TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.6, June 2014, pp. 4854 ~ 4860
DOI: 10.11591/telkomnika.v12i6.5845

Finite Element Analysis for Bobbin Tool Friction Stir Welding

X.M.Liu*[1], J.S.Yao[2], Z.D.Zou[1], Y.Cai[1], H.Meng[1]
[1]Key Laboratory for Liquid-Solid Structural Evolution & Processing of Materials, Ministry of Education, Shandong University, Jinan, 250061, China
[2]Shanghai Aerospace Equipments manufacturer, Shanghai 200045, China
*Corresponding author, e-mail: xuemei_buaa@sdu.edu.cn

Abstract

With DEFORM-3D finite element software, by thermo-mechanical coupling method, the physical modle for bobbin tool friction stir welding was set up. By this model, the temperature field and flow field of AA 2014 aluminium alloy work plate of 6mm was analyzed, which provides useful information for the investigation of this new process. Simulation results show that the temperature field of the cross section presents symmetry approximately about the mid thickness of the work plate. The high temperature zone has large radius at bottom and top surfaces near the shoulders while small radius at the mid thickness, like a waist, which is verified by the experiments. The relativey highest steady temperature keeps about 360℃. Groove defects are easy to be found in the simulation.

Keywords: *DEFORM-3D, bobbin tool friction stir welding, FEM*

1. Introduction

Since friction stir welding (FSW) was invented by The Welding Institute (TWI) in 1990, this technique has been developing fast. Recently, some new types of FSW have emerged, such as friction stir spot welding (FSSW) [1, 2], friction plug welding (FPW) [3-5], and bobbin tool friction stir welding [6, 7]. In this paper, bobbin tool friction stir welding is involved.

There is only one shoulder in conventional FSW technique. To generate a force to react against the welding tool pressure load, it is necessary to have a device of high rigidity and steady back to achieve conventional FSW successfully [6], which restricts its application to weld thin metal plate and complex space curve ,such as circumferential direction welding in tank. Accordingly the bobbin tool is invented by TWI, BOEING and MTS. The bobbin tool has two shoulders and one pin, as illustrated in Figure 1 and Figure 2. By these two shoulders, the large pressure in welding progress could be balanced with its internal self–reacting mechanism, and thus the welding load is taken by the bobbin tool effectively. As well, the steady back could be removed. So, the progress gets more flexible and could be used to more applications, such as circumferential direction welding, which is mentioned above.

Figure 1. Photograph of Bobbin Tool

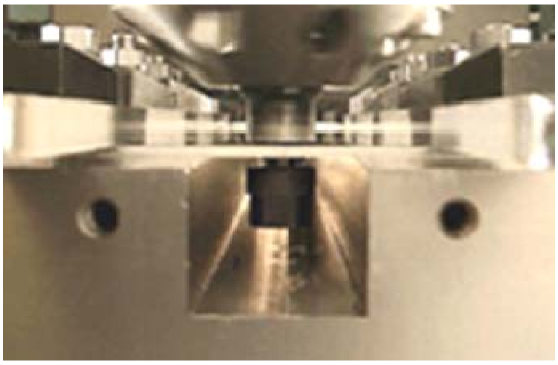


Figure 2. Photograph of Bobbin Tool Friction Stir Welding [7]

Received January 21, 2014; Revised March 19, 2014; Accepted April 1, 2014

In this paper, with DEFORM-3D finite element software, by thermo-mechanical coupling method, the physical model of bobbin tool friction stir welding was set up, and the temperature field and flow field of the welding process was simulated and analyzed. The results could help study the mechanism of the process deeply, set up the basis to broaden its use scope and instruct its application to practice.

2. Thermo-mechanical Process and Analysis

Similar to conventional FSW, the bobbin tool friction stir welding process could be divided into two sequential phases: the preliminary friction preheating phase and the next steady advancing phase. The preheating phase is the essential stage for enough heat to proceed succesfully of the the next advancing period.

At the beginning of the process, due to the violent friction between the work plate and the tool, nearby metal's temperature increase fast, and part work plate metal becomes plastic, then deep plastic. The plastic deformation becomes the main heat source. The process is a typical problem of thermo-mechanical coupling, so the couple calculation is necessary.

