Advanced Technologies & Materials

Review article

Tool geometry effect on material flow and mixture in FSW

*Nada Ratković[a], Živana Jovanović Pešić[a], Dušan Arsić[a], Miloš Pešić[b], Dragan Džunić[a]

Faculty of Engineering University of Kragujevac, Kragujevac, Serbia
Faculty of Engineering University of Kragujevac, Kragujevac, Serbia

ABSTRACT

FSW is a solid-state joining process. It is widely used for joining hard alloys like steel, titanium, and aluminium which are very difficult to join by fusion welding. FSW joint quality is mainly influenced by shoulder and pin geometry, its diameter, tool material, tool rotation speed, and linear traveling speed. The paper presents a brief overview of the tools used during the FSW procedure. The influence of the tool pin on the material flow and mixture was analysed in detail. In addition, the primary and secondary material flow and how it is affected by the shape and dimensions of the tool pin are also discussed.

Key words: FSW, FSW tool, Material flow

1. INTRODUCTION

Friction Stir Welding (FSW) also called "friction welding with a tool" is one of the advanced types of welding technology. Since it was patented (in 1991 at the TWI Institute, Cambridge) until today, this procedure has been developed and has reached a dynamic and wide field of application [1,2]. It is represented in the production processes of various industries: aviation, railway, military, automobile, etc. [3,4].

FSW process enables plate materials welding in all possible positions. It is also possible to join different materials [5]. It is particularly important that hard-to-weld materials, such as aluminum alloys, can be welded with high quality. It is possible to obtain a welded joint with excellent mechanical characteristics, which exceeds the strength of the base material (BM). At the beginning of the application of this procedure, only straight line connections were made, and later curvilinear ones, including circular ones.

The physical essence of the joint formation process itself is the same as in ordinary (conventional) friction welding.

However, heat is not released by friction directly between the contact surfaces of the parts to be joined, but indirectly, using a special tool

2. TOOL GEOMETRY

Tool geometry represents a very important and most influential parameter of the FSW process. The tool consists of two concentric parts: the supporting part and the working part. The tool is cylindrical in shape (Fig.1). The supporting part is the body, and the working part is the pin of the tool. The pin has a smaller diameter and is usually conical in shape, and it can be threaded, grooved, and similar.

The pin of the tool first comes into contact with the elements that need to be joined (plates). After that in welding plates keyhole is formed. The formation of the keyhole is achieved by penetrating through both welded elements until the tool shoulder achieves contact with the upper surface of the plates.

The shoulder of the tool needs to keep the material inside the welding zone. This can be enabled with a sufficiently

large pressure from the tool shoulder on the front surfaces of welding plates. The tool shoulder can be with a flat or profiled surface of different configurations. The shape of the shoulder profile can be with scrolled, knurled, ridged, grooved, or a concentric circles (Fig.2).
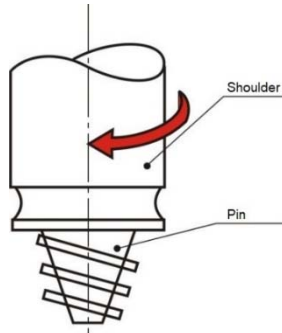

Fig.1 *FSW tool [6]*

A featured shoulder advantage is due to better friction, which contributes to better generation and conduction of heat, as well as a better mixture of materials. The concave profile of the tool shoulder is designed to provide a "reservoir" of the material above the surface of the weld

face, facilitate material flow around the tool and reduce plate thickness in the weld zone. In this way, a smooth and flat weld face is achieved thanks to the featured shoulder.
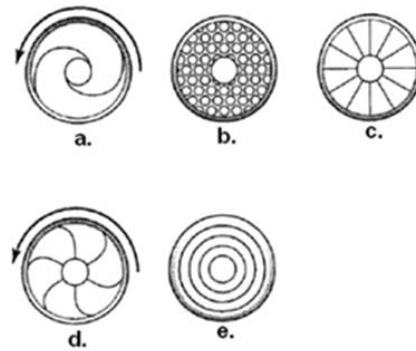

Fig.2 *Shapes of the tool shoulder profile for the FSW process can be: a. scrolled, b. knurled, c. ridged, d. grooved, e. concentric circles [7]*

