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# A Look at Friction Stir Processing for Making Better Surface Properties

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## *Abstract*

Friction stir processing is a surface properties modification method consequential from friction stir *welding. The process uses a non-consumable tool made up of tool steel material. The tool pin and shoulder plunged in the surface of the base material plates and it mover along the predetermined path. The frictional heat stimulates the plastic deformation during the process & enhances the dynamic recrystallization. The process represents an advanced approach that originates from Friction Welding process. Unlike, FSP, FSW focused solely on adapting the upper surface of the material rather than joining it. The process involves a rotating tool that penetrates the material's surface, moving along the desired path to induce surface modification. Surface composites are formed by incorporating reinforcement particles, such as Mo or* $B_4C$*, into grooves beneath the rotating tool, enhancing surface properties. This method effectively refines the microstructure and improves surface characteristics, including hardness, wear resistance, and corrosion resistance. Two primary approaches, the hole method and the groove method, are used in FSP, with the groove method being more common due to its superior results. The process relies on the exchange between the tool shoulder, pin, also workpiece, eliminating this need for shielding gas. FSP is environmentally friendly, energy-efficient, and material-conserving technology. This significantly improves the materials plastic deformation and improves the surface properties. One of its primary uses is in improving surface characteristics such as wear resistance, corrosion resistance, and hardness, especially in metals like aluminum, magnesium, and steel. FSP is also extensively used to repair casting defects such as porosity and shrinkage cavities, while refining coarse microstructures in cast alloys. In the automotive industry, it is employed to strengthen lightweight components like engine blocks and suspension systems by producing fine-grained microstructures and surface composites. The process is applicable in automobile and aerospace industries due to its advances in surface characteristics.*

**Keywords:** FSP, plastic deformation, microstructure refinement, surface properties modification, surface composites

## INTRODUCTION

Friction Stir Processing is a solid state surface improvement technology. The frictional heat generated softens the material without melting it, allowing the material to undergo intense plastic deformation and dynamic recrystallization. The frictional heat produced softens the material without causing it to melt, enabling severe plastic deformation and dynamic recrystallization to occur. It shares its fundamental principles with FSW but is specifically tailored to improve surface characteristics. It offers significant benefits such as refined grain structures, elimination of defects like

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porosity and distortion, and retention of alloying elements. Recognized as an environmentally friendly technique, FSP is often described as a "green efficient technology" due to its lack of gas or smoke emissions [1–5]. The process employs a rotating tool with a non-consumable design, typically featuring a concave shoulder and a threaded pin. This tool generates heat through friction and stirring, enabling plastic distortion and flow within the material. Enhancing material performance relies on microstructural modifications, which can be achieved by fine-tuning the FSP parameters. As an advanced surface modification technique, FSP leads to notable improvements in both microstructure and material properties. The resulting microstructure is divided into three distinct zones as the process stir zone, the thermomechanically affected zone near the stir zone, and the heat affected zone of the process region. The base material flows from retreating side to advancing side, while the tool shoulder exerts forging pressure (Figure 1). The solid-state nature of FSP ensures that modifications are free from defects [6–10].