According to the researchers'study[8], the heat produced by the action between the shoulder and the work plate Q1 is more than 80% of the total heat production, and the heat produced by the action between the pin and the work plate Q2 is only less than 20%. The bobbin tool friction stir welding could be thought as a modification of adding a shoulder based on conventional FSW. So the friction between the shoulder and the work plate has more effect on the process. Due to different heat input, the welding character in bobbin tool friction stir welding is different from conventional process.

During FSW, tool threads wear quickly lead to a "self –optimized" smooth pin surface [9-12], so the pin was simplified as cylindrical smooth here to avoid possible instabilities. Figure 3 is the geometry model of the bobbin tool. Meanwhile, two wokpieces were simplified to be one single plate. The whole plate is 400mm*150mm*6mm. The welding beginning position is 100mm from the boundary of the wokpiece in Y direction,which is the same as the experiment.

Non-uniform mesh is adopted, and the largest ratio of mesh size is 5, as illustrated in Figure 4. Adaptive remeshing is adopted, after remeshing, the zone of samller elements will be ajusted to proper size.

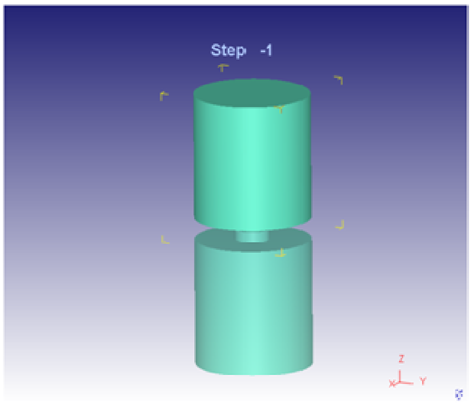


Figure 3. Bobbin Tool Geometry Model

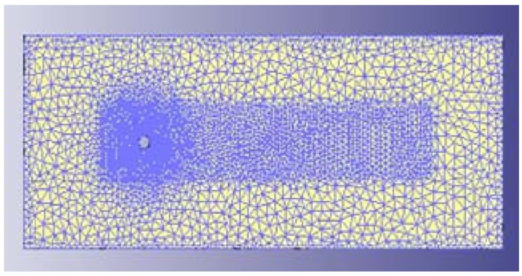


Figure 4. FEM Mesh Generation Layout Plan for Workplate

The bobbin tool is considered to be rigid. The plate is considered to be rigid-viscoplastic. The yield stress of the plate material, which is a function of strain, strain rate, and temperature, can also be treated as flow stress. In this coupled thermo-mechanical problem, the temperature filed analysis is a matter of unsteady heat exchange with inner heat source. The fundamental equation of the heat condition with changeable thermal properties can be expressed as the following 3-D, unsteady equation:

$$\rho c\frac{\partial T}{\partial t}=k\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right)+\dot{q} \quad (1)$$

Where ρ, c and k are density, specific heat, and thermal conductivity of the wokpiece material, respectively, $\dot{q}$ is the internal energy rate.

