilar joining are due to the combination of good mechanical properties of one material and either low specific weight or good corrosion resistance or good electrical properties of second material [1, 2]. Friction stir welding (FSW) is potentially a practicable joining process for dissimilar materials. Being a relatively new process, research and development efforts are concentrated on the role of the materials, welding parameters, tool design on the microstructure and properties of the welded joint [3]. The most convenient joint configurations for FSW are butt and lap joints. The FSW is a solid state process during which a rotating tool containing a pin and a shoulder is plunged into the joint and so, heat is generated by the friction between the tool and the work pieces as well as the plastic deformation [4, 5].

A number of detailed studies have reported on the joining of an aluminum alloy sheet to a steel sheet by FSW [6-8], and an interesting papers have been published on the characterization of friction stir lap joint between aluminum alloy and steel [9-12]. For example, Movahedi et al. [13] did friction stir lap joint between Al5083 and St-12 mild steel. They found that an intermetallic compound layer with a thickness of less than 2 μm will not degrade joint quality. Similar results were suggested by Lee et al. [14] and they reported that 2 μm IMC layers with the composition of $Fe_3Al$, $Fe_4Al_{13}$ can contribute to the joint strength. Kimapong and Watanabe

[15] did FSW lap joint on A5083 to SS400 mild steel and reported a maximum shear strength of about 77 % of the aluminum base material. They also reported in another study [16] on FSW lap joint that the thickness of IMC layer increases from 7.7 to 58.1 μm with decreasing welding speed, which significantly affects the strength of the joint. Rotational speed of the tool, tool traverse speed, and vertical pressure on the plates during welding are the main process parameters of FSW [4]. The role of tool pin is to shear the material to its backside during translation of the tool, and the inserted rotating pin brings the material at both sides of the joint line to the plastic state, aided by frictional heat input of the shoulder [2]. Shen [17] studied the effect of welding parameters ( travel speeds and penetration depth into lower steel sheet) on interfacial bonding in dissimilar Al5754 to DP600 steel friction stir welds lap joint. The results indicated that intermetallic compound of $Fe_4Al_{13}$ was detected at the Al/Fe interface. The weld strength increases significantly by increasing the penetration depth into the lower steel substrate at all travel speeds. Several authors have studied the effect of pin on mechanical characteristic of a welded joint by FSW process. Costa et al. [18] , Ahmadnia et al. [19], and Kemal [20] analyzed the influence of pin geometry and process parameters on the morphology and strength of friction stir lap welds aluminum alloy. Hejazi et al. [21] used an adjustable tool with different pin lengths to perform the double-sided welds. The best results were obtained for a double-sided joint made by a pin length equal to 65 % of the sheet thickness, which showed an increase of 41 % in the ultimate tensile strength compared with the single-sided joint. Khan et al. [22] presented experimental investigations on the effect of shoulder diameter to pin diameter (D/d) ratio on tensile strength during friction stir welding of 6063-T6 aluminum alloy . They have found that for: a D/d ratio of 2.6 a yields maximum tensile strength was obtained whereas a minimum tensile strength was found at D/d ratio 2.8.

In our previous works [23, 24], we have studied the effect of the rotation speed and speed advance on the microstructure and the mechanical properties of the friction stir welded 6061 aluminum to dual phase Steel. The objective of this present work is to focus on the pin diameter effect on mechanical properties and microstructural characteristics of the friction stir welded 6061 aluminum alloy to dual phase steel.

## 2   Materials and experimental methods
### 3.2. Base materials

The dissimilar materials joined by FSW process are a 6061-T6 aluminum alloy and dual phase steel. 6061-T6 aluminum alloy and dual phase steel sheets with the thicknesses of 3.0 and 0.8 mm, respectively, were used as the base materials. Their chemical compositions are given in **Tables 1** and **2**, respectively.

