Vol. 37, No. 4 (2015) 434-439

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Applications of Friction Stir Processing during Engraving of Soft Materials

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Keywords:

Frictions stir processing
Tool speed
Soft material
Carbonization

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A B S T R A C T

Friction stir processing has extensive application in many technological operations. Application area of friction stir processing can be extended to the processing of non-metallic materials, such as wood. The paper examines the friction stir processing contact between a specially designed hard and temperature-resistant rotating tool and workpiece which is made of wood. Interval of speed slip and temperature level under which the combustion occurs and carbonization layer of soft material was determined. The results of the research can be applied in technological process of wood engraving operations which may have significant technological and aesthetic effects.

1. INTRODUCTION

Friction stir processing is based on the friction stir welding (FSW) technique which was invented by The Welding Institute (TWI) in 1991 [1,2]. Friction stir processing (FSP) is a solid-state technique used for joining materials and as a tool for material processing (i.e., surface machining). Although the melting temperature of the material is never reached during FSP, severe plastic deformation occurs at extreme temperatures. The process is performed by traversing a rotating tool through fixed workpiece material along a desired path as shown schematically in Fig. 1. Generally, the FSP tool consists of a cylindrical shoulder and a concentric pin, although off-axis pins have been used successfully as in the study by Cantin et al. [3]. The tool pin is forced into the workpiece, and acts to increase the penetration depth of the weld or processed zone. The tool serves two primary functions: (a) heating of workpiece, and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. The shoulder is positioned at the surface of the workpiece, consolidating material that flows around the pin.

At the retreating side of the tool, the tangential velocity of the rotating tool opposes its forward travel (see Fig. 1). At the advancing side, the tangential velocity of the tool is in the same direction as the tool feed.

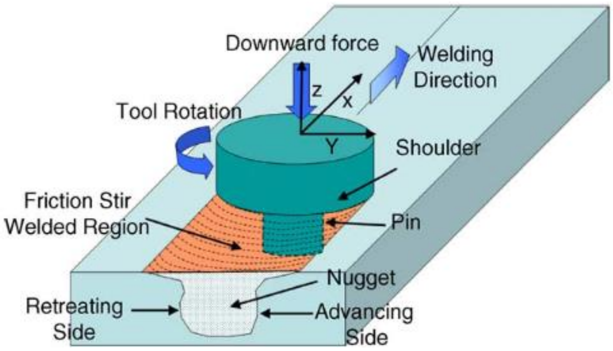

Fig. 1. Friction stir processing schematic.

The effects of FSW/FSP on the microstructure and mechanical properties in the stir zone (SZ) have been extensively investigated [4-7]. The mechanical properties of friction stir processing are improved due to the grain refinement of the microstructure [8-13]. Microstructures, micro hardness and wear properties were studied in order to evaluate the microstructures and mechanical properties of fabricated composites by A. Bahram et al. [14]. The microstructure properties were evaluated by optical microscopy (OM) and field emission scanning electron microscopy (FESEM). The mechanical behaviors of the samples were determined by micro hardness and wear tests. The results showed that the grain size of fabricated composite reduced. Also it was indicated that in comparison to base copper micro hardness of friction stir processed composites in stir zone (SZ) increased significantly. The results of wear test showed that in comparison with specimen with traverse speed of 80 mm/min, higher traverse speed of 160 mm/min increase wear rate of cylindrical pins. Kudzanayi Chiteka [15] and Stoica [16] conducted studied making a choice in selection of friction stir welding/processing (FSW/P) tool material which has become an important task in determining the quality of the weld produced. The tool material selection depends on the operational characteristics such as temperature, wear resistance and fracture toughness that determine the type of materials to be joined. Soft materials can be easily welded using tool steels while harder materials need harder tool materials such as carbide based materials and polycrystalline cubic boron nitride (PCBN). K. Surekha, et al. [17] considered the objective of their study was to obtain a high strength, high conductivity copper by friction stir processing. Three millimeter thick pure copper plate was friction stir processed to a depth of 2.8 mm at low-heat input conditions by varying the travel speed from 50 to 250 mm/min at a constant rotation speed (300 rpm) to obtain fine grains. Grain size of the nugget decreased from 9 to 3 μm and the hardness increased from 102 to 114 HV by increasing the traverse speed from 50 to 250 mm/min. S. Chainarong et al. [18] was to improve the mechanical properties of SSM 356 aluminum alloys by friction stir processing, a solid-state technique for microstructural modification using the heat from a friction and stirring. The parameters of friction stir processing for SSM 356 aluminum alloys were studied at three different travelling speeds: 80, 120 and 160 mm/min under three different rotation speeds 1320, 1480 and 1750 rpm. The hardness and tensile strength properties were increased by friction stir processing. The hardness of friction stir processing was 64.55 HV which was higher than the base metal (40.58 HV). The tensile strengths of friction stir processing were increased about 11.8 % compared to the base metal. The optimal processing parameter was rotation speed at 1750 rpm with the travelling speed at 160 mm/min.