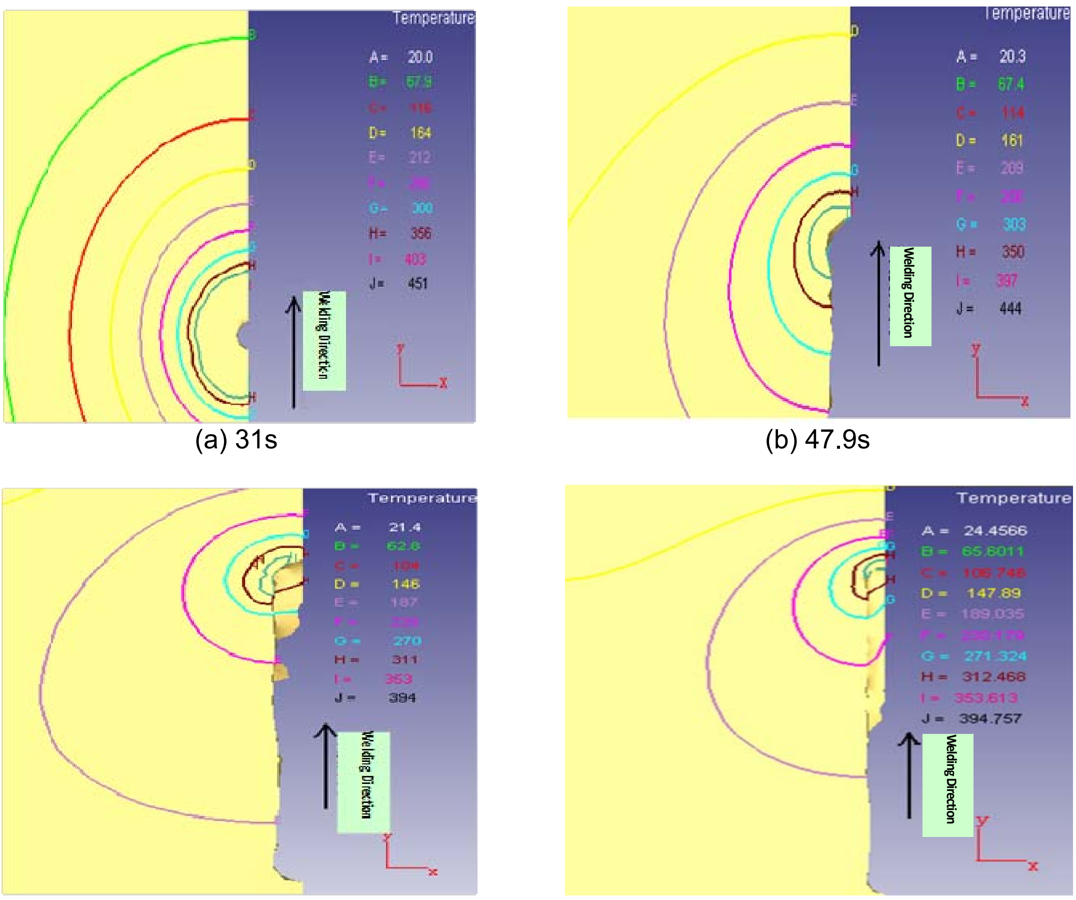
The friction interface between the tool and the wokpiece is the heat generating face. The other faces that contact surroundings are for heat dissipation.

3. Results and Analysis

The temperature field and flow field of workplate are involved in the study.

3.1. The Temperature Field

According to the temperature simulation results, on conditions that the welding pressure is 3500N and the rotating speed is 1000r/min, the preheating phase time is approximately 31s. Figure 5 is the isothermal diagram on half X-Y section (midthickness of the workplate) at different time. It could be concluded that along with moving of the tool, the temperature field around the tool is quasi-steady. The temperature gradient at the front of the welding direction is larger than the back. The reason lies that the back metal has lower cooling speed and higher temperature due to worse thermal conditions.



(a) 31s

(b) 47.9s

(c) 71.2s

(d) 95s

Figure 5. The isothermal Diagram on Half X-Y Section at Different Time (℃)

Figure 6 is the isothermal diagram on cross section vertical to the welding direction at 31s (preheating time) of the work plate. It shows that the temperature near the tool is higher, that is about 450℃. And the zone of higher temperature is wider on the work plate surfaces than the mid thickness. So, the higher temperature zone shows the distribution of narrow at mid thickness and wide at top and bottom surfaces. Different from conventional FSW, the temperature field on X-Z cross section in bobbin tool friction stir welding presents symmetry approximately about the mid thickness of the work plate, like a waist. The reason is that at preheating period, the heat generated by friction between the shoulder and the wokpiece takes great part, compared to the heat by the pin and the work plate. In this study, the two shoulders' diameter are same, as illustrated in Figure 3. At the same rotation velocity and the same pressure, the heat generated by the work plate and each shoulder is the same approximately too.