**Table 1** Chemical composition of 6061-T6 aluminum alloy

| % (Wt.) | Cr | Cu | Fe | Mg | Mn | Si | Ti | V | Zn | Zr | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6061-T6Al | 0.19 | 0.24 | 0.44 | 0.92 | 0.05 | 0.56 | 0.02 | 0.01 | 0.04 | <0.01 | balance |

**Table 2** Chemical composition of dual phase steel

| % (Wt.) | Al | Cr | Cu | Mn | Si | Ti | C | Fe |
|---|---|---|---|---|---|---|---|---|
| Dual Phase steel | 0.02 | 0.19 | 0.01 | 1.96 | 0.21 | 0.02 | 0.16 | balance |

### 3.3. Weld production

The dissimilar materials were joined by FSW process (**Fig. 1**) with a lap joint configuration as shown in (**Figs. 1, 3**). In this process, two lapped plates (Steel and Aluminum alloy) are clamped. A rotating tool is vertically plunged through the upper plate and partially into the lower plate (steel) and traversed along the desired direction joining the two plates. In our case, the rotating pin was gently pushed to the Al-6061-T6 sheet until the pin tip entered (tool offset) - 0.1 mm into the dual phase steel. Then, the tool started to be moved along the joint. The welding tool rotation speed was 1200 rpm and advancing speed was 200 mm/min.
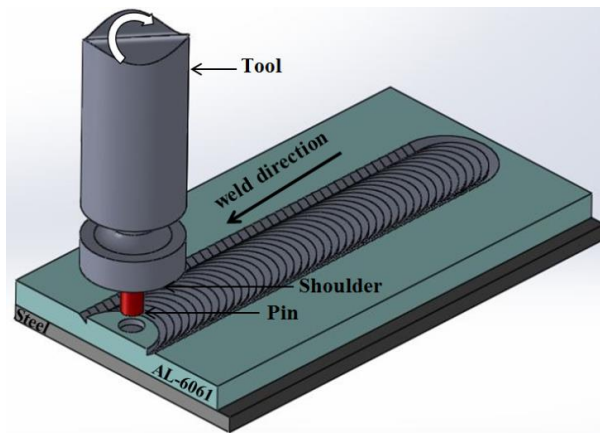


**Fig. 1**  FSW process with a lap joint configuration

The tool utilized for FSW was made of WC-Co (K20). Three welding tools with different pin diameters (5, 6 and 7 mm) were used (**Fig. 2**).
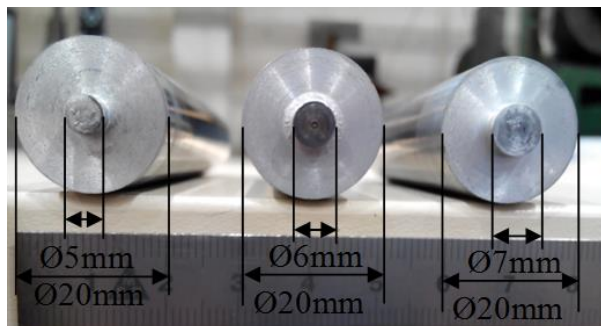


**Fig. 2**  Three welding tools with different pin diameters

The macrograph of welded dissimilar materials, 6061-T6 aluminum alloy and dual phase steel, lap welds is shown in **Fig. 3**.

For microstructural analysis, the cross-sectional samples were prepared using a standard metallographic procedure. The aluminum side was etched by a Killer's solution (HCl: 22.5%, HF: 7.5%, $HNO_3$: 7.5%, $H_2O$: bal.). The microstructure and quantitative chemical analyses of the joints were performed by an optical microscope and scanning electron microscope (SEM, Zeiss Ultra55) equipped with an energy dispersive spectroscope (EDS). The microhardness

measurements were conducted on a Vickers microhardness testing machine (HVS-1000Z) using a load of 500 gf and dwell time of 10 s. The joint strength was evaluated on a tensile testing machine (Zwick 50 kN) using a crosshead speed of 0.5 mm/min at room temperature. The lap-shear specimens with a gauge length of 80 mm and width of 10 mm were prepared. The shear strength properties of each joint were evaluated using three lap-shear specimens cut from the same joint.