FSP has several advantages over other metal working process. First, Friction stir processing achieves refined microstructure, homogeneity and densification because it is a solid-state processing process. Processed zone mechanical and tribological properties can be greatly controlled by adjusting the tool pin and shoulder diameter or length or both and by changing the tool rotation speed, tool transverse speed, tilt angle, and vertical force etc. [19]. Third, as compared to other metal working process it is very difficult to find an adjustable processed depth, but it is possible in FSP by adjusting the length of the tool pin. Fourth, FSP is a environment friendly and energy-efficient process, because the heat input comes from the stirring action between work piece and the tool pin. And the other benefits of FSP like lower distortion, good dimensional stability, no shielding gas required etc. [6, 20-21].

2. THEORETICAL BACKGROUND

Based on literature review it can be concluded that the friction stir processing is widely used in many technological operations. Especially expressed area of application of friction stir processing is forming and welding of metallic materials. Whereby, the friction of metal generate required amount of heat necessary for easier formatting. The fact that friction can achieve high temperatures in a short interval of time it opens the possibility of extending the application of friction stir processing in the processing operations: wood, plastic and other non-metallic materials. In that aim, this paper discusses the surface contact between hard and thermo-stable rotating tools and soft material with low melting point, i.e. the combustion (Fig. 2).

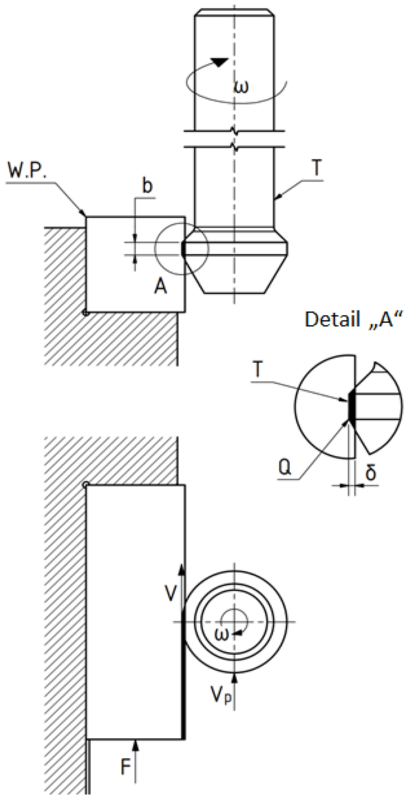

Fig. 2. Schematic view of the surface contact rotating tool and workpiece.

The tool T performs rotational motion while the workpiece performs auxiliary motion with speed V_p. The relative speed of motion of the contact is approximately equal to the peripheral speed of the tool (V). For the reason that, influence of the speed V_p on the amount of heat generated can be ignored in relation to the impact speed V. Tool penetration is marked with δ and the width of contact with b. The rotating tool has not catting geometry, so for that reason, the share of cutting reduced only to cutting micro roughness's tools that have a small value compared to the depth δ. The amount of generated heat Q and achieved temperature T will depend on:

$$Q = \phi_1(\delta, b, V, V_p) \tag{1}$$

$$T = \phi_2(\delta, b, V, V_p) \tag{2}$$

To melting or combustion of non-metallic materials (plastic, wood), compared to metallic materials required are significantly less amount of heat. In connection with this, it can be assumed that at low values of δ and b, and relatively higher values of V and V_p could be possible to reach the melting point non-metallic materials (plastic, wood and similar materials). It is assumed that at certain values of the above parameters, in case of treatment wood to get to the carbonization of the surface layer ie. combustion without oxygen. Determining the size of the influential parameters at which achieves carbonization of the surface layer will be conducted experimentally. This will be determined primarily interval of sliding speed rotating tool on the surface of the workpiece, at which it is possible to achieve combustion and carbonization of the surface layer of the workpiece made of wood. The authors suggest that the phenomenon of combustion wood based on friction stir processing can be effectively used in engraving operations, which can have a significant technological effects in terms of tool life (no need sharpening tools because no cutting tool geometry) as well as in terms of aesthetics obtained relief.

3. EXPERIMENTAL INVESTIGATION

Experimental investigation were performed in order to determine the parameters of friction stir processing, such as, speed sliding V and the depth of penetration tools δ under which combustion and carbonization occurs in the contact zone of the hard and heat-resistant rotating tool and workpiece made of wood.

