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COMPARISON BETWEEN FRICTION STIR WELDING (FSW) AND FRICTION STIR PROCESSING (FSP) OF AA5086 ALUMINIUM ALLOY

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***Abstract*— In this work, an investigation has been carried out on Friction stir welding (FSW) and friction stir processing (FSP) of 3mm thick plates of AA5086-H32 aluminium alloy using high carbon high chromium alloy steel tool with a thread tool pin shape . The process variable are welding type (FSW and FSP) and rotational speed which consist of three different rotational speed (750, 1000 and 1250) rpm and traverse speed remand constant at 40mm/min. It has been observed that the microstructural grain size of (FSP) welded joints is slightly finer than (FSW) joints. Also it was found that (FSW) welded joints have shown lower tensile strength, bending strength, percentage of elongation and Also lower hardness value as compared to the (FSP) welded joints and this trend is common for all welded** joints.

Index terms- **Friction Stir Welding; Aluminium Alloy 5086-H32; Tool Pin Profile; Mechanical Properties.**

I. INTRODUCTION

Friction stir welding (FSW) considered as a solid-state process that means the objects are joining without of base metals melted. This promised with completely new version of welding technology. In FSW, a pin of tool is rotated and plunged into the interface area between the two parts of welded specimens, and that parts clamped securely to prevent them from being diverge from each other. The Frictional heat will be generated between the workpiece and welding tool which causing a percentage of soften in workpiece which not reach the melting state, that situation make tool string easer along the welding. The plastic deformation occurred in the interface area which made transformation of material between the two parts that fabricated the joint between them. The Friction stir welding is a useful way to joint aluminum plates without shielding gas or filler wire, the useful welding range of metal thickness (0.5mm-65 mm) [1]. FSP was developed for improving the surface modification based on the principles of new solid-state welding technique. In this process a special non-consumable rotating tool is used; the shoulder of the tool rubs the surface and gives enough load and generating sufficient heat to soften the material. The pin plunged into the material producing refined microstructure due to "stirring‟ action. The purpose of this article is to Review the process parameters and tools used in FSP and FSW of ferrous materials and Al/Mg Alloys [2]. Fig.1 shows the Process principle of friction stir welding process.

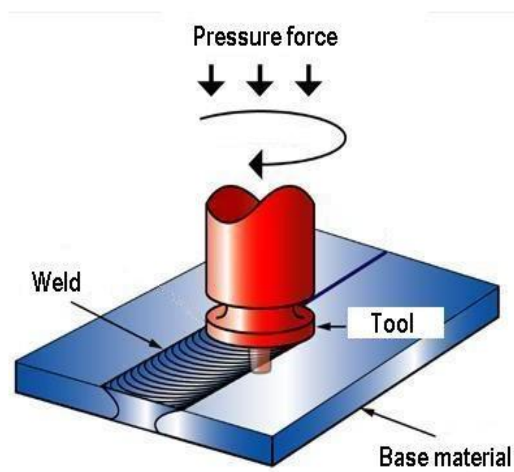

Figure 1. Process principle of friction stir welding process [1]

The resulting microstructure is composed of three primary zones [3]:

- The heat-affected zone (HAZ).
- The thermo-mechanically-affected zone (TMAZ).
- The nugget zone (NZ).

Figure 2. Welded zones [3]

As a result of intense plastic deformation at elevated temperature, grain refinement to a size range from 0.8 to 12 µm can be achieved. It is well known that the nugget zone consists of fine and equiaxed grains Produced due to the dynamic recrystallization. FSP has proven to be successful in the modification of various properties such as formability, hardness, and yield strength, fatigue and corrosion resistance [4].

Friction stir welding Processing parameters including:

- Tool rotation rate
- Tool shape
- spindle tilt angle
- Traverse speed
- target depth

Naturally, there are important effects to the tool during welding: abrasive wear, high temperature and dynamic effects. Therefore, the good tool materials have the following properties:

- good wear resistance,
- high temperature strength, temper resistance,
- Good toughness.

Therefore there are two important fields of friction stir welding tool design: tool material and geometry [5].

