EXPERIMENTAL INVESTIGATIONS OF FRICTION STIR PROCESSED BY CHANGING EFFECTED TOOL PROFILES

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ABSTRACT : Friction Stir Processing (FSP) is a new solid-state processing technique for micro structural modification which was developed based on the principle of Friction Stir Welding (FSW). The basic concept of FSP is remarkably simple. A non-consumable rotating tool with a pin and shoulder is inserted into a single piece of material and traversed along the desired path for localized micro structural modification for specific property enhancement in the processed zone due to intense plastic deformation, mixing and thermal exposure of material. Friction Stir Processing (FSP) is a solid–state surface modification technique to alter the properties of metals and alloys. This work studies the effect of FSP on pure copper with three different tool pin profiles (plain cylindrical, square and taper) at low-heat input condition. The tool rotational speed and tool traverse speed were kept constant to maintain the low heat input., micro hardness and tensile strength were analyzed to evaluate the modifications occurred in the mechanical properties.

I.INTRODUCTION

Friction Stir processing (FSP) is a solid state process known for its ability to modify microstructures and provide improved properties over conventional processing technologies. The development of FSP is based on the friction stir welding (FSW) technology. FSW, a solid state joining process invented at The Welding Institute (TWI) in 1991, is a viable technology for joining Al alloys which are difficult to fusion weld [1,2]. FSP uses the same methodology as FSW, but it is used to modify the local microstructure and do not join metals together.FSW works by plunging a spinning tool into the joint of two materials and then traversing the rotating tool along the interface (Fig.1). The friction caused by the tool heats up the materials around the pin to a temperature below the melting point. The rotation of the tool “stirs” the material together and results in a mixture of the two materials. In FSP a specially designed cylindrical tool is rotated and plunged into the selected area. The tool has a small diameter pin with a concentric large diameter shoulder and when moved to the part, the rotating pin contacts the surface and due to friction, heats and softens a small column of metal. The tool shoulder and length of entry probe controls the penetration depth. When the shoulder contacts the metal surface, its rotation creates additional frictional heat and plasticizes a large cylindrical metal column around the inserted pin. The shoulder provides a forging force that contains the upward metal flow caused by the tool pin. During FSP, the area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the entire selected area is processed to a fine grain size. The rotating tool provides a continual hot working action, plasticizing metal, within a narrow zone, while transporting metal from the leading phase of the pin to its trailing edge. The processed zone cools, without solidification, as there is no liquid, free forming a defect free recrystallized, fine grain microstructure. Essentially FSP is a local thermo mechanical metal working process that changes the local properties without influencing properties in the remainder of the structure. FSP is most commonly used with aluminum, but it is also used for processing other alloys. It has been applied to Al, Cu, Fe, Ni –based alloys with resulting property improvements. The advantages offered by FSP method make it suitable for many applications. Recently, FSP technology has been used in aerospace, automotive, marine and rail industries along with various other applications.

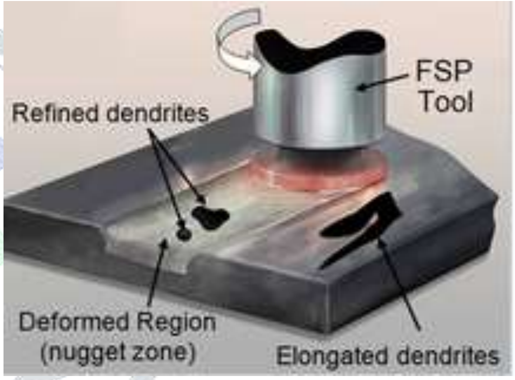


Fig:1fsp

Working Principle of FSP

- A specially designed non-consumable cylindrical tool is rotated and plunged into the selected area, to friction process the required location within a plate or sheet
- Tool has a small diameter pin with a concentric larger diameter shoulder
- Tool shoulder and length of entry probe control the penetration depth
- When tool descended to the part, the rotating pin contacts the surface, rapidly friction produced between tool pin and metal surface heats and softens a small column of metal
- Rotating tool provides:
- Continuous heating of work piece
- Plasticizing metal
- Transporting metal from the leading face of the pin to its trailing edge

When the shoulder contacts the metal surface, its rotation creates additional frictional heat and plasticizes a larger cylindrical metal column around the inserted pin • The shoulder additionally provides a forging force that contains the upward metal flow caused by the tool pin.

- During FSP, work piece and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the required area is processed
- The processed zone cools, without solidification, as them is no liquid, forming a defect-free recrystallized, fine grain microstructure.

TOOL PIN PROFILES

The shape of the tool pin profile influences the flow of plasticized material and affects weld properties. Friction stirring pins produce deformational and frictional heating to the joint surfaces. The pin is designed to disrupt the faying, or contacting surfaces of the work piece, shear material in front of the tool and move material behind the tool. The commonly used pin profiles are a) round bottom cylindrical pin b) flat bottom cylindrical pin c) truncated cone pins d) whorl pin e) MX triflute pin f) trivex pin g) thread less pins h) retractable pins.