3.1 Experimental conditions - materials (samples), test conditions (modes), tools and measuring instruments

Experimental investigation has been carried out under the following conditions:

- The material of the workpiece is dry beech wood hardness 8.687 HBS 2.5 / 15.625 / 30.
- Rotating tool with which it has performed process was made of steel HSS-E hardness 65 HRC,
- Sliding speed of rotating tool was varied at an interval of for approximately 2-3 m / s.
- Rotating tool penetration in the workpiece varied in the interval δ = 0.2 to 0.08 mm.
- Auxiliary speed motion of rotating tool is V_p = 200 mm / min.
- Width tool is constant at b = 2 mm.

Processing is performed on a single spindle vertical milling machine numerical HAAS Toolroom Mill TM-1HE, with manual tool change. During the processing IC camera monitored temperature values that are developed in the contact zone. Figure 3 gives a 3D view of the workpiece and rotating tools, while Fig. 4 provides a photographic representation of machining processes.

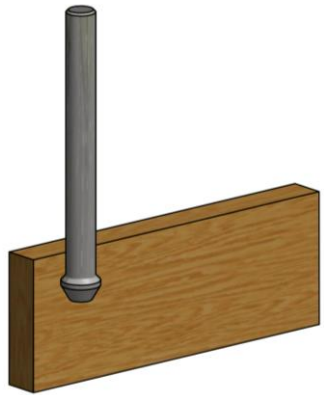

Fig. 3. 3D view of rotating tool and workpiece.

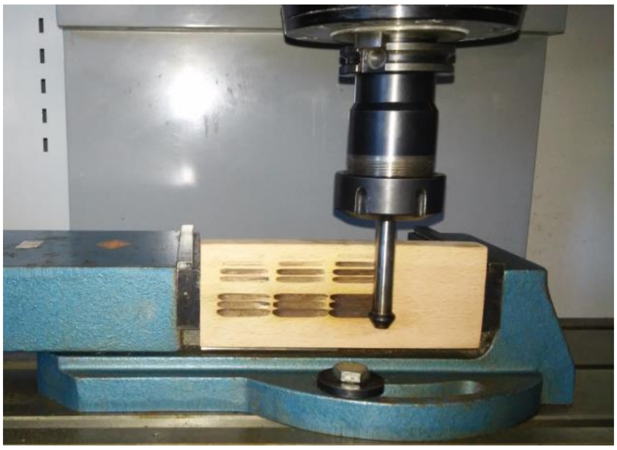

Fig. 4. Realistic representations of friction stir processing.

3.2 Analysis of investigation results

In Fig. 5 a photographic representation of traces of processing resulting from the different combinations of treatment regime is shown. The temperature in the contact zone which is generated in the rotating tool penetration depth of 0.8 mm, the speed of the main motion of 3500 o / min and the speed of auxiliary motion of 200 mm / min is shown in Fig. 6.

Fig. 5. The photographic view of traces after friction stir processing thretmant.

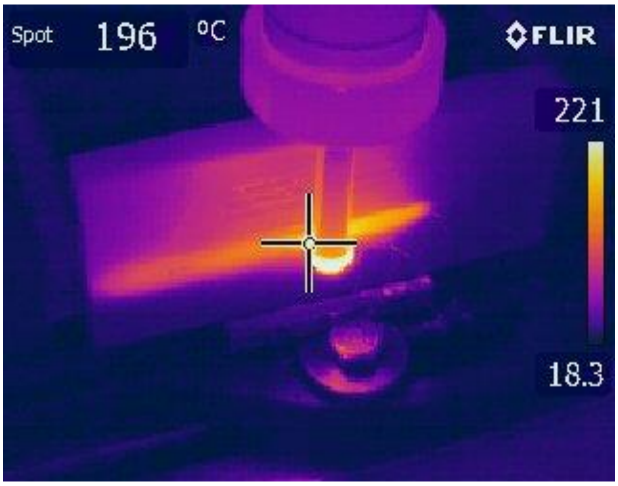

Figure 6. The temperature generated in the contact zone.

Table 1 shows the dependence of temperature generated in the contact zone of the rotating tool and the workpiece relative to the treatment regime. In the table is marked with δ penetration depth of the tool in the workpiece, V is the speed of the main motion, and V_p is speed of auxiliary motion.

Table 1. Temperatures in the contact zone of the rotating tool and workpiece.

