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Influences of Tool Pin Profile and Welding Parameters on Friction Stir Weld Formation and Joint Efficiency of Aa5083 Joints Produced By Friction Stir Welding

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ABSTRACT— *In this investigation, an attempt has been made to understand the effect of welding parameters and tool pin profile on formation of friction stir processing zone and tensile properties in AA5083 aluminium alloy. Friction stir welding between 5083 aluminium alloy plates with a thickness of 2.5 mm was performed. Five different tool pin profiles (Taper cylindrical, triangular, cylindrical, square and cone) have been used to fabricate the joints at three different rotational speeds i.e. 900, 1400 and 1800 rpm under a constant traverse speed of 16 mm/min. Tensile properties of the joints have been evaluated and correlated with the friction stir weld zone formation. From this investigation it has been found that the tool pin profiled designs had little effect on heat input and tensile properties, weld properties were dominated by thermal input rather than the mechanical deformation by the tool for the plate thickness of 2.5 mm. Cylindrical pin profiled tool produces mechanically sound defect free welds compared to other tool pin profiles.***

Keywords— *Friction stir welding, AA5083 aluminium alloy, tool pin profile, tensile properties, surface morphology*

I. INTRODUCTION

Aluminium alloy AA5083 is commonly used in the manufacturing of pressure vessels, marine vessels, armorer vehicles, aircraft cryogenics, drilling rigs, structures and even in missile components etc. Aluminium alloy AA5083 is considered as non-heat treatable alloy and therefore conventional post welding treatments are not used. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. FSW process was developed by The Welding Institute (TWI) of Cambridge, England in 1991[1]. This joining technique is simple, environment friendly, energy efficient, and becomes major attraction for automobile and aircraft industries. Due to the high strength of the FSW joints, it allows considerable weight savings in light weight construction compared to conventional joining technologies [2]. In contrast to conventional joining welding process, there is no liquid state for the weld pool during FSW, the welding takes place in the solid phase below the melting point of the materials to be joined. Thus, all the problems related to the solidification of a fused material are avoided. Materials which are difficult to fusion weld like the high strength aluminium alloys can be joined with minor loss in strength [3].

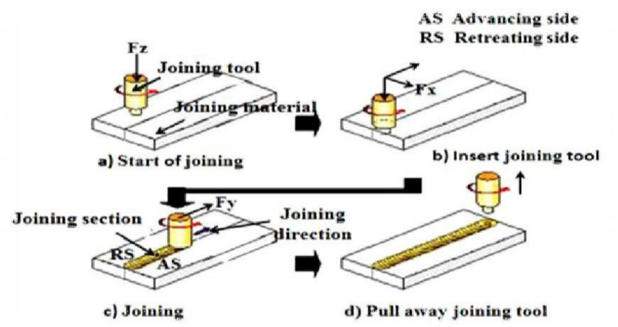


Fig.1 Schematic representation of FSW [6]

In friction stir welding a non-consumable rotating tool with a specially profiled threaded/unthreaded pin and shoulder is rotated at a constant speed. The tool plunges into the two pieces of sheet or plate material and through frictional heat it locally plasticised the joint region. The tool then allowed to stir the joint surface along the joining direction [4]. During tool plunge, the rotating tool undergoes only rotational motion at only one place till the shoulder touches the surface of the work material; this is called the dwelling period of the tool. During this stage of tool plunge it produces lateral force orthogonal to welding or joining direction [5] as shown in fig.1.