II. 2 EXPERIMENTAL WORK

The base material used in this research was aluminum alloy AA5086-H32 plate's thickness of 3 mm. A pair of workpieces every one of them with dimension 100mm ×200mm ×3 mm were abutted to form square plate and clamped tightly on the backing plate for welding, having chemical composition and mechanical properties standard [6] and measured values as shown in **Table 1** and **2** respectively.

Table.1 chemical composition of Aluminium alloy5086-H32 standard (**ASTM B92-02a**) [6] and measured values

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Standard	0.4	0.5	0.1	0.2–0.7	3.5–4.5	0.05–0.25	0.25	0.15	Remainder
Measured	0.4	0.5	0.1	0.14	4.05	1.22	0.25	0.15	Reminded

Table2. Mechanical properties of Aluminium alloy 5086- H32 standard (**ASTM B92-02a**) [6] and measured values

	Ultimate strength (MPa)	Yield strength(MPa)	Modulus of elasticity(GPa)
Standard	325	210	71
Measured	312	205	70

The welding process curried out by using the C-TEK CNC milling machine as showing in **Fig.**3.

Figure 3. C-TEK milling machine

The welding tool material is High Speed Steel. The tool has Thread pin profile as shown in **Fig.4.**

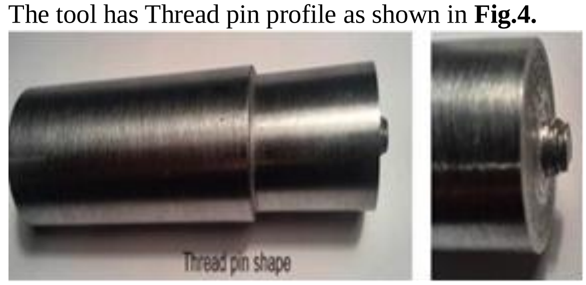

Figure 4. Tools profile shapes

The tool material is available in rods. The Cylindrical tools geometries were manufactured by using turning machine according to the specified dimensions.

Specifications of the tool and welding parameters are given in the **Fig.5** and **Table.2**

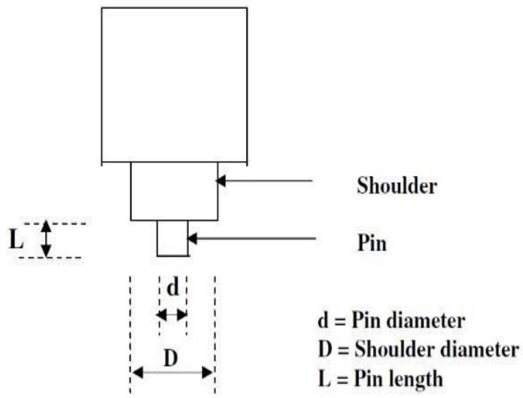

Table 2. Tool details and welding parameters

Process parameters	Values
Pin length (mm)	2.8
Tool shoulder diameter D (mm)	15
Pin diameter d (mm)	5
D/d ratio	3
Rotation speed (RPM)	750,1000,1250
Welding speed (mm/min)	40

In the FSP process, the plates were turned over about an axis along the joint after the primary pass was produced, so that the second welding passes started at the same position along the joint line, and the advancing side of the second pass was over the retreating side of the first pass weld. All of the welds were produced along the rolling direction of the aluminium Plate. Tool rotation speed variable as showed in **Table.2**, traverse speeds and tool tilt angle were kept constant at 40 mm/min and zero for traverse

Speed and tilt angle respectively he process variables were, rotation speed and passes type FSW and FSP . In both cases, depth of depression was 2.9 mm. For Friction Stir Welding and friction stir processing were adopted:

- Friction stir welding (FSW) Tool pin length was 2.8 mm

  Time taken was 4 min for length 150 mm

- Friction stir processing FSP) Tool pin length was 2.8 mm

  Time taken was 8 min for length 150 mm

Tensile test specimens were prepared according to the (ASTM E8).Tensile test was carried out on the Testing Machine at room temperature. After necking. The load and elongation was recorded. The bending test carried out according to the (ASTM-E290). Micro hardness test was done on **Viker's** Hardness Tester to determine the hardness value curve along the welding cross-section line. Microstructuree test done according to the (ASTM E407-76)

III. RESULTS AND DISCUSSION

The welded specimens are categorized as shown in Table 3.