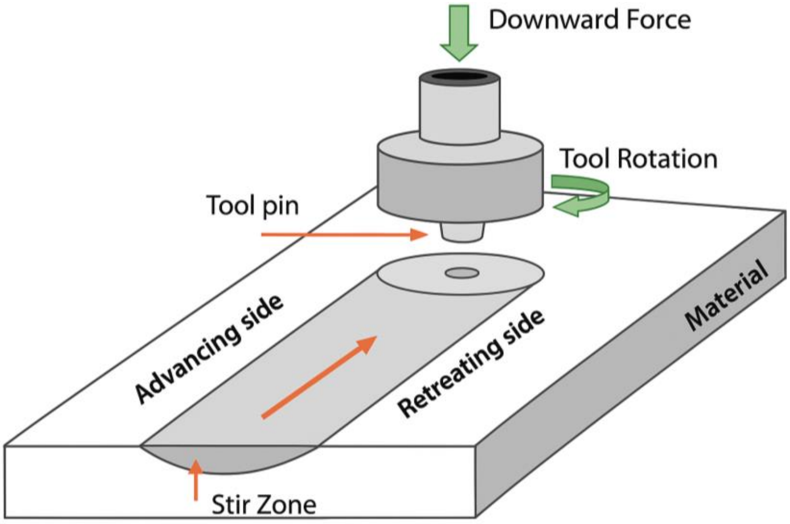


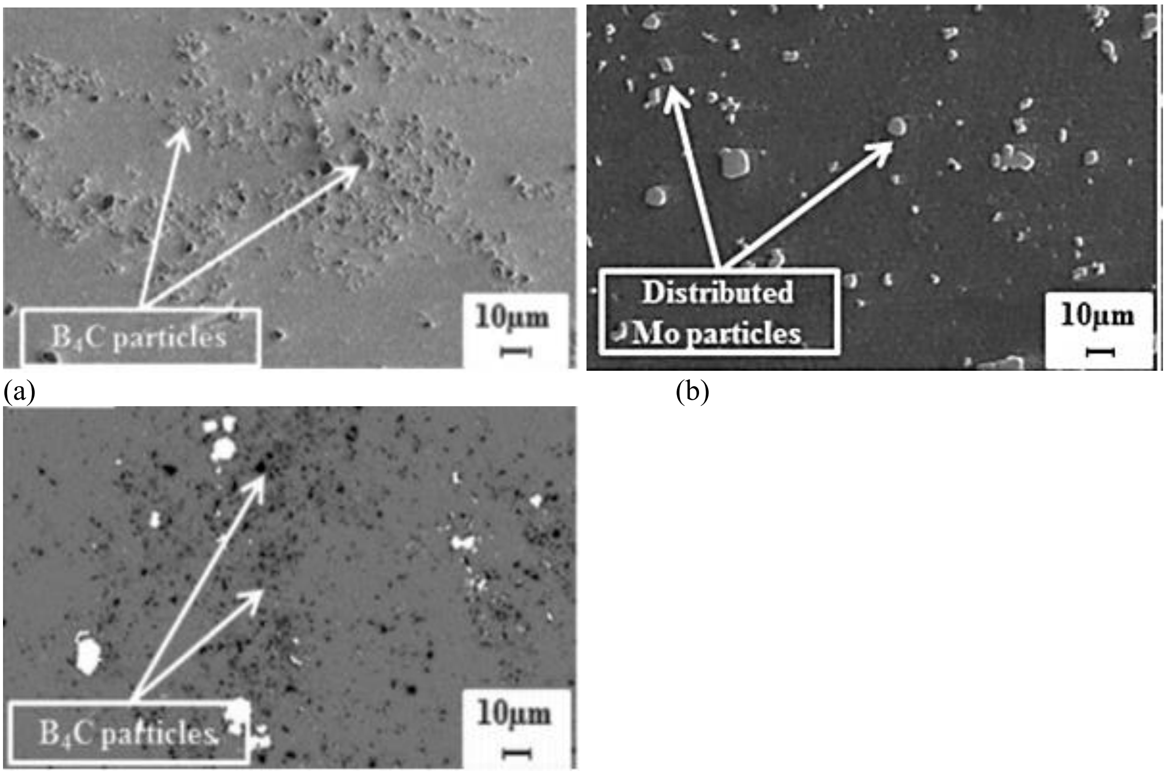
**Figure 1.** Schematic of FSP [1] Equiaxed & fine grains are generated in the nugget zone during FSP as contributes of dynamic recrystallization, occurring without the melting of the base material. Key parameters such as tool traverse speed, rotational speed, insertion depth of the tool, and tilt angle are crucial for producing a high-quality, defect-free surface. During FSP, material mixing and stirring occur primarily at top surface of the processed zone, directly beneath rotating tool. This innovative technique provides multiple advantages, such as improved corrosion resistance, enhanced mechanical properties, refined grain structures, reduced porosity in castings, and the ability to create customized alloys.

## REVIEW

Necar Merah et al. [1] investigated the sound effects of the Friction Stir Processing technique on microstructural and corrosion behavior. Their findings showed that the processed material developed an asymmetric grain structure, with finer grains observed on the advancing side. Although ductility tends to decrease, fracture toughness can vary based on processing parameters, tool geometry, and the type of steel used. The improved surface characteristics resulting from FSP contribute to enhanced fatigue performance and the formation of more stable passive films, offering superior corrosion resistance.

Marek Stanislaw Weglowski et al. [2] examined the microstructural distribution during FSP, highlighting the importance of material flow and plastic deformation across the central stir zone, next thermomechanically affected zone & heat affected zone of the process region. The learning demonstrated that the tool facilitates material transfer from the retreating side to the advancing side through forging action. It was also revealed that the region between the stir zone and plays a critical role in determining the resulting property modifications.