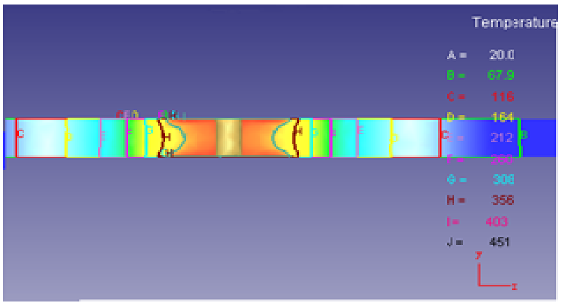


Figure 6. The isothermal Diagram on X-Z Cross Section at 31s

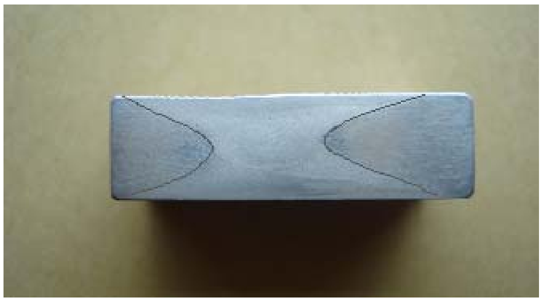


Figure 7. Macro Photo of the Weld Specimen Cross Section (X-Z) after Etching

This can be verified indirectely by the macro photo of the weld specimen cross section (X-Z) after etching, as illustrated in Figure 7. In the photo, two gray line are added to indicate the sketch of a waist in a plane. Its sketch is similar to higher zone distribution in Figure 6. Due to different heat generation, temperature cycle and force, different zone has grain of different size, as well some other propertits. Yet for those zones that undergo similar temperature cycle and force, they could have similar microstructure and similar appearance after etching. This balanced heat input and temperature distribution in bobbin tool friction stir welding can aviod the root defcts effectively.

At the mid thickness of the wokpiece, 15 points' temperature change with time were tracking. The 15 points were distributed as Figure 8. Point A, B, C, D, E are on the welding line, with the internal of 20mm. Point A is the beginning welding point. A1, B1, C1, D1, E1 are on the retreating side with the internal of 20mm. A2, B2, C2, D2, E2 are on the advancing side with the internal of 20mm too. A1, A and A2 have the same Y coordinate, Z coordinate, but different X coordinate, and each internal is 8mm. The same situation is true for B1、B and B2, and so on.

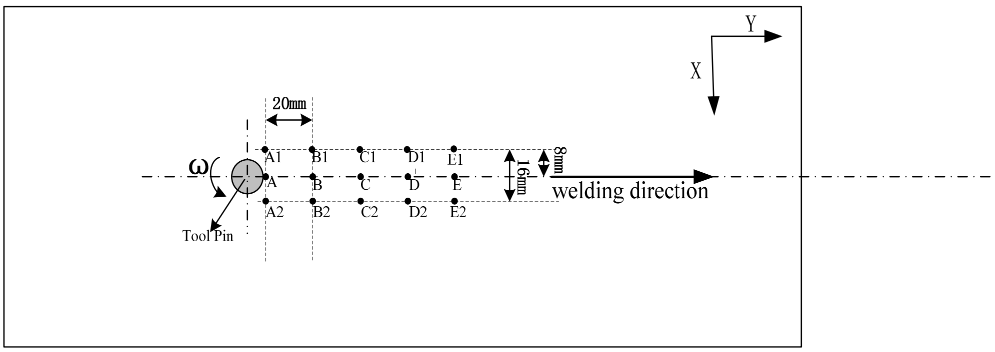


Figure 8. Tracking Points Distribution

Figure 9 is the simulation results of the temperature profile with time of point A, B, C, D, E. The figure shows that the temperature changing trends for each point are the same approximately. And point A is a little special, because it locates at the welding beginning position. While in the unsteady preheating period, the temperature here experiences more instability and fluctuation.

The temperature increases by the curve with several inflexions, but not increases continuously, which is similar to popular friction welding. The existence of inflexion is associated with the change of the friction torque virus time and the flow of vico-plastic material on the friction interface [13].

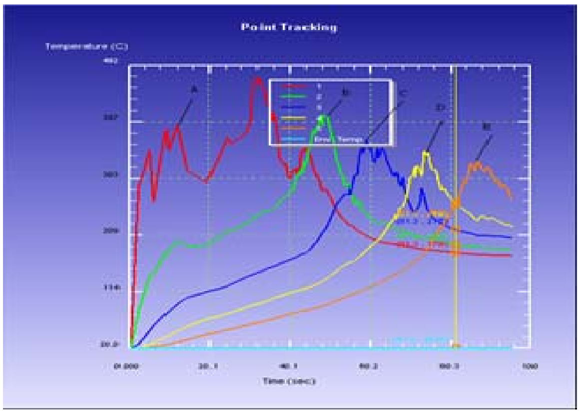
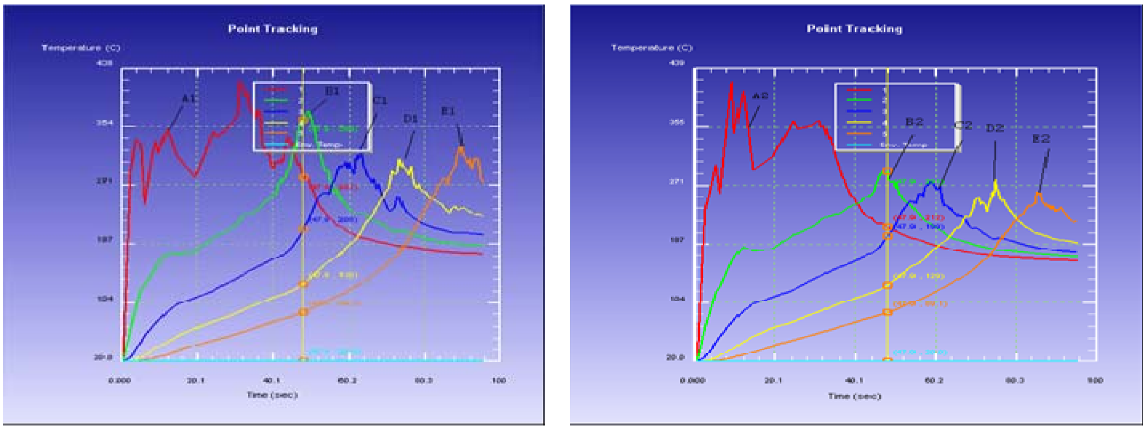