PROCESS PARAMETERS

The following are the parameters which influence the friction stir processing.

(a) Tool shoulder diameter,
(b) Tool pin profiles
(b) Tool rotation speed
(d) Tool traverse speed
(e) Number of passes
(f) Axial force
(g) Tool tilt angle

APPLICATIONS

The FSP is used when metals properties want to be improved using other metals for support and improvement of the first. This is promising process for the automotive and aerospace industries where new material will need to be developed to improve resistance to wear, creep, and fatigue. (Misha) Examples of materials successfully processed using the friction stir technique include AA 2519, AA 5083 and AA 7075 aluminum alloys, AZ61 magnesium alloy, nickel-aluminum bronze and 304L stainless steel.

II. LITERATURE REVIEW

Surface composites by friction stir processing

Surface composites are suitable materials for engineering applications encountering surface interactions. Friction stir processing (FSP) is emerging as a promising technique for making surface composites. FSP can improve surface properties such as abrasion resistance, hardness, strength, ductility, corrosion resistance, fatigue life and formability without affecting the bulk properties of the material. Initially, FSP was used for making surface composites in aluminum and magnesium based alloys. Recently surface composites including steel and titanium based alloys have also been reported. While influence of process parameters and tool characteristics for FSP of different alloys has been considerably reviewed during the last decade, surface composites fabrication by FSP and the relation between microstructure and mechanical properties of FSPed surface composites as well as the underlying mechanisms have not been wholesomely reviewed. The present review offers a comprehensive understanding of friction stir processed surface composites. The available literature is classified to present details about effect of process parameters, reinforcement particles, active cooling and multiple passes on microstructure evolution during fabrication of surface composites. The microstructure and mechanical characteristics of friction stir processed surface micro-composites, nano-composites, in-situ composites and hybrid composites are discussed. Considering the importance of tool wear in FSP of high melting point and hard surface composites, a brief note on tool materials and the limitation in their usage is also provided. The underlying mechanisms in strengthening of friction stir processed surface composite are discussed with reported models. This review has revealed few gaps in research on surface composites via FSP route such as fabrication of defect-free composites, tailoring microstructures, development of durable and cost effective tools, and understanding on the strengthening mechanisms. Important suggestions for further research in effective fabrication of surface composited by FSP are provided.

III. EXPERIMENTAL PROCEDURE

The experimental study includes the butt joining of 3 mm pure copper plates. The welding process is carried out on a vertical milling machine (Make HMT FM-2, 10hp, 3000rpm) as shown in Fig6.1. Tool is hold in tool arbor as shown in Fig 6.2. Special welding jigs and fixtures are designed to hold two plates of100mm X 70 mm X 4mm thickness as shown in fig 6.4.1. Table 6.1 shows the combinations of the tool rotational speed (RPM), welding speed (mm/min) and tool geometry and diameter of the tool shoulder to the diameter of the tool pin (Ds/Dp). These combinations are chosen based on the literature survey and the capability of the milling machine used for the experimental study.

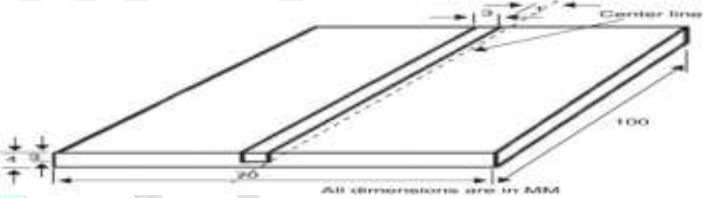


Fig. 6.4.1 schematic sketch of COMPOSITE.

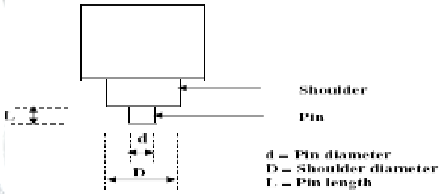


Fig 6.4.2 Schematic diagram of tool

Table 6.1 FSP process parameters and tool dimensions

Process Parameters	Values
Tool rotation speed (rpm)	1120, 900
Welding speed (mm/min)	31.5, 20
Pin length (mm)	2.5
Tool shoulder diameter, D (mm)	24
Pin diameter, d (mm)	8/6
Tool tilt angle	2.5
Tool pin geometry	Cylindrical taper threaded
Tool material	H13 tool steel

Non consumable tool made of H13 tool steel (Typical chemical composition is shown in the table 6.2) is used to fabricate joints, and diameter of shoulder and pin used were 24 and 8mm and the length of the pin 2.5mm (depend on the plate thickness). The tools used for the present study are square pin profile and triangle pin profile with shoulder as shown in Fig 6.5. A constant axial force is applied for the entire friction stir processing (FSP) experiments.