**Fig. 3**    Macroscopic view of a completed joint

## 3    Results and discussion
### 3.4. Optical observations

**Fig. 4** shows the optical observation of a joint cross-section of the 6061-T6 aluminum alloy and dual phase steel lap welds. It is clear from this general view of the welded region that all the deformation and transformation occurring during welding process occurs on the aluminum side of the joint, because aluminum is a soft material than the steel. Consequently, the investigation of this aluminum side represents the objective of this investigation. Distinct regions from advancing side to the retreating side in aluminum part can be also observed.
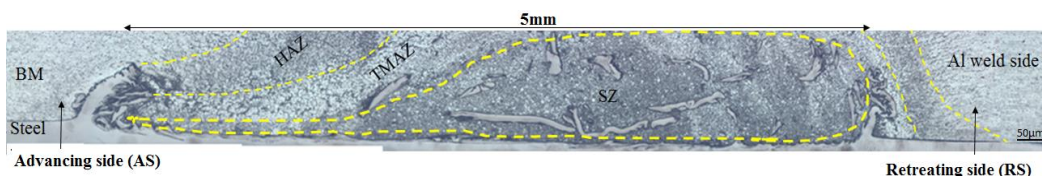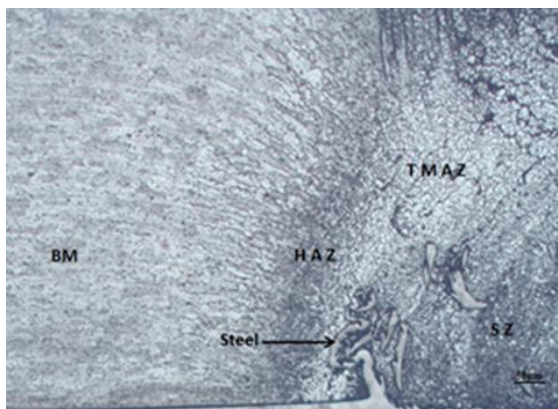


**Fig. 4**    Optical microscopy of different zones in welded join by friction stir welding of aluminium alloy Al6061-T6 to dual phase steel. (Process conditions: rotational speed of 1200 rpm; advancing speed of Vf = 200 mm/min, and tool offset of Pr = -0.1 mm, Ø = 5 mm)

In order to give more details in the welded region, **Fig. 5** shows the magnification of the region near the advancing side. This region exhibits four distinct zones, namely Base Metal (BM), Heat Affected Zone (HAZ), Thermo-Mechanically Affected Zone ( TMAZ), and Stirred Zone (SZ), also called Nugget Zone. The (SZ) has the highest strain and undergoes recrystallization reaction. This reaction is due to the mechanical action of the tool probe that generates a continuous dynamic recrystallization process as it has been indicated [25].The highest temperature and the severe plastic deformation during the welding in the (SZ) result in a new equiaxed fine grain structure. It has been reported that the structure of weld nugget was mainly plastic diffusion combination as found in other weld materials by FSW [26].

In addition, the microstructure analysis indicated, the presence of steel particles in aluminum matrix. However, the TMAZ is characterized by a deformed grains. These grains are elongated through the teeth tips due to the high deformation,which is comparable to the hot-working of metallic material. Concerning the HAZ, it is not different from the microstructure of the base

metal. It is known that the microstructural evolution in HAZ takes place only under the influence of thermal cycle. However, no plastic deformation effect has been observed in this area as it has been confirmed by a previous work [27].



**Fig. 5**    Optical microscopy of different zones in welded joint by friction stir welding of aluminium alloy Al6061-T6 to dual phase steel. (Process conditions: rotational speed of 1200 rpm; advancing speed of 200 mm/min, and tool offset of -0.1 mm)