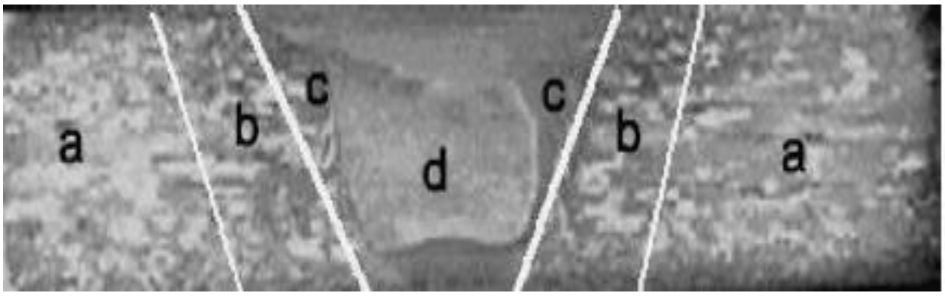


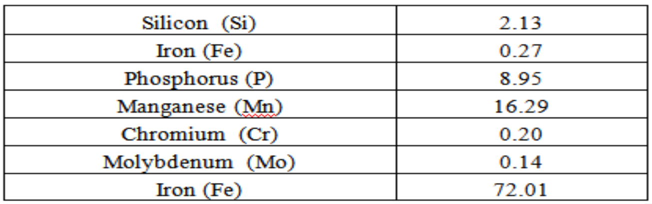
Fig. 2 Different regions of FSW joint: (a) unaffected base metal, (b) heat affected zone (HAZ), (c) thermo-mechanically affected zone (TMAZ) and (d) friction stir processed (FSP) zone. [7]

FSW joints usually consist of four different regions as shown in Fig. 2. They are: (a) unaffected base metal (b) heat affected zone (HAZ) (c) thermo-mechanically affected zone (TMAZ) and (d) friction stir processed (FSP) zone. The formation of above regions is affected by the material flow behaviour under the action of rotating non-consumable tool. However, the material flow behaviour is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters [8]. The effects of welding parameters and tool profiles on tensile properties and surface morphology in AA5083 aluminium alloy are not reported. Hence, in this investigation an attempt has been made to understand the effect of tool pin profiles and welding speed on FSW formation, tensile properties and surface morphology.

II. EXPERIMENTAL WORK

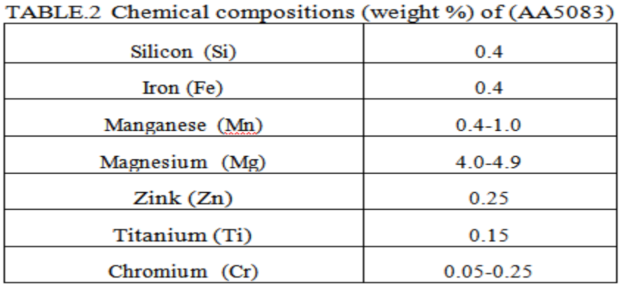
The rolled plates of 2.5 mm thickness, AA5083 aluminium alloy, have been cut into the required size (200mm×100mm×2.5mm) by power hacksaw cutting and milling. Square butt joint was formed by FSW in a single pass welding procedure. No special treatment was carried out before welding and testing. Non-consumable tools made of stainless steel SS316 have been used to fabricate the joints and the chemical composition of tool material (SS316) and workpiece material was analysed by energy dispersive X-ray spectroscopy, chemical composition is shown in table 1.

TABLE.1 Chemical compositions (weight %) of the tool material (SS316)



Silicon (Si)	2.13
Iron (Fe)	0.27
Phosphorus (P)	8.95
Manganese (Mn)	16.29
Chromium (Cr)	0.20
Molybdenum (Mo)	0.14
Iron (Fe)	72.01

TABLE.2 Chemical compositions (weight %) of (AA5083)



Silicon (Si)	0.4
Iron (Fe)	0.4
Manganese (Mn)	0.4-1.0
Magnesium (Mg)	4.0-4.9
Zink (Zn)	0.25
Titanium (Ti)	0.15
Chromium (Cr)	0.05-0.25

TABLE.3 Welding parameters and tool dimension

Process parameters	Values
Rotational speed (rpm)	900, 1400, 1800
Welding speed (mm/min)	16
D/d ratio of tool	3.75
Pin length, L (mm)	2
Tool shoulder diameter, D (mm)	15
Pin diameter, d (mm)	5