Table 3. Specimen specifications

Symbol	Process type	Rotating speed (RPM)
FSW 4	Friction stir welding	750
FSP 4	Friction stir processing	750
FSW 5	Friction stir welding	1000
FSP 5	Friction stir processing	1000
FSW 6	Friction stir welding	1250
FSP 6	Friction stir processing	1250

3.1 TENSILE TEST

The welded specimens were put under tensile testing by using (Testometric) tester and the values of ultimate tensile strength and joint efficiency were noted. The results of tensile stress of the base metal and welded specimens in single and double pass are shown in **Tables 4**. The stress strain curve for tensile test of the specimens are shown in **Fig.6-8**

.respectively. **Fig.9** shows the summary of ultimate tensile strength for all specimens

Table 4. Ultimate tensile strength results

Process symbol	Ultimate tensile strength (MPa)	Efficiency of tensile
BM	312.7	100
FSW 4	170.2	54
FSP 4	259.6	83
FSW 5	270.3	86
FSP 5	286.3	91
FSW 6	248.1	79
FSP 6	295.2	94

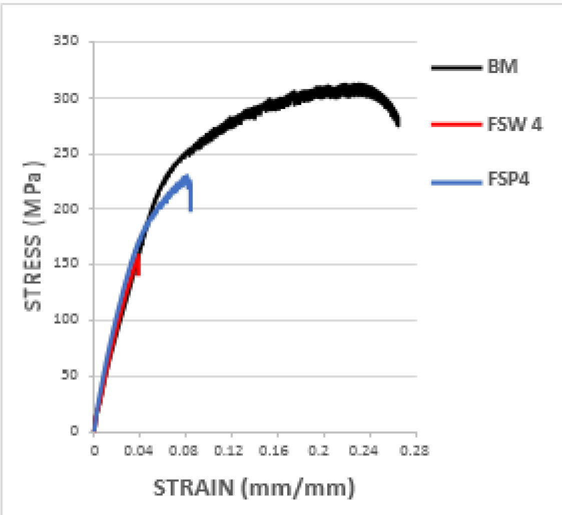

Figure 6. Tensile results of specimens welded at 750 RPM

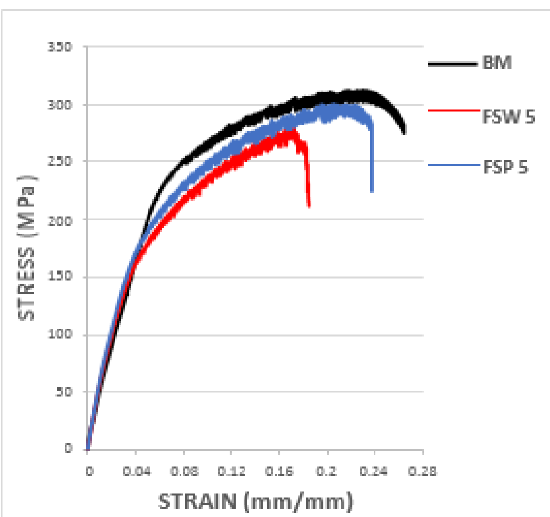

Figure 7. Tensile results of specimens welded at 1000 RPM