**Fig. 6** presents the pin diameter effect of welding tool on the optical micrographs evolution of a joint of the 6061-T6 aluminum alloy and dual phase steel lap welds. From these cross- section observed, two main phenomena were observed inside the core of welded joint: mixture of the dissimilar materials and grain refinement. Because the nugget zone (WN) represents a highly dynamic and turbulent zone, the particles of steel disappear by increasing the pin diameter. Consequently, the stir process was produced during friction welding. In addition, refinement grain is also influenced by pin diameter. This refinement is due to the high temperature induced by high pin diameter used in the welding process. The fine recrystallized grains in the stirred zone were attributed to the generation of high deformation and temperature during FSW.
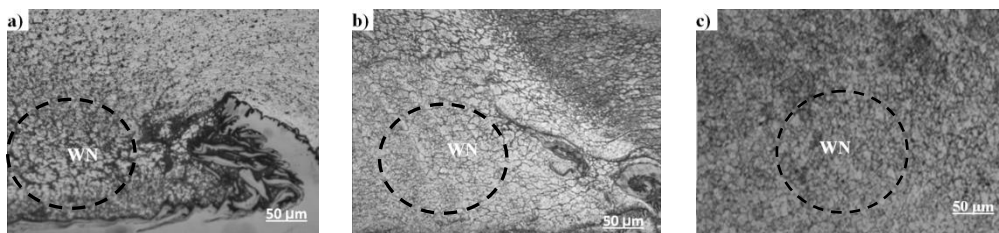


**Fig. 6**    Optical microscopy of different zones in welded joint by friction stir welding of aluminum alloy Al6061-T6 to dual phase steel. Close to the advancing side. (Welding conditions: rotational speed of 1200 rpm; advancing speed of 200 mm/min, and tool offset of: Pr = - 0.1 mm) with following pin diameters, a): Ø = 5, b): Ø = 6 and c): Ø =7 mm.

### 3.5. SEM observation and EDS analysis

In order to examine the weld joint, of the welded dissimilar materials, a scanning electron microscopy (SEM) was used (**Fig. 7**) with the EDS analysis (**Table 3**). From the **Fig. 7**, a

distinct interfacial layer with a different colors from either steel or aluminum can be observed, which indicates a newly formed phase of intermetallic compounds (IMC). The composition of the IMC layer was identified using energy dispersive spectroscope (EDS) technique (**Table 3**). The EDS analysis indicated that there were intermetallic particles in the weld nugget zone. To give more details about this analysis, selected regions were chosen inside the SZ (marked with A, B, C, and D) (**Fig. 7**). **Table 3** presents the chemical composition of each region.

Region A: It shows a presence of Al-rich phase which corresponds to the aluminum alloy without any mixture.

Region B: EDS analysis revealed Al in side Fe-rich phase.

Region C: Mixture of the two dissimilar alloys which corresponds also to the formation of an intermetallic compound. From its chemical composition, it can be deduced that the intermetallic compound was $AlFe_3$

Region D: Formation of an intermetallic thin layer ($Fe_2Al_5$). The two regions C and D correspond to a mixture of 80 % Al with 6.5 % Fe.
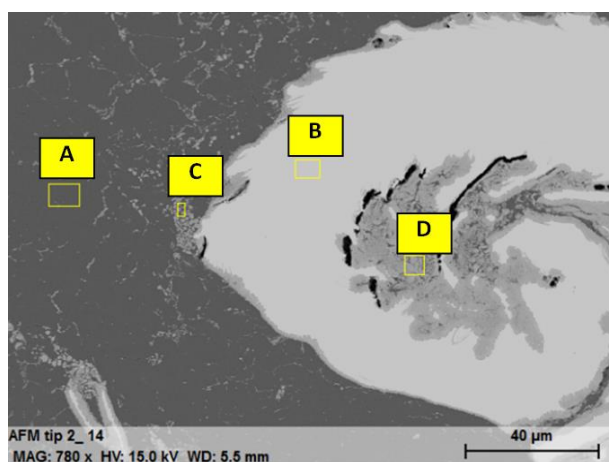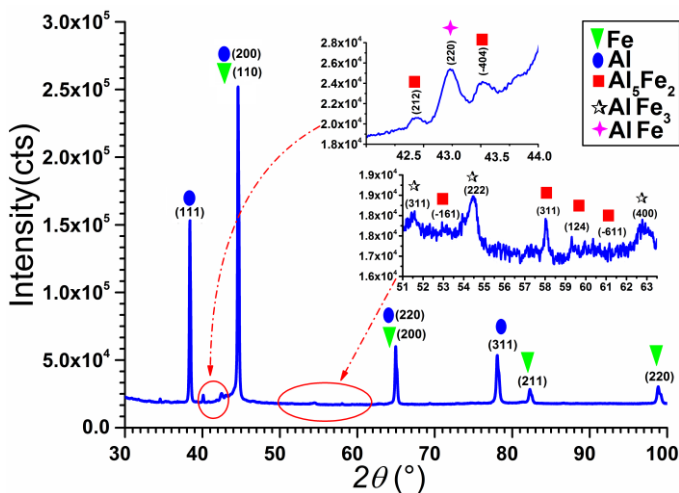


