EXPERIMENTAL STUDY OF PROCESS PARAMETERS AND EFFECT OF TOOL DESIGN ON PROPERTIES OF FRICTION STIR SPOT WELDS

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Abstract: Friction stir welding (FSW) has produced a great impact in several industries due to the advantages that this process presents. In particular, the automotive industry has developed a variant of the original process, called Friction Stir Spot Welding (FSSW), which has a strong interest related to the welding of aluminium alloys and dissimilar materials in thin sheets. Aluminium-steel welding is an actual challenge, being FSSW an alternative to produce these joints. However, the information available related to the influence of process parameters on the characteristics of aluminium-steel joints is scarce. In the present investigation Aluminium 8011 was used. Keywords: friction stir spot welding; Aluminium; Microstructure, Macrostructure.

Keywords: friction stir spot welding (FSSW); Aluminium; Tool design; Weld assessment; Microscopic structure; Macroscopic structure; Metallographic studies.

1. Introduction

The application of lightweight metals such as aluminium alloys in transportation industries, especially in automotive industry, is rapidly developed in order to reduce CO2 exhaust gas and fuel consumption. However, steels are still widely used for structural components because of the lower absolute strength and higher material cost of aluminium alloys. Therefore, assembling both aluminium alloys and steels is necessary to develop hybrid body structures. It is known that fusion welding between aluminium alloy and steel are not reliable because brittle intermetallic compounds are formed along the interface, which results in the lower strength of welds. Recently, joining aluminium alloys to steels are tried by a friction stir welding (FSW) technique, which is a solid state welding process, and successfully achieved high strength welds. A spot welding process using FSW technique has been newly developed, which is called friction stir spot welding (FSSW) or friction spot joining (FSJ). This method is expected to apply to joining for body parts made of aluminium sheet in transportation systems because traditional resistance spot welding of aluminium alloy usually results in poor reliability of joints. FSSW is a solid state joining process as well as FSW, and it is believed that FSSW is suitable for joining dissimilar metals. Consequently, FSSW was applied not only for the joining between dissimilar aluminium alloys but also aluminium alloy and steel.

2. Experimental Details

2.1 Materials

Aluminium 8011:

Metal sheet of aluminium (Al 8011) was used for the experiment. Thickness of the sheets used in the experiment was 3.0 mm.

Table 1: Chemical composition of the material

Chemical composition in % for grade 8011

Fe	Si	Mn	Ti	Al	Cu	Mg	Zn	Impurity
0.6 - 1	0.5 - 0.9	max 0.2	Max 0.08	97.57 - 98.9	max 0.1	Max 0.05	max 0.1	other, each 0.05;

Table 2: Mechanical Properties of the material

Mechanical properties under T=200 C for grade 8011 (8011)

Assortment	Dimension	Direct.	σ_B	σ_T	σ_5	ψ	KCU	Heat treatment
-	Mm	-	MPa	MPa	%	%	kJ / m2	-
soft , GOST 618-73			30-40		2-3			
hard , GOST 618-73			100-120					

2.2 Preparation of Materials

The material aluminium was in the form of a big sheet with uniform thickness of 3 mm. The Aluminium was then shear cut to the dimension of 215x35 mm. Further the workpieces were milled to obtain a perfect flat surface on the edges.

Figure 2. Aluminium work piece.

3. Experimental details of FSSW

3.1 Tool design

The tool design generally involves the selection of tool material and tool dimensions to suit the thickness of base plates. Based on preliminary investigations the tool was selected. The detail of the tool which is used in this investigation is given in the following table. Tungsten carbide tool is used it is not subjected to wear in welding of aluminium sheets.

Table3: chemical composition of tool material

Material	W%	Ni%	Co%
Tungsten carbide	90.0	6.0	4.0

Table4: Details of the tool used for the welding

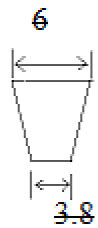
Tool material	Shoulder dia in mm	Probe dia	Probe height	Shoulder type
WC	25		80	threaded

Figure3.a and b Showing top view and front view of the tool used.

3.2 Experimental set up and welding operation

The entire experiments were carried out on FSW machine. For each trial following procedure is carried out.

1) Checking linearity of welding plate.

2) The metal sheets to be welded are placed properly in position with the help of jigs and fixtures and bolted tightly for correct alignment throughout the procedure.

