An overview of Friction Stir Processing on Copper

G.Lakshmikanth[1], G.Krishnakanth[2], Mebratu Markos[3]

[1]Assistant Professor, Mechanical Engineering Department, Wolaita Sodo University, Ethiopia
[2]Assistant Professor, Mechanical Engineering Department, SRK Institute of Technology, Vijayawada
[3]Head of Department, Mechanical Engineering, Wolaita Sodo University, Ethiopia

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Abstract - *Friction stir processing (FSP) is energy efficient, one- step, solid-state surface modification technique. FSP is an emerging metal working technique and an effective method for producing fine-grained structure and surface composite, modifying the microstructure of materials, and synthesizing the composite. The objective of this review article is to provide the current state of understanding and development of friction stir processing technology on copper. This paper also presents the critical reviews on copper based particulates reinforced surface composites using friction stir processing route. Finally the influencing parameters for obtaining successful copper based surface composites are given and discussed.*

Key Words**:** FSP, Copper, Surface composites, Microstructure, Mechanical properties.

1. INTRODUCTION

Friction stir processing (FSP) is developed based on friction stir welding (FSW) technology. Friction stir welding, is a solid state joining technique invented in 1991 by The Welding Institute (TWI), is extensively used in joining of Al, Mg, Cu, Ti and their alloys . In FSW, a cylindrical-shouldered tool, with a profiled probe or pin is rotated at a constant speed and fed at a constant traverse rate into the joint line between two pieces of sheet or plate material, which are butted together as shown in Fig. 1.

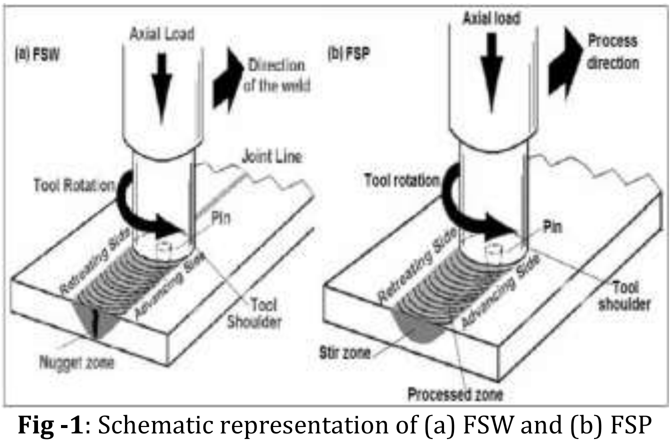

Fig -1: Schematic representation of (a) FSW and (b) FSP

FSP is a green, energy efficient, one-step processing route and an emerging surface-engineering technology. It has been successfully applied to alter the grain structures of various metals and alloys to change the surface properties without influencing properties of the bulk material and also producing surface level composites. It can also be used as a repair tool for sensitive parts. Actually, FSP is a novel grain refinement method based on strong couplings of thermo-mechanical phenomena, applied to light metal alloys for various end applications. Fig.1 (b) depicts FSP and how it differs from FSW as in Fig.1 (a). FSP uses a specially designed, no consumable tool with shoulder and pin. The tool rotates at a constant rotational speed against the work surface moving at a fixed traverse (processing) speed to develop a friction stir processed zone. When the pin descends to the work piece and the shoulder contacts the work surface, heat is generated by friction between the tool shoulder and the top of the work piece causing plastic flow by the rotation of the tool pin. As the processed zone cools at ambient condition, it forms a defect free recrystallized fine Grain microstructure. Fig.2 illustrates the schematic representations of step by step working principle of FSP.

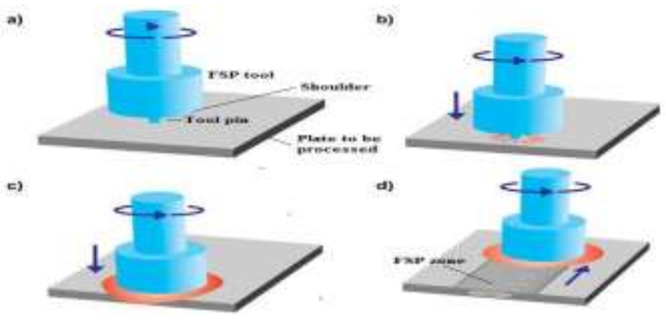

Fig-2: Steps of FSP (a) Rotating tool prior to contact with the plate (b) Tool pin makes contact with the plate, creating heat (c) Shoulder makes contact, restricting further penetration while expanding the hot zone and (d)Plate moves relative to the rotating tool, creating FSP zone

This thermo-mechanical conditions introduce three distinct regions namely stir zone (SZ), thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) during FSP. The processed zone with various regions is illustrated in Fig.3.The formations of these regions are affected by the material flow behavior under the action of non-consumable tool. The degree of plastic deformation and the heat generation during FSP are the dominant factors in determining grain refinement at processed zone. In FSP, heat is generated by a combination of friction and plastic dissipation during deformation of the metal. The dominating heat generation mechanism is influenced by the process parameters, thermal conductivities of the workpiece, pin profiles, tool geometry and the backing plate. Nevertheless, the amount of heat generation during FSP is a decisive issue to produce a defect-free FSPed zone. FSP has been applied to Al, Mg, Cu, Fe, and alloys with resulting property improvements. Fig. 4 shows a list of attributes and links to the FSP processes with potential applications. The benefits and limitations of FSP in different aspects are presented in Table 1.