Five different tool pin profiles (Taper cylindrical, triangular, cylindrical, square and cone) shown in fig. 3 and fig. 4 have been used to fabricate the joints. Using each tool, three joints have been fabricated at three different rotational speeds and in total 15 joints (5×3) have been fabricated. The welding parameters and tool dimensions are presented in table 3. The chemical composition and mechanical properties of workpiece material (AA5083) is represented in table 2 and 4. Tensile test were carried out over parent material i.e. AA5083 and stress strain curve showing yield point, ultimate tensile strength and % elongation is as shown in fig. 5. All the detailed analysis about different pin profiled tool such as tool dimensions, pin volume , swept volume and ratio of swept volume to pin volume is given in table 5 and detailed analysis about tool surface area, pin surface area and shoulder surface area is given in table 6. It has been found that tool with triangular pin profile has highest shoulder surface area and least pin volume.

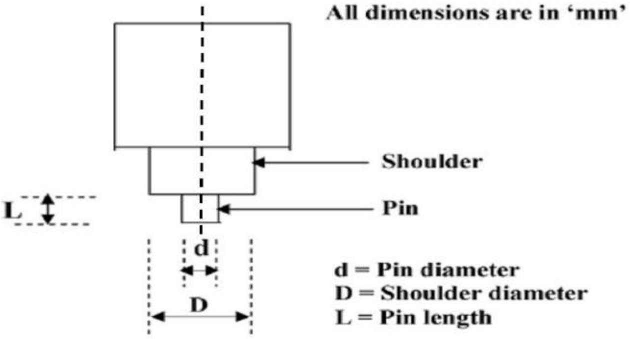
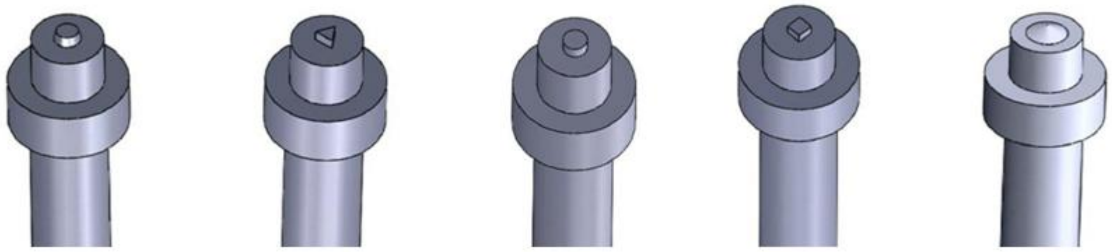


Fig.3 FSW tool dimensions

TABLE 4. Mechanical properties of AA5083 material

Parameters	Values
Tensile yield strength	121 MPa
Ultimate tensile strength	175 MPa
Elongation (%)	6.37
Vickers hardness	75 HV



(a) Taper **(b) Triangular** **(c) Cylindrical** **(d) Square** **(e) Cone**

Fig.4 FSW tool pin profile

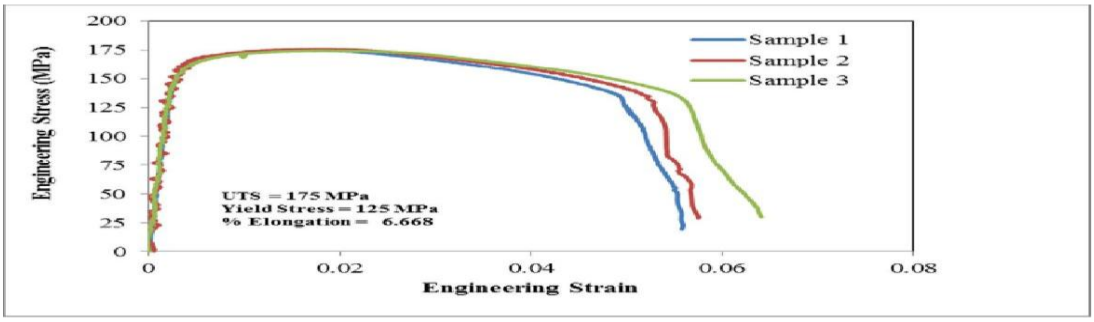


Fig.5 Tensile properties of parent material (AA5083)