Figure 9. The Simulation Result of Temperature History of Mid Weld Point

Figure 10 is the simulation results of the temperature profile of retreating side and advancing side respectively. The max temperature for the point at retreating side is about 40℃ higher than advancing side. This is because the plastic material moves from the advancing side to the retreating side by the tool, taking some heat with it. The relativey highest steady temperature keeps about 360℃.



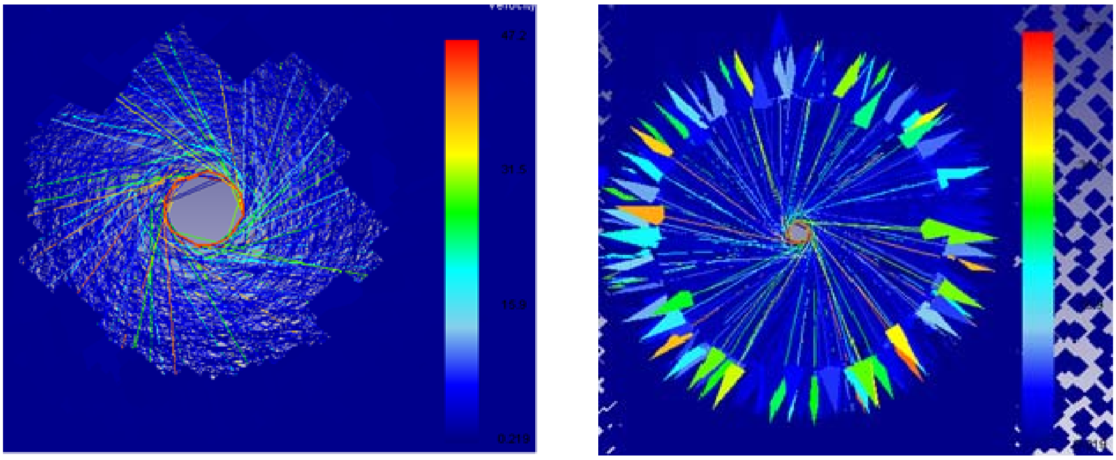
(a)The retreating side (b)The advancing side

Figure 10. The Simulation Result of Temperature History of Different Side Point

3.2. The Flow Field

During the process of bobbin tool friction stir welding, the flow pattern is more complex than conventional FSW, due to the existence of the second shoulder. The metal flow pattern can affect the weld figuration straightly and effectively.

Figure 11 is the flow distribution on top and bottom surface for workplate. The simulation results showed that the max velocity of the flowing material could be 47mm/s on conditions of the study. Two shoulders help move of the workplate material. Surface figuration of both side is good.



(a) Top surface (b) Bottom surface

Figure 11. Flow Distribution (velocity) on Top and Bottom Surface for Workplate

In the simulation, if the temperature of the work plate metal is higer, the flow stress is lower, then the weld would have better figuration due to easy flowing. Otherwise, defects like crack, lack of penetration and groove might occur.

However,in the simulation, to avoid possible instabilities, there is no obliquity of the tool, and simplified cylindrical pin is adopted. So there are more tendencies to form the defect of groove in the weld, as shown in Figure 12. For perspicuous understanding, only the wok plate is involved in Figure 12.