Table 1: Benefits and limitations of FSP

Technical	• One-step processing technique • Good dimensional stability and repeatability • Depth of processed zone can be controlled by the pin Length • Suitable for automation • No surface cleaning required
Metallurgical	• Solid state process • Grain refining and homogenization • Minimal distortion of parts • No chemical effects and no cracking • Excellent metallurgical properties • Possibility to treat thermally sensitive materials
Energy	• Energy efficient technique • Low energy consumption route for surface composite • Fabrication Energy efficiency
Environmental	• Green technique • No fumes produced • Reduced noise
Limitations	• New technique and availability of data • Lack of predictive models in FSP • Keyhole at the end of each pass • Need of a backing plate and suitable fixture
Benefits	• New technique and availability of data • Lack of predictive models in FSP • Keyhole at the end of each pass • Need of a backing plate and suitable fixture

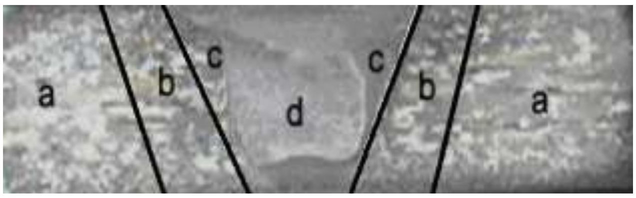

Fig 3- Different regions in FSP (a) Unaffected base metal (BM) (b) Heat affected zone (HAZ) (c) Thermo-mechanically affected zone (TMAZ) and (d) Stir zone (SZ)

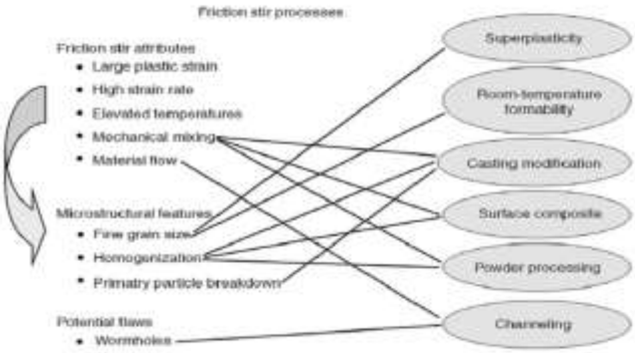

Fig -4: Schematic view of list of attributes and links to the FSP processes

2. FRICTION STIR PROCESSING OF COPPER

Today, copper and copper alloys remain one of the major groups of commercial metals, ranking third behind only iron/steel and aluminum in production and consumption. Copper and its alloys have found extensive applications because of its high thermal and electrical conductivity, plasticity, softness and formability. However, copper in pure form has poor strength, wear and fatigue resistance and hence is unsuitable for high end applications like contact terminals of electrical switches and sliding surfaces. Friction stir processing (FSP) overwhelmed the above limitations of the pure copper. Mishra et al have developed this innovative solid-state processing technology, which is being used to enhance locally the mechanical properties of conventional materials by producing ultrafine grained structures, which is rather attractive in situations where strength and/or fatigue crack initiation are serious concerns. FSP is a unique process to modify the microstructure and other mechanical properties at selective locations . The current understanding of FSP of copper and its alloys, with particular concern for the effects of process parameters, microstructure evolution, microstructure-property relationships and modeling are summarized in this section.

Surekha and Els-Botes, (2011) have developed a high strength and high conductivity copper by FSP at low –heat input conditions by varying the traverse speed (50-250 mm/min) at constant rotation speed (300 rpm) . 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. Fig.5 implies that the yield strength (YS), ductility (% Elongation) and ultimate tensile strength (UTS) of the processed zone is higher compared to the base metal and the YS and UTS increased with the increase in traverse speed. At constant rotation speed, with the increase in traverse speed, the heat input and the grain size decreased and hence the mechanical properties improved and the yield strength obeyed Hall–Petch relationship.