TABLE.5 Effect of pin profile on dynamic to static volume ratio

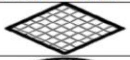
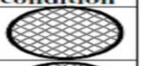
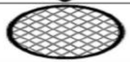
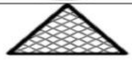
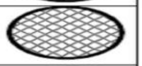
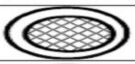
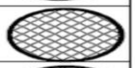
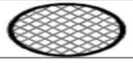
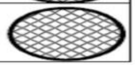
Tool pin profile	Dimensions (mm)	Pin volume mm^3	Swept volume mm^3	Swept volume/ Pin volume	Area occupied by pin in static condition	Area occupied by pin in dynamic condition
Square	Pin Height : 2 3.55 mm sq.	25	39.269	1.57		
Straight cylindrical	Pin Height : 2 Pin Dia. : 5	39.269	39.269	1		
Triangular	Pin Height : 2 Triangle Side : 4.33	16.237	39.269	2.418		
Taper cylindrical	Pin height : 2 Root Dia. : 5.5 Tip Dia. : 4.483	39.269	39.269	1		
Cone	Pin height : 2 Root Dia. : 8.660	39.269	39.269	1		

TABLE.6 Pin, shoulder and tool surface area for different pin profiled tool

S. No.	Tool pin profile	Shoulder surface area (mm^2)	Pin surface area (mm^2)	Tool surface area (mm^2)
1	Square	164.219	40.776	204.995
2	Cylindrical	157.081	51.05	202.131
3	Triangular	168.597	34.098	202.695
4	Taper cylindrical	152.957	48.11	201.067
5	Cone	117.814	129.746	247.56

The welded joints are sliced using power hacksaw and then machined to the required dimensions to prepare tensile specimens as shown in fig.6. American Society for Testing of Materials (ASTM E8M-04) guidelines is followed for preparing the test specimens. Tensile test has been carried out in 100kN; electro-mechanical controlled Universal Testing Machine (INSTRON) as shown in fig.7 (a). The specimen is loaded at the strain rate of 2mm/min as per ASTM specifications & extensometer is attached to specimen, so that tensile specimen undergoes deformation as shown in fig.7(b). The specimen finally fails after necking and the load versus displacement has been recorded. The 0.2% offset yield strength, ultimate tensile strength and percentage of elongation have been evaluated.

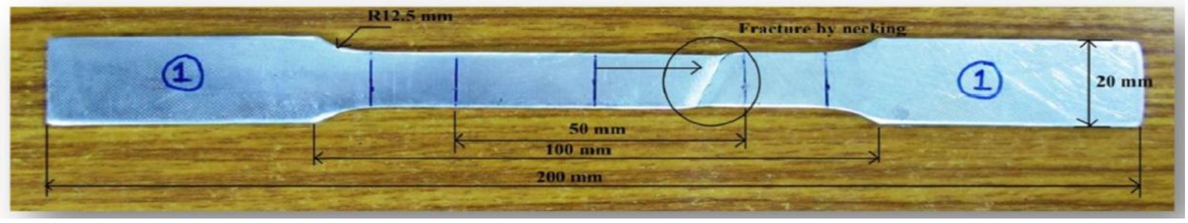


Fig. 6 Tensile test specimen

(a) (b)

Fig. 7 (a) Universal Testing Machine (INSTRON) (b) Specimen mounted over UTM along with extensometer

III. RESULT AND DISCUSSION

3.1 Tensile properties:

Transverse tensile properties of FSW joints such as yield strength, ultimate tensile strength, percentage of elongation and joint efficiency have been evaluated. Two specimens were tested at each condition and average of the results of two specimens is presented. It can be inferred that the tool pin profile and rotational speed are having influence on tensile properties of the FSW joints. Of the fifteen (5x3) joints, the joints fabricated by square tool profile and cylindrical pin profile exhibited superior tensile properties compared to other joints irrespective of rotational speed.