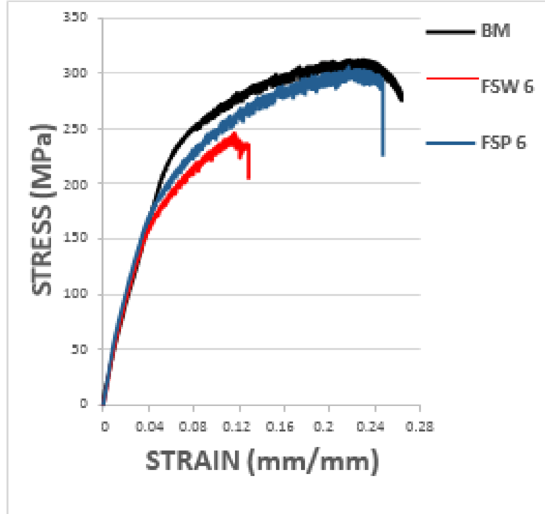

Figure 8. Tensile results of specimens welded at 1250 RPM

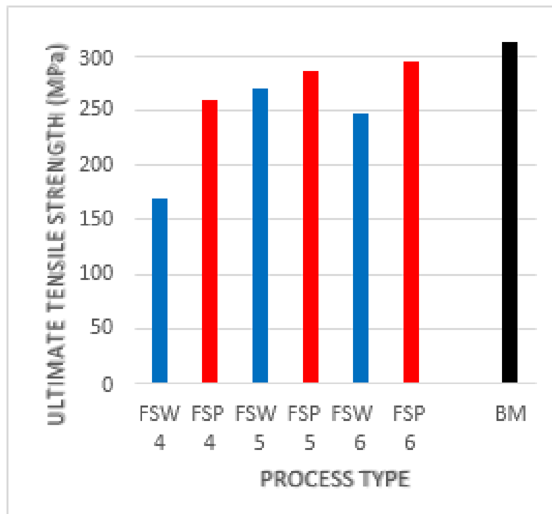

Figure 9. Results for all tensile specimen

Table 4 shows that the specimens welded with using FSP welding type exhibited superior tensile properties [7], the best specimens of FSP welded specimens group reaches to 295.2 MPa tensile strength at 1250 RPM. The specimens that welded by using Friction stir welding (FSP) welding type showed lower tensile strength and percentage of elongation as compared with specimens that welded using (FSP) welding type [8] therefore the best result in FSW welding type not exceed 270.3 MPa at 1000 RPM but.

3.2 BENDING TEST

Bending force results recorded in Table 6.the Figures (10-12) configured the force-deflection curve for the specimens also according to the rotational speed and Fig.13 identified the summary of bending strength of all welded specimens.

Table 5 Bending results specimens

Process symbol	Bending force (N)	bending Efficiency
BM	342.5	100
FSW 4	265.2	77
FSP 4	280.4	82
FSW 5	268.5	78
FSP 5	307.8	90
FSW 6	273.6	80
FSP 6	314.6	92