3) Now the FSW welding head containing the tool is brought in position by hydraulic mechanism. The tool is then made just to touch the surface of the metal. From this position the tool feed is given. Now the welding cycle is started and after the completion of the cycle the tool is drawn back automatically by the hydraulic mechanism.

4) Parameters such as tool rotation speed, plunge depth and welding time were given for each work pieces. For each FSSW process the same set up procedure was followed. With the variation in one of the parameters. FSSW analysis parameters. The mechanical performance of a FSSW connection is mainly dependent on the process parameters such as rotational speed (RS), plunge depth (PD) and dwell time (DT).

Table5: summarizes the parameters that were used in the various experiments carried out on FSSW of Aluminium. Showing parameters for the analysis of process parameters.

Welding time sec	Plunge depth mm	Welding condition	Rotational speed RPM	Tensile strength KN
2	5.9	Case 1	1500	3
4	5.9	Case 2	1500	5.3
6	5.9	Case 3	1500	5.3
2	5.9	Case 4	2000	4.3
4	5.9	Case 5	2000	4.3
6	5.9	Case 6	2000	4.6
2	5.9	Case 7	2500	4.2
4	5.9	Case 8	2500	3.6
6	5.9	Case 9	2500	3.1
4	5.8	Case 10	1500	4.5
4	5.7	Case 11	1500	3.5

3.3 Weld assessment

All welds were inspected visually for surface roughness, presence of surface grooves extent of any side flash. The width of the weld should be constant. A reduction of weld width directly after the start of welding is sign that the tool shoulder was not in sufficient contact with workpiece surface and internal voids are assumed to be present. The amount of expelled material should not exceed the amount needed for good welds. The bottom of the welds was examined for checking whether sufficient clamping has been applied.

4. Metallographic studies

Micrography is very essential for the study of structural characteristics of the weld metal. Important phase of metallography is microscopic examination. The weld were prepared for the microscopic and macroscopic examination in a step by step procedure as follows.

1) Grinding

Hand grinding using silicon abrasive was performed. The grit papers of 400, 600, 800, 1000 and 1200 grades were used. This operation was performed as per standards. The emery paper was kept on a clean glass plate kept on a hard and levelled surface of a table. The specimen was generally drawn back and forth across the length of the paper under moderately applied pressure for getting unidirectional and uniform scratches on the surface. During subsequent grinding on successive grades of emery paper, new scratches were formed at right angles, alternately to the scratches formed by the preceding papers by turning the specimen by 90^0 during each operation. The specimen was cleaned thoroughly with soap in running water and dried before moving on to the next emery sheet. This was done to prevent coarse abrasive particles from the previous papers to be carried on the finer grit papers.

2) Polishing

Disc polishing machine was used for this purpose. Silicon carbide powder of 1000 grit size was uniformly smeared on a clean cloth, fixed to the disk of the polishing machine. The specimen which was hand ground for about 1200 grit size in the preceding operations, was now polished on the rotating cloth at the speeds in the range of 600 -800 rpm and polishing time of about of 10-15 min. depending on the situation, until all the scratches on the surface of the specimen were removed. The specimen was thoroughly cleaned with water and dried. Final polishing was done on a micro cloth. Diamond paste of 3 µm size grit size was smeared on the cloth. The specimen was polished on the rotating cloth for about 5-10 min. until all the scratches were eliminated and a bright mirror surface is obtained. The specimen was again cleaned with soap water, dried and kept ready for the next operation i.e. etching.

3) Etching

The specimen was thoroughly washed in water. Then the etching is done immersing the sample in solution of 5ml HF (48%) n 100ml H2O for 40-50 sec with intermediate washing in running water. This procedure is repeated for five times before the final etched sample is obtained. After the etching process the specimen were viewed under optical microscope for micrograph and under stereo microscope for macroscopic examination of the weld nugget.

5. Results and Discussions

This chapter deals with the various test results obtained on the experiments conducted. Further the influence of various process parameters is discussed. Results are interpreted and conclusion are derived.