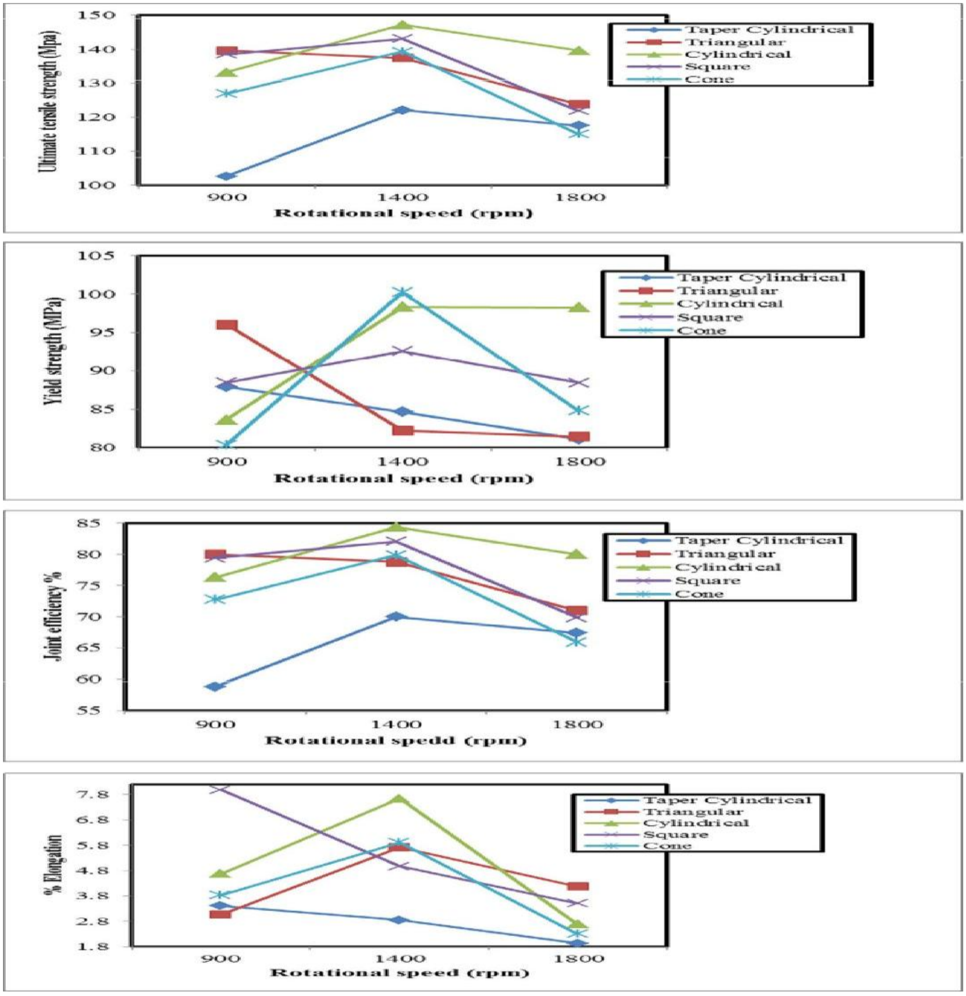


Fig.8 Effect of rotational speed and tool pin profile on tensile properties (a) Ultimate tensile strength (b) Yield strength (c) Joint efficiency % (d) % Elongation

The joints fabricated at a rotational speed of 900 rpm have shown lower tensile strength and elongation compared to the joints fabricated at a rotational speed of 1400 rpm and this trend is common for all the tool profiles except triangular pin tool. Similarly, the joints fabricated at a rotational speed of 1800 rpm have also shown lower tensile strength and elongation compared to the joints fabricated at a rotational speed of 1400 rpm. The effect of welding speed is concerned, the joint fabricated at a rotational speed of 1400 rpm is showing superior tensile properties compared to other joints, irrespective of tool profiles except triangular pin tool is shown in fig. 8. Tensile strength of the AA5083 joints fabricated by triangular pin tool significantly decreases as rpm increases. Triangular pin tool showed highest tensile strength at 900 rpm and then decreases for the joints fabricated at 1400 rpm and 1800 rpm.