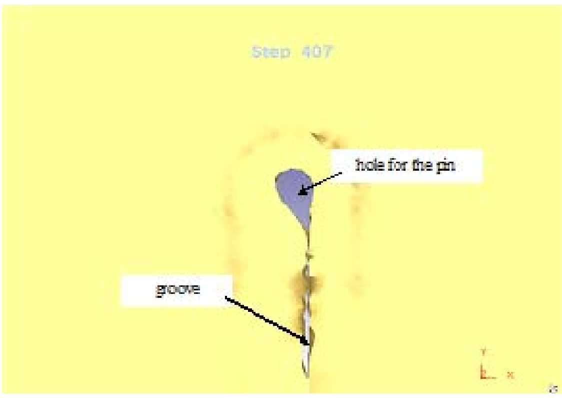


Figure 12. Groove in the Simulation

4. Conclusion

Bobbin tool friction stir welding is a new type of FSW. As a new kind of FSW technique, the bobbin friction stir welding has differences and similarities with conventional FSW.

The heat input in the bobbin tool friction stir welding is different, because of the additional shoulder. The temperature field on X-Z cross section in bobbin tool friction stir welding presents symmetry approximately about the mid thickness of the work plate, like a waist, which is verified indirectly by the macro photo of the weld cross section. In bobbin friction stir welding simulation, the max temperature for the point at retreating side is about 40℃ higher than advancing side, which is similar to conventional friction stir welding. Due to the simplification for the tool, the defect of groove is more easy to be found in the simulation.

Acknowledgements

The authors appreciate the financial support from Promotive research fund for excellent young and middle-aged scientisits of Shandong Province (Grant NO. BS2011ZZ007).

References

[1] Sakano R, Murakami K, Yamashita K, Hyoe T, Fujimoto M, Inuzuka M, et al. *Development of spot FSW robot system for automobile body members.* Proceedings of the 3rd international symposium of friction stir welding. Kobe. 2001. (CD-ROM).
[2] Mazda Develops World's First Aluminum Joining Technology Using Friction Heat. Mazda News Release. 2003: 27.
[3] Paula J Hartley. Friction plug weld repair of space shuttle external tank. *Welding & Metal Fabrication.* 2000; 96-7.
[4] ZhaoYan-Hua, Liu Jing-Duo, Zhang Li-Na, Sun Zhong-Shao, Wang Guo-Qing. Study on friction plug welding of 2014 aluminum Alloy FSW joint. *Hangkong Cailiao Xuebao/Journal of Aeronautical Materials*. 2010; 30(1): 41-46.
[5] Chen Hao, Liu Jing-Duo, Zhang Li-Na, Zhang Yi-Kun, Du Yan-Feng. *Study on friction plug welding of aluminum alloy.* International Astronautical Federation - 58th International Astronautical Congress. India. 2007; 8:5374-5383.
[6] Tomohiko Goto, Hiroaki Sato, Daisuke Tanaka, Hideaki Sakaguchi, Takeshi Yamada, Hidenori Hara. Highly Reliable Tank Structure of H-IIB Launch Vehicle.Mitsubishi Heavy Industries, Ltd. Technical Review. 2005; 42(5): 1-4.
[7] Guan Qiao, Luan Guohong. *The current status and development of FSW.* The Eleventh Welding Conference of China. Shanghai. 2005; 1: 15-29.
[8] Wang Xijing, Bao Kong, Jin Long, Han Xiaohui, Guo Ruijie. Analysis and comparision of FSW temperature field simulation of plates 3mm-LY12 and 10mm- LF2. *Journal of Lanzhou University of Technology*. 2005; 31(3): 1-4.
[9] PA Colegrove, HR Shercliff. Two-dimensional CFD modelling of flow round profiled FSW tooling. *Science and Technology of Welding & Joining*. 2004; 9(6): 483–492.
[10] Livan Fratini, Gianluca Buffa. CDRX modelling in friction stir welding of aluminium alloys. International Journal of Machine Tools & Manufacture. 2005; 45: 1188–1194.
[11] RA Prado, LE Murr, KF Soto, JC McClure. Self-optimization in tool wear for friction-stir welding of Al 6061+20% Al2O3 MMC. *Materials Science and Engineering* A. 2003; 349: 156-165.
[12] G Buffa, J Hua, R Shivpuri, L Fratini. A continuum based fem model for friction stir welding-model development. *Materials Science and Engineering: A.* 2006; 419: 389-396.
[13] SG Du, L Fu, XW Liu. FEA coupled with thermo- mechanical effect on friction welding. *Chinese Journal of Mechanical Engineering*. 2002; 38(6): 77-82.