5.1 Results

5.1.1 Tensile test and results

The tensile test were carried on each welded specimen. Tensile-shear tests were carried out in order to evaluate the performance of welds. The Bi-00-201 series of "plug 'n' play" test systems are the most cost effective solution to mechanical testing requirements for strength, fatigue and fracture in the 5 to 25 KN force range of static and dynamic loading. The welded specimens are now tested on Nano Servo Hydraulic UTM to evaluate their tensile strength. After fixing the sample in appropriate position, the load is applied gradually by the hydraulic mechanism. For tensile test the graphs of load vs stroke for each sample were obtained from the machine this shows the variation of load bearing capacity with respect to stroke length. For each sample the plot was analyzed and investigated that at how much stroke length the sample has maximum tensile load carrying capacity.

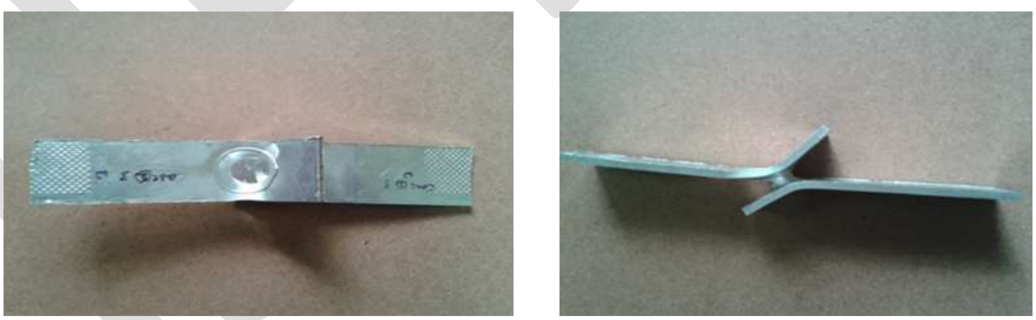
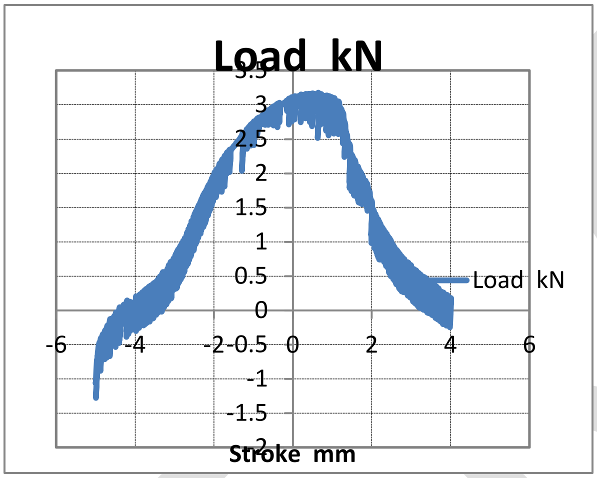


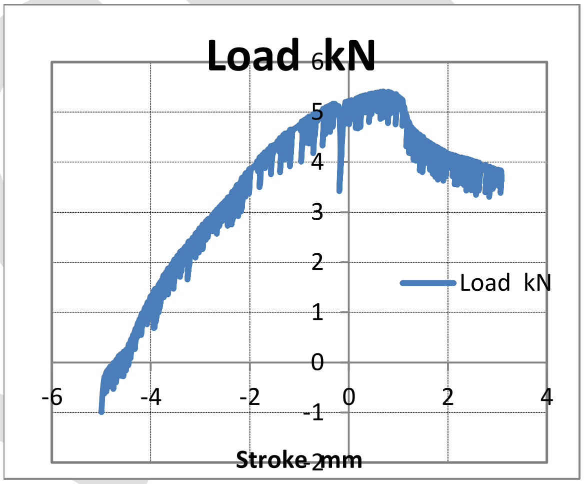
Fig4.A and B specimen after the tensile test (top view) and specimen after the tensile test (side view)

Fig4.C A specimen after the failure

Case 1;



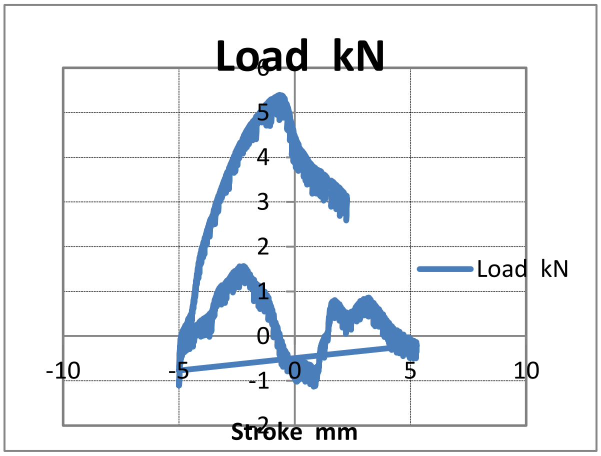
Case2;