This is because as triangular pin has highest shoulder area so it generates sufficient heat for welding at 900 rpm and produces defect free joint. As rpm increase excessive heat generation causes the formation of flash defect due to those tensile properties gets deteriorated. Weldability is significantly affected by the rotational speed. At high rotational speed (1800 rpm) straight cylindrical tool is the best; at the middle rotational speed (1400 rpm) straight cylindrical and square tool are the best; while for low rotational speed (900 rpm) triangular and square tool are the best. But the joints fabricated by taper cylindrical and cone pin profiled tools exhibited inferior tensile properties compared to their counterparts, irrespective of rotational speed used. During tensile test, most of the specimens failed in the FSP region but not in the weld line. Most of the specimens were failed in HAZ at advancing side and very few specimens were failed at centre line of the weld. Fig.9 is showing top and bottom surface of weld. Fig.10 is showing specimen fractures in HAZ at advancing side and specimen fractures along weld line.

As the rotational speed increases, the heat input also increases. However, the calculated maximum temperatures are nearly the same in all the rotational speeds. This phenomenon can be explained by the following two reasons: first, the co-efficient of friction decreases when a local melt occurs, and subsequently decreases a local input; secondly, the latent heat absorbs some heat input. When the rotational speed increases, the heat input within the stirred zone also increases due to the higher friction heat which in turn result in more intense stirring and mixing of materials. As the spindle speed increases from 900 rpm to 1400 rpm, both the strength and joint efficiency improved, reaching maximum before falling again at high rotational speeds i.e. 1800 rpm.

Higher tool rotational speed resulted in higher heat generation and this led to the excessive release of stirred material to the upper surface, which produced micro voids in the stir zone. Presence of micro voids deteriorated the tensile properties of the joint fabricated at a rotational speed of 1800 rpm compared to the joint fabricated at a rotational speed of 1400 rpm. The joint fabricated with a rotational speed of 1400 rpm produced higher strength properties of the joints.

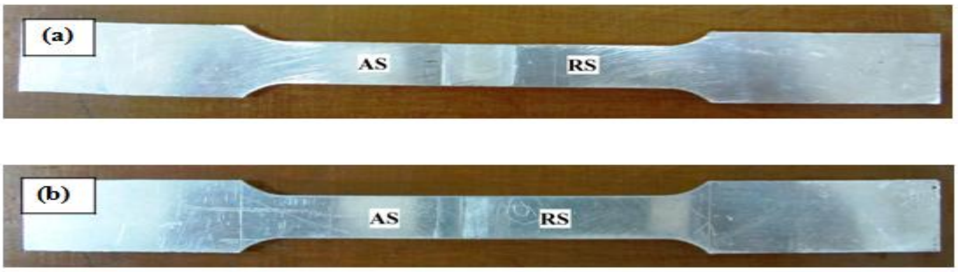


Fig.9 Showing (a) Top surface of weld (b) Bottom surface of weld

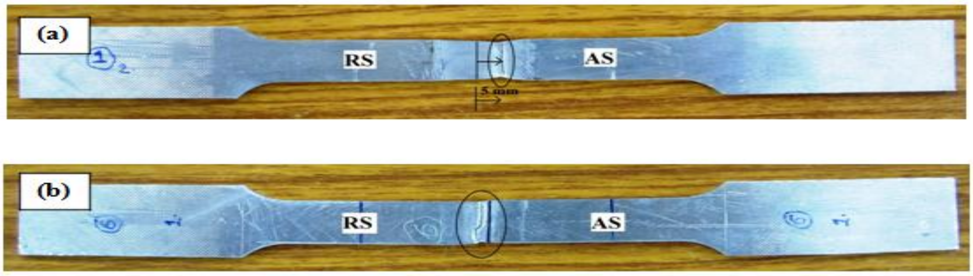


Fig.10 Showing (a) Specimen fractures in HAZ at advancing side (b) Specimen fractures at weld centre line