The shape of the tool pin and its dimensions, the length of the pin, the diameter, the tilt angle of the tool, the depth of immersion of the tool, the vertical force of the tool, the thickness of the weld plates, and a number of other factors affect the properties of the welded joint.
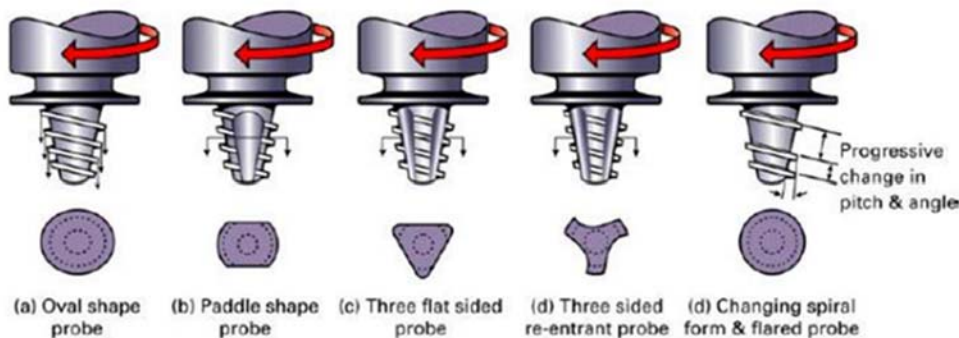.

Fig. 3 *Profiled tool pin shapes for FSW process [7]*

The spirally profiled tool pin (Fig.3) ensures good friction and material mixture, pushing it down so that a high-quality weld face is obtained, especially if the tool with three spiral flutes is used (Fig. 4).

Fig.4 *Tool for FSW process with three spiral flutes [6]*

The pin profile of this tool is designed to reduce the weight of the tool and allow better material mixture. There are also tools with different geometrical pin shapes such as triangular, square, polygonal, and similar (Fig. 5).
For lap welding of aluminum alloy sheets, a multi-stage tool has been developed, the pin of which is a pentagonal profile (Fig.6) with reduced diameter, so that it achieves a good material mixture and does not reduce the thickness of the joint thanks to the concave profile of the tool shoulder. Geometric adjustments are necessary for the FSW tool in order to make the welding process more efficient. The tool should be set to a small leading angle in relation to the workpiece normal (1° - 3°), thus the axis is slightly inclined in relation to the axis of the machine spindle (Fig.7). Asymmetric position of the tool pin enables a better flow and mixture of the material.
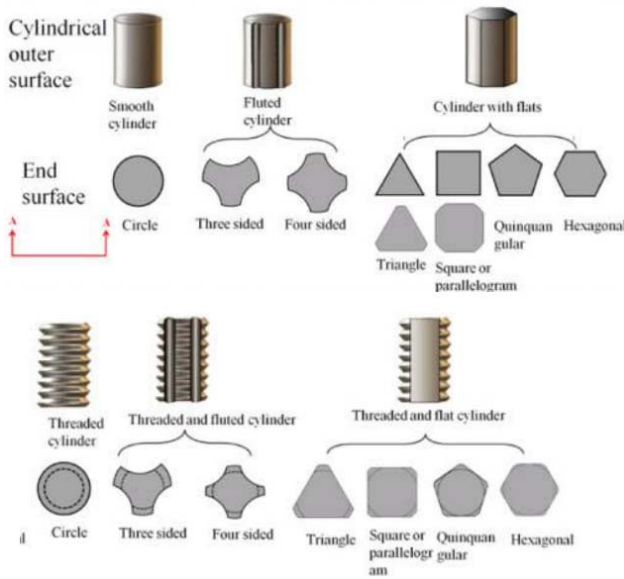
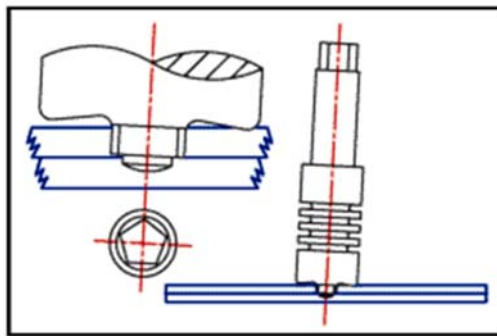Fig.5 *Tools with different pin shapes [8]*

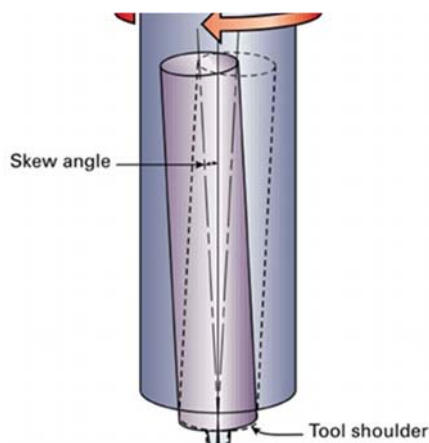Fig.6 *Schematic of the multi-stage tool for the FSW process [6]*

Fig.7 *Schematic of the asymmetric tool for the FSW process [6]*

3. MATERIAL FLOW AND MIXTURE DURING THE FSW PROCESS

The FSW process is characterized by three-dimensional material flow (translational, rotational, and vertical). By researching the process itself, it was determined that the

material flow can be described by two components: primary and secondary.