δ[mm]	T_1 [˚C] V=25000 o/min	T_1 [˚C] V=30000 o/min	T_1 [˚C] V=35000 o/min	V_p [mm/min]
0.2	25.1	47.3	67.1	200
0.4	57.2	55.8	83.8	200
0.6	44.2	121	150	200
0.8	135	187	196	200

According to obtained results (Table 1) it can be concluded that with increasing depth of penetration the rotating tools and the speed of main motion comes to generating greater amounts of heat. The temperature in the contact zone of the rotating tool and the workpiece reaches a value of 196 ^{0}C at a main motion V = 35000 / min, the depth of penetration tools δ = 0.8 mm and the speed of the auxiliary motion Vp = 200 mm / min

3.3 Example of possible industrial application of research results

Results obtained by experimental research can be applied in the processes of engraving wood, in which the tool can be with a certain values of the angle of the cone, which to a certain depth of a few millimeters, penetrates in the material of workpiece (Fig. 7).

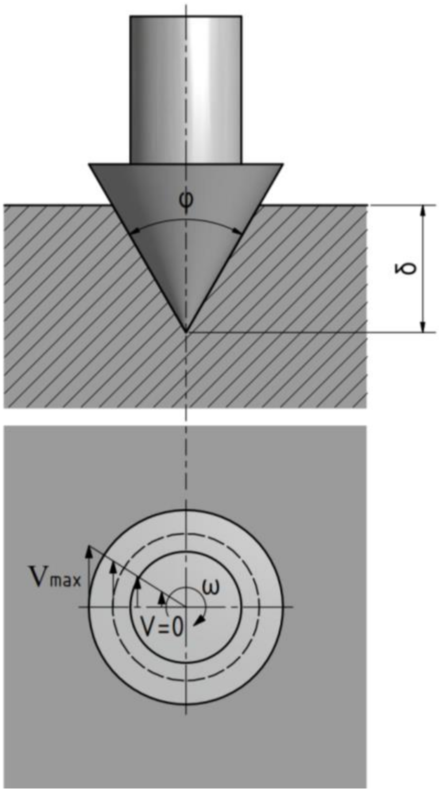

Fig. 7. Possible form of the rotating tools.

Based on Fig. 7 it can be concluded that the sliding speed of this type of tool range from zero values on top of the rotating tool to the maximum value V_{max}. The authors assume that the engraving operations to reach combustion and carbonization of material if medium speed sliding are similar speeds obtained under the experimental research.

In Fig. 8, the sample after friction stir processing at the depth of penetration δ = 1.5 m, and the speed V_{max} = 2 m / s.

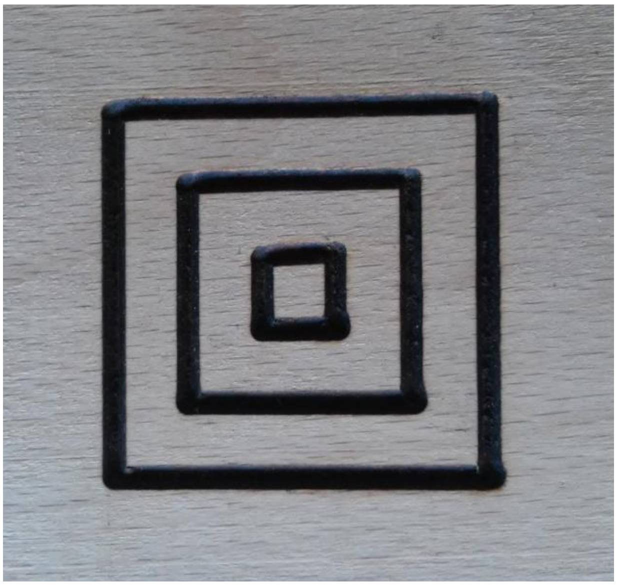

Fig. 8. Sample after friction stir processing.

4. DISCUSION

Friction stir processing is widely used in operations of forming and welding of metallic materials. The results presented in this paper indicate that the friction stir processing can be efficiently used in operations of engraving wood and other non-metallic of material of relatively low melting point and combustion. Application tool without cutting geometry can have major economic effects in terms of a significant reduction in processing costs. The temperature at which a contact layer of wood combustion (Figure 6) absolutely not affect the durability of tools made of high speed steel. This part of the costs relating to the sharpening tools is negligible, which is not the case with the tools that are currently used in operations of wood engraving. Considering the results obtained it is likely that the area of application of friction stir processing can significantly expand the treatment of various types of materials made of plastic.

5. CONCLUSION

Based on the results, it can be concluded that the friction stir processing can be effectively used in the processing operations and non-metallic material (wood). The paper shows that, at certain speeds slip friction wood and hard tool reaches a temperature of 196^{0}C, which allows the contact layer burning wood. This phenomenon allows from perform operations wood engraving tools, without cutting geometry, which can have a very significant economic and aesthetic effects. According to obtained results it is very likely that the heat generated by friction can be applied to the processing of various types of plastics, which will be the subject of future research.

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