V.P. Mahesh et al. [3] conducted FSP on an AA 1050 aluminum plate measuring 150 mm × 100 mm × 6 mm, incorporating molybdenum and boron carbide particles as reinforcements. The process utilized a HSS tool. Post-processing analysis using optical microscopy revealed an even spreading of fortification elements in the processed zone. The avg. grain size was found to be 9.59 µm for molybdenum and 2.11 µm for boron carbide. Further microstructural evaluation using Scanning Electron Microscopy, along with corrosion testing, indicated improved material properties, including enhanced corrosion potential, reduced current density, and increased resistance to pitting corrosion following FSP (Figure 2).



(a) (b)

(c)

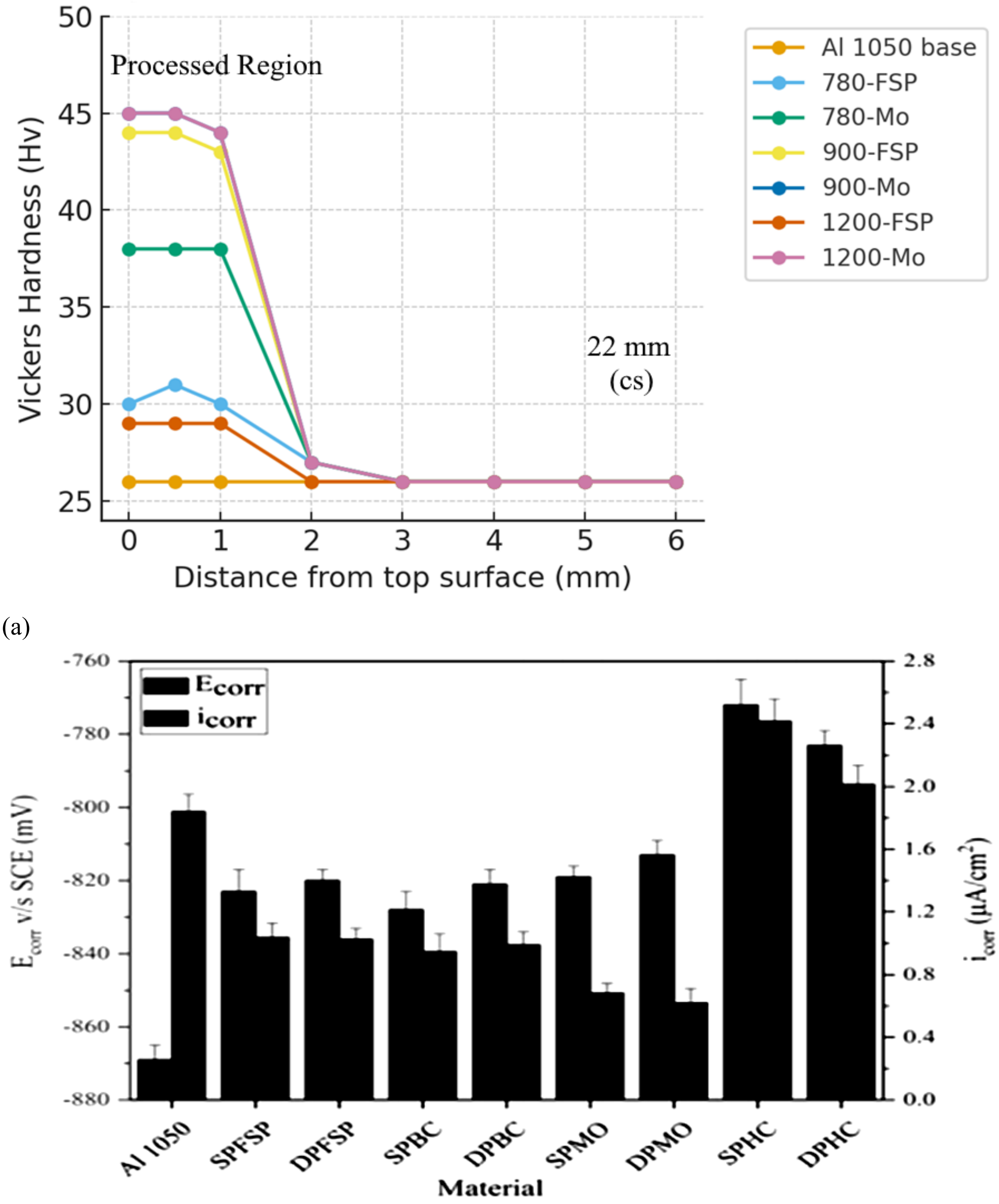
**Figure 2.** (a) SPBC, (b) SPMO, (c) SPHC [3, 5].