**Fig. 7**    Observation of welded joint by friction stir welding of aluminum alloy Al6061-T6 to dual phase steel. Close to the advancing side. (Welding conditions: rotational speed of 1200 rpm; advancing speed of 200 mm / min, offset of: Pr = - 0.1 m, and $\emptyset$ = 6 mm.

**Table 3** EDS analysis of friction stir welded 6061-T6 aluminum alloy to dual phase steel after welding conditions: rotational speed of 1200 rpm; tool offset of - 0.1 mm, and diameter pin 6 mm.

| Element | Mg | Al | Si | Mn | Fe | Cu |
|---|---|---|---|---|---|---|
| Region A | 1.00 | 98.85 | 0.15 | - | - | - |
| Region B | - | 0.41 | 0.41 | 2.01 | 97.17 | - |
| Region C | 1.39 | 80. 60 | 0.52 | - | 17.49 | - |
| Region D | 3.79 | 85.07 | 4.12 | - | 6.50 | 0.53 |
| Mean value | 2.06 | 66.23 | 1.30 | 2.01 | 40.39 | 0.53 |
| Sigma | 1.51 | 44.56 | 1.89 | 0.00 | 49.48 | 0.00 |

### 3.6.  XRD analysis

**Fig. 8** presents the X-ray diffractogram of the welded joint 6061-T6 aluminum alloy to dual phase steel. As it is shown, peaks of $AlFe_3$, $AlFe$, and $Fe_2Al_5$ phases have been detected which confirm some previous works [28] and also, this IMC is a mixture of two main elements (Fe to Al). These new phases confirm the atomic diffusion during the welding process. This phenomenon has been deeply explained in the work of et al. [29, 30]. They attributed the atomic diffusion to the heat flow during welding process. The presence of some peaks of Al and Fe is due to the diffraction side of the Al plate and steel plate or dual phase steel particles.



**Fig. 8**   XRD diffractogram of aluminum side of welded joint by friction stir welding of aluminum alloy Al6061-T6 to dual phase steel.

### 3.7. Mechanical testing

Concerning the mechanical properties of welded joint, it has been found that the changes in hardness are mainly associated with the grain size variations, dislocation density, and distribution of small particles of intermetallic compounds [31].

**Fig. 9** shows the typical microhardness variations in the direction perpendicular to the weld interface of the dissimilar materials. The results show a distinct change in hardness along the aluminum side. Three microhardness profiles of the FSW joints present a W-shaped profile and the shape of all curves are similar to that observed in other friction stir weld [32], i.e., the lowest hardness inside the core of the welded region, however the highest hardness values are in HAZ and TMAZ.