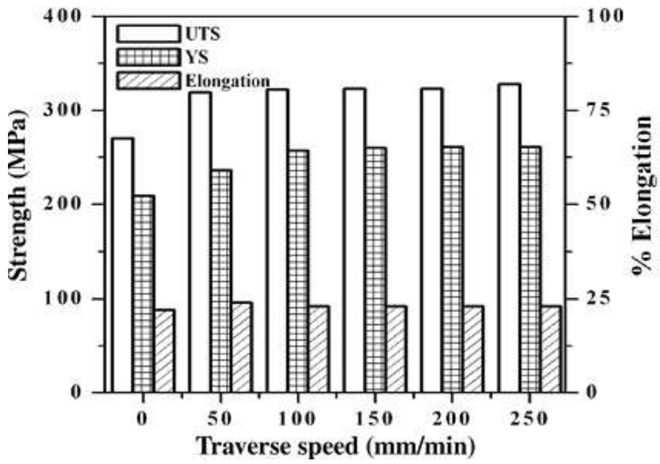

Fig -5: Mechanical properties of FSP Copper

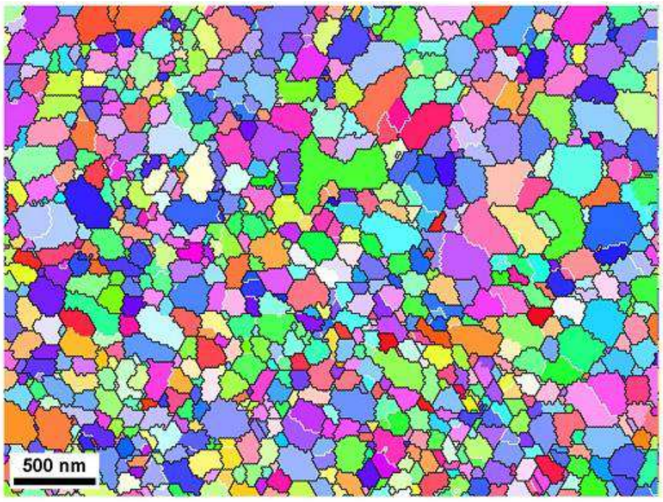

Fig -6: Grain structures in the FSP copper

3. LITERATURE REVIEW

The present section provides an exhaustive review of published data on the effect of process parameters on friction stir welding / processing works on copper. It discusses various types of constraints and the approaches adopted for the study of the effect of various parameters. The process of production of large number of items requires removing the excess material from the raw material. The activity involves large number of machine as well as human parameters which makes it complex phenomenon. The production activity determines the overall cost of the basic product. In the age of competition the cost has to be minimal. To achieve this production activity needs to be optimized in terms of cost/time. The cost/time of production depends upon human parameters such as competency level and wages whereas the more important part is process parameters. These parameters apart from the production rate, influence quality of finished product during a machining operation. To study the influence of various parameters involved one needs to find out from the available data, the practice involved and the shortcomings if any and the possible remedial measures. Literature Review has been presented in a tabular form. Nearly 15 papers related to study of friction stir welding / processing have been considered. Processing parameters such as tool geometry, tool rotational speed, tool tilt angle, processing speed, axial load and groove width &depth have been studied along with their effect. The review table given below explains the details of parameters considered in earlier studies by various researchers.

The shape of the tool pin profiles influences the flow of material that is plasticized and affects weld properties`A tool pin profile with straight edges increases the material flow compared with a cylindrical tool pin profile . The axial force on the work piece material and the flow of material near the tool were affected by the orientation of threads on the pin surface . Tri-flute type pin tool with conical threaded geometry was used to produce good welds in case of AA2024-T4 and AA7075-T6 aluminium alloys . The material flow behaviour is predominantly influenced by the FSW tool pin profiles, tool dimensions, and process parameters .Khodaverdizad have investigated the effect of tool pin profile on FSWed pure copper joints. The results revealed that square pin profile produced finer recrystallized grain structure, higher degree of plastic deformation at the stir zone.In theirinvestigation, S. Cartigueyen et al.has made an attempt to study the effect of tool pin profiles on the formation of stir zone in pure copper at low heat input condition. FSP of copper is carried out with a constant rotational speed(350rpm) and traverse speed(50m/min) and shoulder diameter of 18mm with six different FSP tool pin profiles.

4. Friction Stir Processing

Friction stir processing (FSP) is a method of changing the properties of a metal through intense, localized plastic deformation. This deformation is produced by forcibly inserting a non-consumable tool into the workpiece, and revolving the tool in a stirring motion as it is pushed laterally through the workpiece. The precursor of this technique, friction stir welding, is used to join multiple pieces of metal without creating the heat affected zone typical of fusion welding. When ideally implemented, this process mixes the material without changing the phase (by melting or otherwise) and creates a microstructure with fine, equated grains. This homogeneous grain structure, separated by high-angle boundaries, allows some aluminium alloys to take on superplastic properties. Friction stir processing also enhances the tensile strength and fatigue strength of the metal. In tests with actively cooled magnesium-alloy workpieces, the microhardness was almost tripled in the area of the friction stir processed seam

5. CONCLUSIONS

The area of the surface composite was significantly influenced by the selected process parameters. The area of the surface composite increased when tool rotational speed was increased due to increase in frictional heat generation. The area of the surface composite reduced when processing speed was increased because of reduction in frictional heat gen-eration. The area of the surface composite reduced when groove width was increased due to increase in flow stress of plastized copper. The distribution of B4C particles in the surface composites was influenced by tool rotational speed and processing speed. Lower tool rotational speed and higher processing speed resulted in poor distribution of B4C particles and vice versa. The increase in groove width did not affect the distribution of B4C particles in a significant manner. The B4C particles refined the grains of copper because of its pinning effect. The interface between B4C particles and copper matrix was clean without the presence of any voids or reaction products. The absence of porosity can be attributed to good wettability between copper and B4C particles and sufficient flow of plasticized copper during FSP at the selected process parameters.

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