The base material crossed a certain level of ductility and strength. However, with the introduction of reinforcement particles, both strength and ductility improved significantly. As the amount of reinforcement increased, further enhancements in strength and ductility were observed.

The addition of reinforcement resulted in significantly increased hardening in the processed zone comparing to the base material. In single-pass samples, the particle size was relatively large, whereas in double-pass samples, the particle size was smaller. The addition of reinforcement resulted in increased surface hardness, which further improved with higher tool rotational speeds. Regarding corrosion behavior, single-pass samples exhibited lower corrosion rates, while double-pass samples showed higher corrosion rates. A low Epit value, indicative of pitting corrosion, demonstrated that molybdenum reinforcement enhanced corrosion resistance. However, hybrid composites were found to reduce corrosion resistance.

Ritukesh S. et al. [4] prepared test plates of an Al-$TiB_2$ metal matrix composite (MMC) using FSP. The plates had dimensions of 150x100x5 mm. The tool was made of H13 tool steel material. Microstructural assessment was accomplished using OM and SEM. The processed Al-$TiB_2$ composite exhibited improved corrosion resistance as a result of FSP.

Ghazal M. et al. [5] applied friction stir processing to Al-Si12 samples to progress surface eminence and refine the microstructure, in combination with selective laser melting. The FSP was conducted in both water & air environments to assess the impact of variable conserving rates. The FSP-treated samples exhibited significantly lower microhardness compared to the SLM samples, a difference ascribed to the presence of an extremely smaller Si-phase network in the SLM microstructure. Nevertheless, FSP effectively reduced surface roughness and enhanced the microstructural quality of the SLM samples (Figures 3 and 4).



(a)

(b)

**Figure 3.** (a) Hardiness distribution of the FSPed materials, (b) $E_{corr}$ and $i_{corr}$ plots [4, 5, 9].

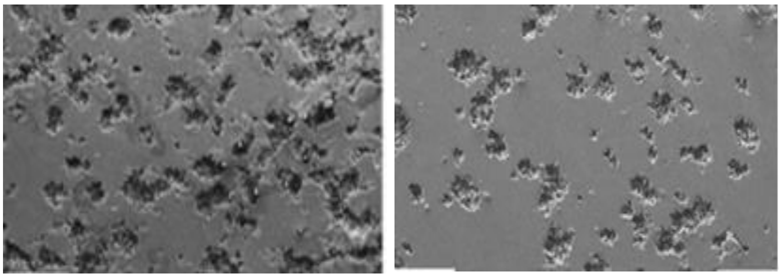


**Figure 4.** Post-corrosion micrographs of a) Al1050 alloy, b) Al-$B_4C$ [4, 8, 9].

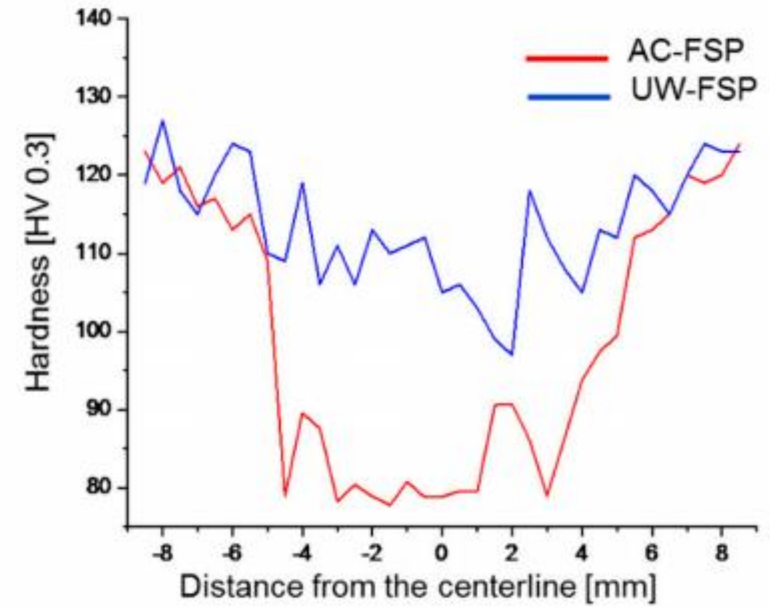
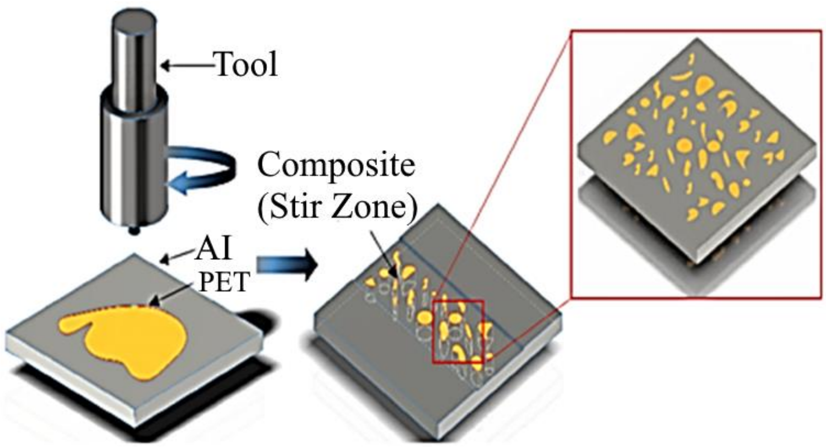