Primary flow refers to the material flow around the tool pin. This flow is analogous to the laminar flow of liquid around a rotating cylinder (Fig.8). The shape of the tool pin determines the stream flow, both in the longitudinal and the vertical direction. Fig. 9 shows a simplified schematic of the two-dimensional material flow around the tool pin during the FSW process.
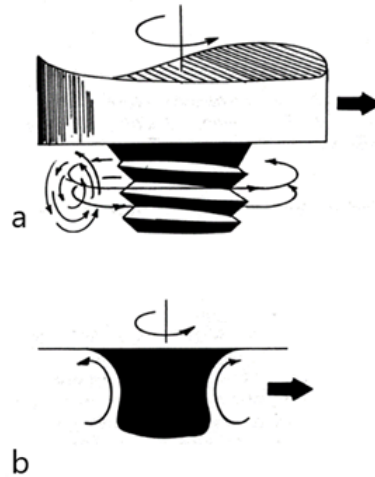

Fig.8 *Scheme of material flow around the tool pin during the FSW process (a) - turbulent flow, (b) - laminar flow [6]*

The tool pin thread is designed to push the material vertically down toward the root of the weld, thereby causing a vertical component of material flow.

Additional vertical material flow occurs through the rotation of the tool shoulder. A part of the material immediately below the tool rotates around the top of the tool multiple times.

Secondary material flow occurs when material that was previously located on the retreating side of the weld near the weld face flows and remains on the advancing side of the weld face. Secondary material flow is characteristic of thinner plates.
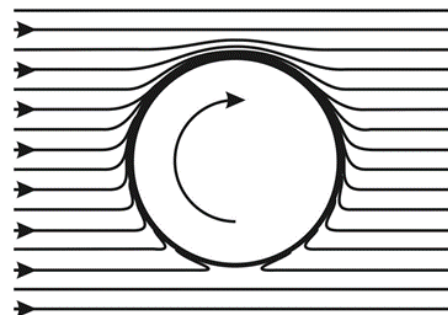

Fig.9 *Schematic of the two-dimensional material flow around the tool pin during the FSW process [6]*

4. CONCLUSIONS

Given that FSW is a completely non-linear process, it is difficult to give a comprehensive, clear definition of

material flow, because FSW does not allow geometric simplification due to its configuration. Geometric simplification is not possible because there is a complex three-dimensional flow and material mixture around the tip of the tool that is different on the advancing and retreating sides as well as in relation to the body of the tool. This points to the fact that there is neither a line nor a plane of symmetry to consider.

It is important to note that this represents a viscous-plastic material flow, created by the interaction of a solid body (tool) and a rigid base that supports the joint, and on the other side of the base material, which has basically elastic behavior. This means that there is a need for the so-called "hybrid" formulation that takes into account both phenomena, and is based on rigid body mechanics and fluid mechanics.

ACKNOWLEGDEMENTS

REFERENCES

[1] Thomas, W.M., Nicholas, E.D., Needham, J.C., Murch, M.G., Templesmith, P., Dawes, C.J. (1991), G.B. Patent Application No.9125978.8.

[2] Dawes, C., Thomas W., (1995), TWI Bulletin 6, November/December, p. 124.

[3] Thomas, W.M., Nicholas, E.D. (1997) Friction stir welding for the transportation industries. Mater Des,18:269–73.

[4] Heidarzadeh, A., Mironov, S., Kaibyshev, R., Çam, G., Simar, A., Gerlich, A., Khodabakhshi, F., Mostafaei, A., Field, D.P., Robson, J.D., et al. (2021) Friction Stir Welding/Processing of Metals and Alloys: A Comprehensive Review on Microstructural Evolution., Progress in Materials Science, 117, 100752, doi:10.1016/j.pmatsci.2020.100752.

[5] Mishra, R.S., Ma Z.Y., (2005) Friction Stir Welding and Processing. Materials Science and Engineering: R: Reports, 50, 1–78, doi:10.1016/j.mser.2005.07.001.

[6] Ratković, N. (2009), Friction welding process of machine parts of different shapes and materials (in Serbian), PhD thesis, Faculty of Engineering, University of Kragujevac, Kragujevac.

[7] Meilinger, Á., Török I., (2013), The importance of Friction Stir Welding,Tool, Production Processes and Systems, vol. 6. No. 1., pp. 25-34.

[8] Zhang, Y.N., Cao, X., Larose, S., Wanjara, P. (2012) Review of Tools for Friction Stir Welding and Processing, Canadian Metallurgical Quarterly, 51, 250–261, doi:10.1179/1879139512Y.0000000015.