3.2 Surface appearance of weld sample:

The surface appearances of the friction stir welded plates by cylindrical pin profiled tool are shown in fig. 11. No large defects were formed in and near the stir zone but weld fabricated at 1800 r/min shows the flash defect at retreating side is shown in fig 11. Although semi-circular trace is observed in the stir zone for 900 rpm, the surface morphology becomes smoother with an increase in the tool rotational speed. Namely, the sound stir zone with very smooth surface morphology is successfully obtained at the relatively high rotation speeds ranging from 900 to 1800 rpm. This result shows that there are optimum tool rotation speeds in order to obtain defect- free welds with smooth surface for the FSW of AA 5083 alloy plates. As the rotational speed increases heat input due to mechanical friction and plastic deformation increases, and as the temperature of the weld metal rises, the metal softens, due to softening of the material proper mixing and stirring could be possible by tool shoulder and pin and thus surface morphology becomes smoother with an increase in the tool rotational speed. But as even increase in rotational speed causes decrease in flow stress of material and less heat is imparted to the metal by mechanical work, friction phinomenon gets replaced by stick-slide phenomenon between tool and workpiece. This continues a temperature regulating mechanism that tends to stabilize the temperature and avoid melting of weld metal. At times due to excessive heat input and less shpulder pressure, shoulder unable to contains the material beneath it and flash defect occures at retreating side of the weld is shown in fig. 11. The evolution of welds morphology and dimensions was related with the variation in welding parameters. It is now possible to say that the weld morphology also depends on base material properties.

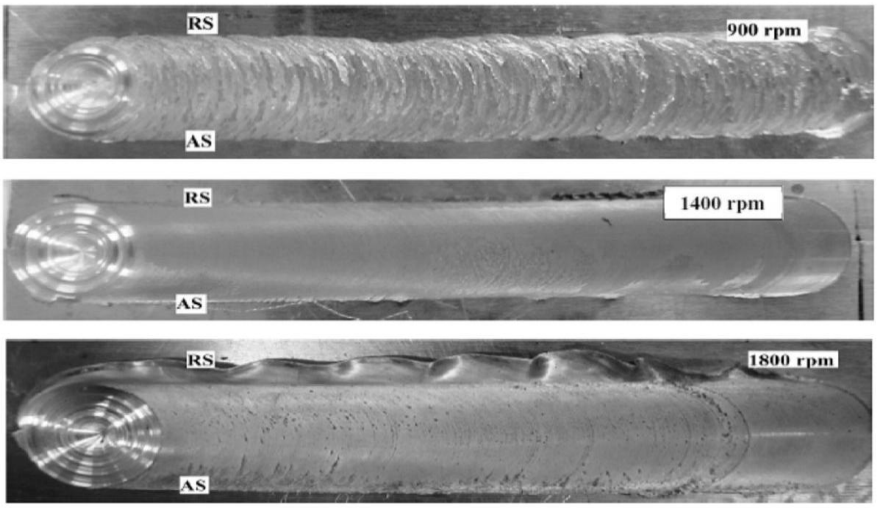


Fig.11 Surface appearances of 5083 aluminium alloy plates friction-stir-welded by cylindrical pin profiled tool at rotation speeds of 900, 1400 and 1800 r/min with welding speed of 16 mm/min

IV. CONCLUSION

In this investigation an attempt has been made to study the effect of tool pin profiles and welding parameters on the formation of friction stir weld and tensile properties in AA5083 aluminium alloy. From this investigation, the following important conclusions are derived.

1. For AA5083 whose deformation resistance is relatively high, tool pin profiled designs had little effect on heat input, power consumption and tensile properties.
2. Joints fabricated at rotational speed of 1400 rpm and weld speed of 16 mm/min exhibited superior tensile strength properties and produces defect free FSW zone irrespective of tool pin profile except triangular pin tool.
3. Weldability is significantly affected by the rotational speed. At high rotational speed (1800 rpm) straight cylindrical tool is the best; at the middle rotational speed (1400 rpm) straight cylindrical and square tool are the best; while for low rotational speed (900 rpm) triangular and square tool are the best.
4. Maximum strength properties of 105 MPa yield strength, 149 MPa of tensile strength and 84.9 % of joint efficiency respectively was attained without any defect for the joint fabricated using straight cylindrical tool at rotational speed of 1400 rpm and weld speed of 16 mm/min.

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