Concerning the effect of pin diameter on microhardness of welded join, it can be observed that the microhardness in the weld zone is higher for welded dissimilar materials by lowest pin diameter, because the heat input is slow with the low friction. However, the lowest hardness is obtained after welding by the highest pin diameter. In this last case, the high friction induced by highest pin diameter which increases the heat input and consequently causes softening phenomenon in aluminum side. An increase in diameter hardness caused fragmentation of iron in aluminum as shown in **Fig. 10**.
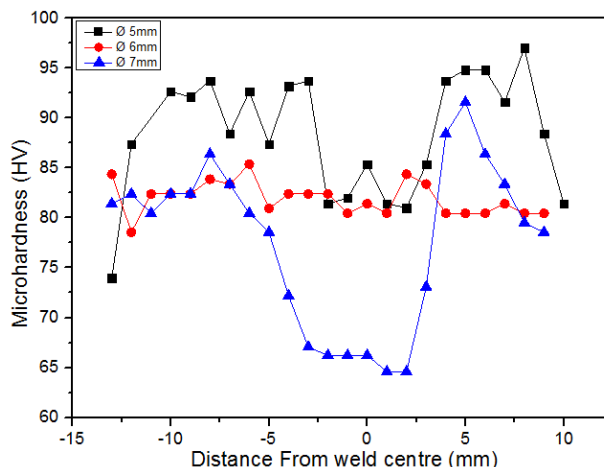
**Fig. 9** Hardness profiles of welded Al6061-T6 to dual phase steel after welding conditions: rotational speed of 1200 rpm; and tool offset of - 0.1 mm) with different pin diameters
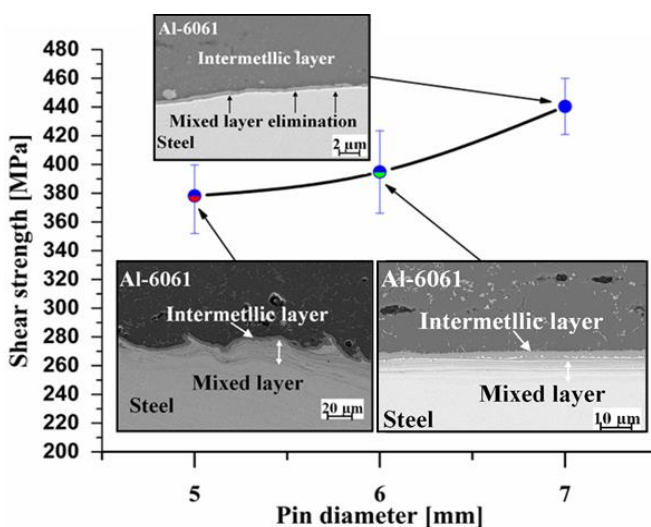


**Fig. 10** Curve of shear strength vs. pin diameter after welding conditions: rotational speed of 1200 rpm; and tool offset of - 0.1 mm of friction stir welded 6061-T6 aluminum alloy to dual phase steel, and the appropriate SEM image of the interface Al/steel obtained with different pin diameters

The effect of pin diameter on shear strength of welded joint is represented in **Fig. 10** . It is clear that the shear tensile strength increases by the increase of the pin diameter. In our case, the maximum shear strength is obtained for pin diameter of 7 mm. This high resistance is due to the mixture of the dissimilar materials and grain refinement in stirred zone. It has been reported that the joint is a result of mechanical deformation and may be characterized by a combination of two hot working processes: forging and extrusion [33]. For the heat treatable aluminum alloy,

the strengthening is mainly due to the presence of precipitates rather than the grain size [34, 35]. The intermetallic layer is continuous and relatively uniform (mixed layer elimination) , which leads to a high tensile strength. This result is supported by the theoretical work of Pretorius et al. [36].

## Conclusions

In summary, the effect of pin diameter on the microstructure, hardness and strength properties of friction stir welded 6061-T6 aluminum alloy to dual phase steel have been investigated. The following conclusions were drawn:

1) Friction Stir Welding (FSW) technique was successfully applied to joining of Al6061 alloy to dual phase steel.

2) Different zones were observed (SZ, TMAZ, and HAZ) in welded dissimilar materials. The main microstructural transformation was observed in stirred zone and thermomécanical affected zone. The weld nugget (SZ) is mainly composed of very fine dynamically recrystallized grains and dual phase steel particles.

3) The maximum shear strength is obtained for high pin diameter. It is due to the fine intermetallic layer formation, which is formed of $AlFe_3$, $AlFe$, and $Fe_2Al_5$ phases.