Table 6.2 Chemical Composition of H13 Tool Steels

Element	Min.(% by Weight)	Max.(% by Weight)
Carbon	0.37	0.42
Manganese	0.20	0.50
Phosphorus	0	0.025
Sulphur	0	0.005
Silicon	0.80	1.20
Chromium	5.00	5.50
Vanadium	0.80	1.20
Molybdenum	1.20	1.75

Fig 6.5Tool pin profiles

The direction of welding is normal to the rolling direction. Single pass welding procedure is used to fabricate the joints. After welding NDT (X- ray radiography) was performed to detect any defects in the composites. The welding parameters are presented in Table6.4. Joints were fabricated using different combinations of rotational speed and welding speed and different tool profile. The photographs of the fabricated joints are shown in Fig 6.6,. Mechanical properties of base metal as shown table 6.3 Experiments conducted at deferent combination tool rotating speed, welding speed and tool profile.

Round tool work piece

square tool work piece

Tapered tool piece

Characterization of Composites

The composites were sliced using wire cut EDM and then machined to the required dimensions to prepare microstructure, tensile, impact specimens as shown in Fig 6.9. The specimens for metallographic examination were sectioned to the required sizes from the joint comprising weld zone (WZ), thermo mechanically affected zone (TMAZ), and heat affected zone (HAZ) and base metal (BM) regions. The specimens were polished using different grades of emery papers. Final polishing was done using the diamond compound (0.5µm particle size) in the disc-polishing machine. Specimens were etched with a solution of 100ml distillate water, 15ml hydrochloric acid and 2.5gram $FeCl_{3.}$ Micro structural analysis was carried out after deep etching the specimens using optical microscope (Make: Leitz) with image analyzing software (Biovismat).

Tensile specimens were machined as per ASTM E8M in the traverse direction from the welded joints and are shown in Fig 6.10.Tensile test was carried out in 60 tons, servo controlled Universal Testing Machine (Make: FIE-Blue star, India; Model: TUE-600©) the specimens were loaded at the rate of 1.5 kN/min as per ASTM specifications. Impact tests was performed by using Charpy impact test equipment.

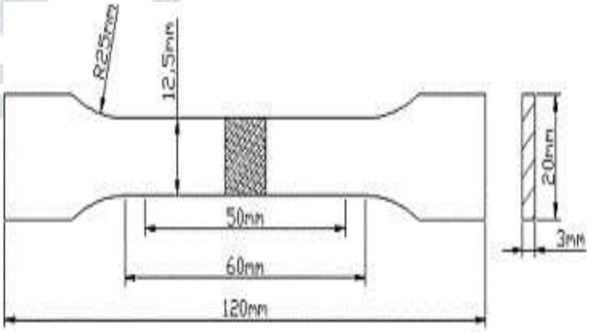
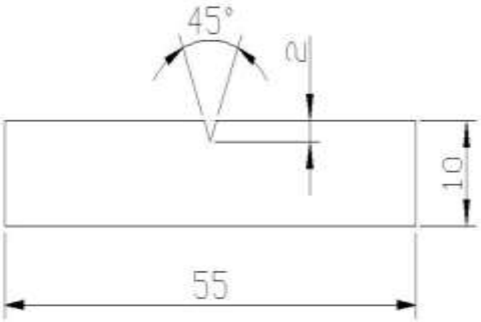


Fig 6.10schematic sketch of Tensile Specimen

Impact specimens were machined as per ASTM E8M in the traverse direction from the welded joints and are shown in Fig 6.11.

Impact test was carried out by using Charpy impact machine as shown in Fig.6.12. To study microstructure, the specimens were mounted by using mounting machine as shown in Fig 6.13.



Tensile Testing

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined young's modulus, poisons ratio, yield strength and strain-hardening characteristics.

IV. TENSILE TEST RESULTS

TOOL TYPE	TENSILE STRENTH(N/mm^2)
Round	149.523
Square	145.543
Taper	152.312

V.CONCLUSION

The effect of heat input on mechanical properties of the pure copper plates friction stir processed by different FSP tool pin profiles were investigated in this study. The observations of this investigation are summarized below.

1. Of the three tool pin profiles used to form FSP zones on copper plate, the three pin profiles (round, square and taper) show successful formation of FSP surface on copper
2. The microhardness of the processed copper plates was influenced by their grain sizes. The grain sizes were monitored by heat input during processing. High heat generation leads to grain growth in the stir zone which lowers the microhardness values.
3. Pin profiles are also responsible for heat generation during processing at stir zone. If the contact area of the pin is more with flowing material, then generation of frictional heat is also more.
4. Tensile properties of the processed copper plates depend on the heat input and subsequent mechanical mixing in stir zone. taper and round pin profiled tools show better mechanical mixing and better tensile strength values.

VI. REFERENCES

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