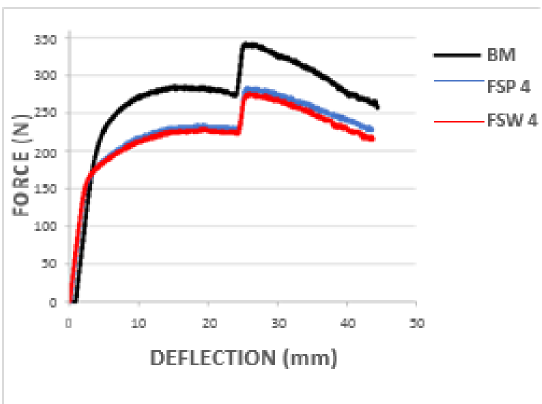

Figure 10 Bending results of specimens welded at 750 RPM

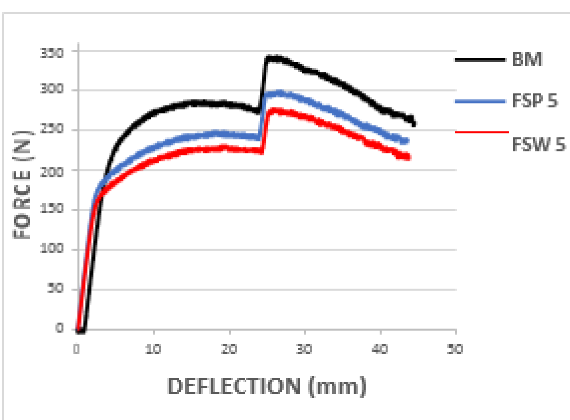

Figure 11 Bending results of specimens welded at 1000 RPM

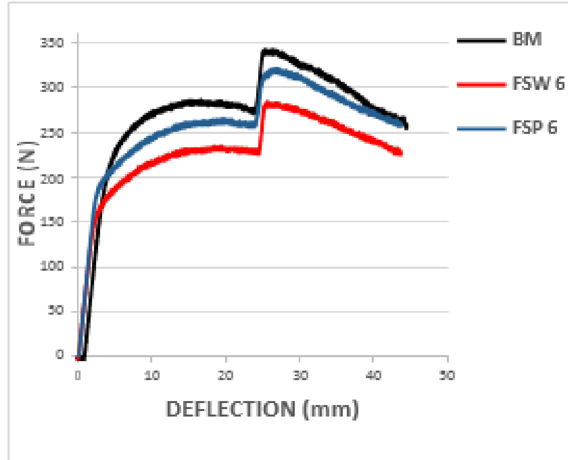

Figure 12 Bending results of specimens welded at 1250 RPM

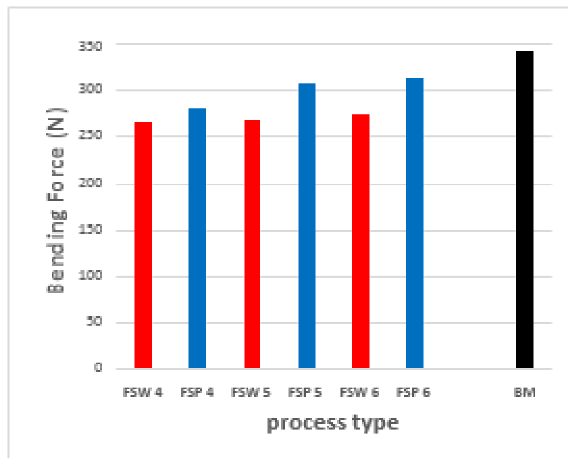

Figure 13 Summary of bending results of all specimens

Table 5 shows that the specimens welded with using FSP welding type exhibited superior tensile properties [7] which reaches the best specimens of FSP welded specimens group to 307.8 N bending strength at 1250 RPM. The specimens that welded by using Friction stir welding (FSW) welding type showed lower bending strength force and deflection as compared with specimens that welded using (FSP) welding type [8] therefore the best bending strength result in FSW welded specimens not exceed 273 N at 1250 RPM but also it consider as a good results which efficiency reached to 80% when it compared with bass metal.

3.3 MICROHARDNESS TEST

Vickers micro-hardness profiles of the welded zones were measured on a cross- section perpendicular to the welding direction using a Vickers indenter. The micro hardness of base metal is **87 HV**. Micro hardness at the nugget zone (NZ) of FSW and FSP is shown in **Table7**. A plot of micro hardness as a function of position from the weld center line is plotted for both single and double pass as showing in **Fig.14.** and **Fig.15** shows the summary of hardness value at the nugget zone for all specimens.

Table 6. Micro-hardness results of specimens

Process type	NZ hardness (HV)
BM	87
FSW 4	66
FSP 4	72.1
FSW 5	74
FSP 5	76
FSW 6	69
FSP 6	79