## References

[1] E. Taban, J. E. Gould, And J. C. Lippold: Materials & Design,Vol. 31, 2010, No 5,P. 2305-2311, DOI: 10.1016/j.matdes.2009.12.010

[2] E. E. Patterson, Y. Hovanski, And D. P. Field: Metallurgical And Materials Transactions A,Vol. 47, 2016, No 6,P. 2815-2829, DOI: 10.1007/s11661-016-3428-4

[3] V. Sinka: Acta Metallurgica Slovaca,Vol. 16, 2010, No 2,P. 116-121,

[4] S. Rajakumar, C. Muralidharan, And V. Balasubramanian: Proceedings Of The Institution Of Mechanical Engineers, Part B: Journal Of Engineering Manufacture,Vol. 224, 2010, No 8, p. 1175-1191, DOI: 10.1243/09544054JEM1802

[5] S. Rajakumar And V. Balasubramanian: Materials & Design,Vol. 40, 2012,P. 17-35, DOI: 10.1016/j.matdes.2012.02.054

[6] E. Taban, J. E. Gould, And J. C. Lippold: Materials Science And Engineering: A,Vol. 527, 2010, No 7,P. 1704-1708, DOI: 10.1016/j.msea.2009.10.059

[7] M. Dehghani, A. Amadeh, And S. A. Mousavi: Materials & Design,Vol. 49, 2013,P. 433-441, DOI: 10.1016/j.matdes.2013.01.013

[8] X. Liu, S. Lan, And J. Ni: Materials & Design,Vol. 59, 2014,P. 50-62, DOI: 10.1016/j.matdes.2014.02.003

[9] M. Haghshenas, A. Abdel-Gwad, A. Omran, B. Gökçe, S. Sahraeinejad, And A. Gerlich: Materials & Design,Vol. 55, 2014,P. 442-449, DOI: 10.1016/j.matdes.2013.10.013

[10] W. Zhang, D. Sun, L. Han, And D. Liu: Materials & Design,Vol. 57, 2014,P. 186-194, DOI: 10.1016/j.matdes.2013.12.045

[11] Y. Wei, J. Li, J. Xiong, F. Huang, F. Zhang, And S. H. Raza: Materials Characterization,Vol. 71, 2012,P. 1-5, DOI: 10.1016/j.matchar.2012.05.013

[12] N. J. Mena, S. Crucifix, Y. Helal, C. Van Der Rest, Z. Boumerzoug, P. J. Jacques, And A. Simar et. al. Friction Melt Bonding of Al6061 to Dual-Phase steel. Modelling and comparison to FSW for lap-joints.Workshop on Dissimilar Welding (Goin, France, 03/07/2015), http://hdl.handle.net/2078.1/161528

[13] M. Movahedi, A. Kokabi, S. S. Reihani, And H. Najafi: Science And Technology Of Welding And Joining, Vol. 17, 2012, No 2, P. 162-167, DOI: 10.1179/1362171811Y.0000000092

[14] C.-Y. Lee, D.-H. Choi, Y.-M. Yeon, And S.-B. Jung: Science And Technology Of Welding & Joining, Vol.14, 2013, No 3, P. 216-220, DOI: 10.1179/136217109X400439

[15] K. Kimapong And T. Watanabe: Materials Transactions, Vol. 46, 2005, No 10, P. 2211-2217, DOI: 10.2320/matertrans.46.2211

[16] Y. Chen, T. Komazaki, Y. Kim, T. Tsumura, And K. Nakata: Materials Chemistry And Physics, Vol. 111, 2008, No 2, P. 375-380, DOI: 10.1016/j.matchemphys.2008.04.038

[17] Z. Shen, Y. Chen, M. Haghshenas, And A. Gerlich: Engineering Science And Technology, An International Journal, Vol. 18, 2015, No 2, P. 270-277, DOI: 10.1016/j.jestch.2014.12.008

[18] M. Costa, D. Verdera, J. Costa, C. Leitao, And D. Rodrigues: Journal Of Materials Processing Technology, Vol. 225, 2015, No 0, P. 385-392, DOI: 10.1016/j.jmatprotec.2015.06.020