**Figure 5.** Air cooled FSP and under water FSP treated surface hardness distribution [3, 9].

The surface roughness decreased, and the grain size was refined. A big change in corrosion behavior was observed, with the water-cooled FSP samples exhibiting higher corrosion resistance compared to the air-cooled samples (Figure 5).

Arpan Rout et al. [6] reinforced aluminum (Al) surfaces with polyethylene terephthalate (PET) using Friction Stir Processing (FSP). The aluminum plates measured 150x100x6 mm. A rectangular groove measuring was machined along the full length of each plate to accommodate PET chips. The process employed an H13 tool steel (Figure 6).



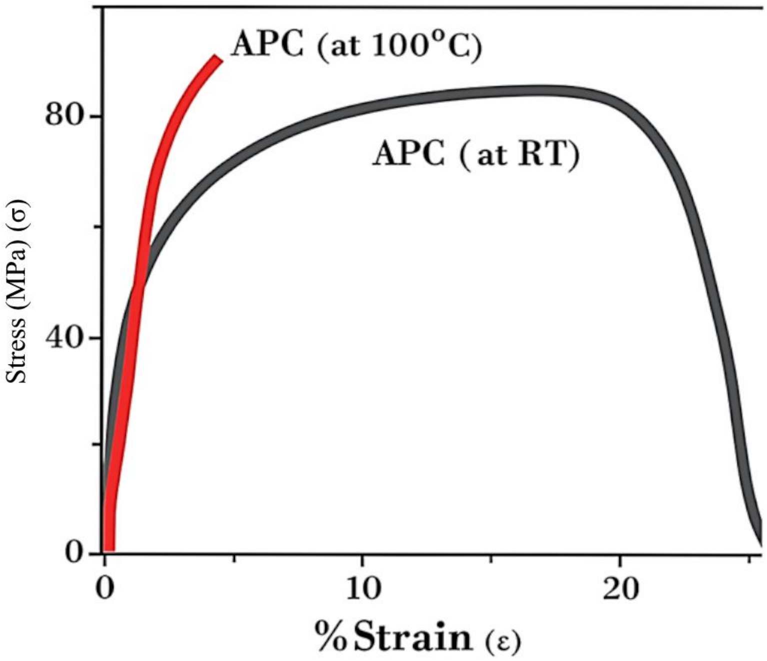


**Figure 6.** Diagram illustrating the Friction Processing of Al+PET [5, 9].

Stress-strain curves were obtained for both base aluminum (Al) and the aluminum-polymer composite (APC) at room temperature, as well as for the APC at an elevated temperature of 100°C. Small PET particles were dispersed across the top surface and embedded within the aluminum matrix. Scanning Electron Microscopy (SEM) confirmed the presence of these PET particles, while Transmission Electron Microscopy (TEM) revealed their uniform distribution and complete incorporation into the matrix. At room temperature, the Al + PET compound demonstrated improved strength & ductility due to the reinforcing effect of the PET particles during Friction Stir Processing (FSP). However, with increasing temperature, the polymer's reinforcing capability diminished, resulting in less pronounced mechanical performance at elevated temperatures.

## CONCLUSIONS

A review of the literature on FSP of material surfaces indicates that FSP-treated samples exhibit improved corrosion resistance and lower corrosion rates.

- The second processing pass further enhanced corrosion resistance, as finer particles in the surface composites were more uniformly distributed.
- Mechanical particle shearing took place within the composites, with no intermetallic compounds detected in the processed area.
- Surface hardness increased with an increase in the tool shoulder diameter. Conversely, a smaller tool shoulder diameter led to a significant reduction in the avg. grain size of the processes region.
- The processes material showed a noteworthy improvement in both strength & ductility of the processes region.

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