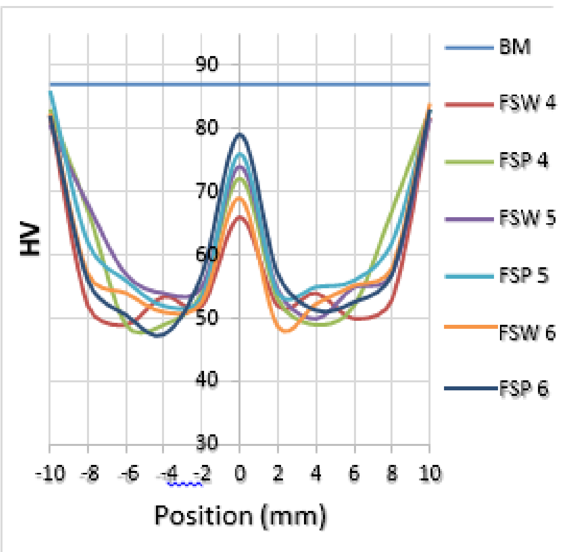

Figure 14. Micro-hardness results

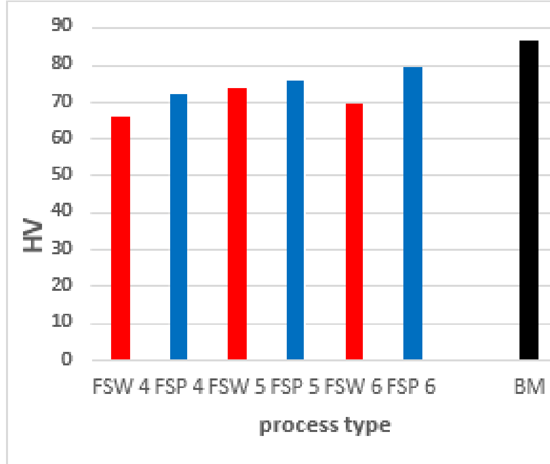

Figure 15. Summary of microhardness results at nugget zone of all specimens

Figures (11-13) shows that the specimens that the specimens welded by using friction stir processing (FSP) area has a higher Vickers hardness value than friction stir welding (FSW) because of FSP is caused to grain refinement and according to the Hall-Petch relationship the hardness increases as the grain size decreases[9] .

3.4 MICROSTRUCTURE TEST Welding line zones explained by using optical microscope. The results of that test configured in Fig.16 indicates the welded zones (NZ, TMAZ and HAZ) for the best mechanical properties of friction stir welding (FSW) and friction stir processing (FSP) welded specimens

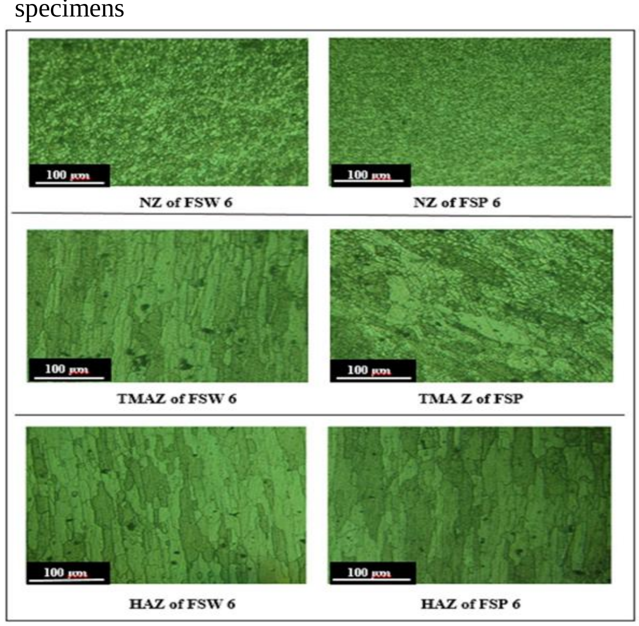

Figure 16. Microstructural results of FSW and FSP specimens

the welding zones consists of three zones: the nugget zone (NZ), the thermo- mechanical affected zone (TMAZ), and the heat affected zone (HAZ).The grain size distributions ware shown in Fig.16 , and it is obvious that grain size within the nugget region is much smaller than that of other regions and the diameter of grain size for NZ

.The mechanical properties of welding depend on the grain size of joint region so when the joint region grain size near the grain size of bass metal that mean the properties of that joint will be near the bass metal properties , from above the mechanical properties depend on grain size [10]. From Fig.16 it can be seen that the FSP is giving ultra-fining and modification of microstructure for nugget (welding) zone and other welding zones this refining leads to increase the mechanical properties.

IV. CONCLUSION

In this investigation an endeavor has been made to evaluate the effect of rotational speed variation (750,1000 and 1250) on tensile and bending strength , microhardness values and microstructural results of friction stir welding (FSW) and friction stir processing (FSP) of 5086-H32 Aluminum alloy. The joints fabricated by friction stir processing (FSP) have shown the ultimate tensile strength, percentage elongation and bending strength was greater than the joints fabricated by friction stir welding (FSW) and this sequence of values is common for all rotational speeds. Micro-hardness of (FSP) specimens are larger as compared to the joints produced by (FSW).Also the microstructural results showed that the (FSP) cross section of welding line showing more finer that the microstructure of FSW welding line as a result of friction stir processing effect which refining the microstructure and that effect increasing the mechanical properties of welding.

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