[19] M. Ahmadnia, S. Shahraki, And M. A. Kamarposhti: The International Journal Of Advanced Manufacturing Technology, Vol.87, 2016, No 5, P. 2337-2352, DOI: 10.1007/s00170-016-8636-y

[20] M. K. Kulekci, A. Şik, And E. Kaluç: The International Journal Of Advanced Manufacturing Technology, Vol. 36, 2008, No 9-10, P. 877-882, DOI: 10.1007/s00170-006-0901-z

[21] I. Hejazi And S. E. Mirsalehi: Transactions Of Nonferrous Metals Society Of China, Vol. 26, 2016, No 3, P. 676-683, DOI: 10.1016/S1003-6326(16)64158-4

[22] N. Z. Khan, Z. A. Khan, And A. N. Siddiquee: Materials Today: Proceedings, Vol. 2, 2015, No 4, P. 1450-1457, DOI: 10.1016/j.matpr.2015.07.068

[23] Y. Helal And Z. Boumerzoug: Dissimilar Friction Stir Welding Of Al-6061 To Steel. In: Prospects Of Fundamental Sciences Development (Pfsd-2016): Proceedings Of The Xiii International Conference Of Students And Young Scientists, Aip Publishing, Vol. 1772, 2016, p. 030008, DOI: 10.1063/1.4964546

[24] Z. Boumerzoug And Y. Helal: Metals, Vol. 7, 2017, No 2, P. 42, DOI: 10.3390/met7020042

[25] J.-Q. Su, T. Nelson, R. Mishra, And M. Mahoney: Acta Materialia, Vol. 51, 2003, No 3, p. 713-729, DOI: 10.1016/S1359-6454(02)00449-4

[26] K. A. Hassan, A. Norman, D. Price, And P. Prangnell: Acta Materialia, Vol. 51, 2003, No 7, p. 1923-1936, DOI: 10.1016/S1359-6454(02)00598-0

[27] R. S. Mishra, P. S. De, And N. Kumar: Fundamentals Of The Friction Stir Process. In: Friction Stir Welding And Processing, Edited By, Springer, 2014, p. 13-58, DOI: 10.1007/978-3-319-07043-2

[28] K. Ramachandran, N. Murugan, And S. S. Kumar: Materials Science And Engineering: A, Vol. 639, 2015, No 0, p. 219-233, DOI: 10.1016/j.msea.2015.04.089

[29] W. Ratanathavorn: 'Dissimilar Joining Of Aluminium To Ultra-High Strength Steels By Friction Stir Welding', Kth Royal Institute Of Technology, 2017

[30] I. Brodova, O. Chikova, I. Shirinkina, T. Yablonskikh, And V. Astaf'ev: The Physics Of Metals And Metallography, Vol. 114, 2013, No 5, p. 406-410, DOI: 10.1134/s0031918x13050025

[31] J. Esparza, W. Davis, E. Trillo, And L. Murr: Journal Of Materials Science Letters, Vol. 21, 2002, No. 12, p. 917-920, DOI: 10.1023/a:1016061303955

[32] O. S. Salih, H. Ou, W. Sun, And D. Mccartney: Materials & Design,Vol. 86, 2015, p. 61-71, DOI: 10.1016/j.matdes.2015.07.071

[33] V. Sinka: Acta Metallurgica Slovaca,Vol. 20, 2014, No. 3, p. 287-294, DOI: 10.12776/ams.v20i3.312

[34] M. Mahoney, C. Rhodes, J. Flintoff, W. Bingel, And R. Spurling: Metallurgical And Materials Transactions A,Vol. 29, 1998, No. 7, p. 1955-1964, DOI: 10.1007/s11661-998-0021-5

[35] C. Rhodes, M. Mahoney, W. Bingel, R. Spurling, And C. Bampton: Scripta Materialia,Vol. 36, 1997, No. 1, p. 69-75, DOI: 10.1016/S1359-6462(96)00344-2

[36] R. Pretorius, C. C. Theron, A. Vantomme, And J. W. Mayer: Critical Reviews In Solid State And Materials Sciences,Vol. 24, 1999, No 1, p. 1-62, DOI: 10.1080/10408439991329161