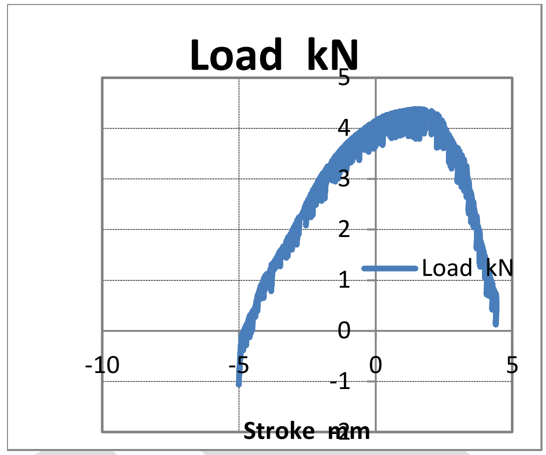
Case1: The graph shows the variation of load with stroke length. The stroke length varies from -4.9952 to 3.8892 mm, a total of 8.8944 mm. The load varies from -1.2771 kN reaches a maximum of 3.1642 kN and then falls back to -0.1278 kN. The maximum load occurs at a stroke length of 0.4887 mm.

Case2: The graph shows the variation of load with stroke length. The stroke length varies from –4.996 to 3.02 mm, a total of 8.016 mm. The load varies from -0.9842 KN reaches a maximum of 5.3899 KN and then falls back to 3.5608kN. The maximum load occurs at a stroke length of 0.5765 mm.

Case 3;



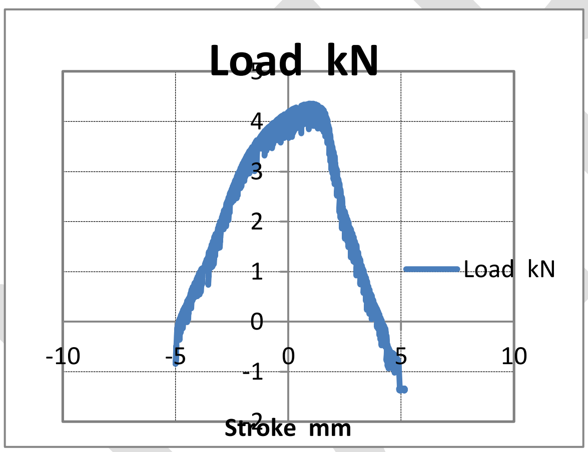
Case 4;



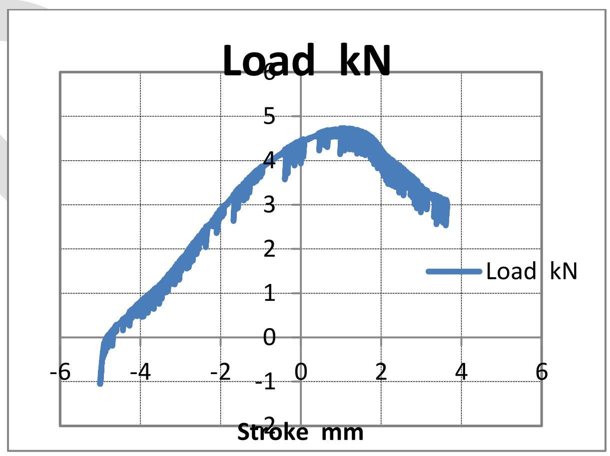
Case3: The graph shows the variation of load with stroke length. The stroke length varies from -5.004 to 2.2243 mm, a total of 7.2283 mm. The load varies from-1.086 kN reaches a maximum of 5.3288kN and then falls back to 2.5864kN. The maximum load occurs at a stroke length of -0.8902 mm.

Case4: The graph shows the variation of load with stroke length. The stroke length varies from --5.001 to 4.388 mm, a total of 9.389 mm. The load varies from-1.0583 kN reaches a maximum of 4.3887kN and then falls back to 0.1326kN. The maximum load occurs at a stroke length of 1.3887 mm.

Case 5;



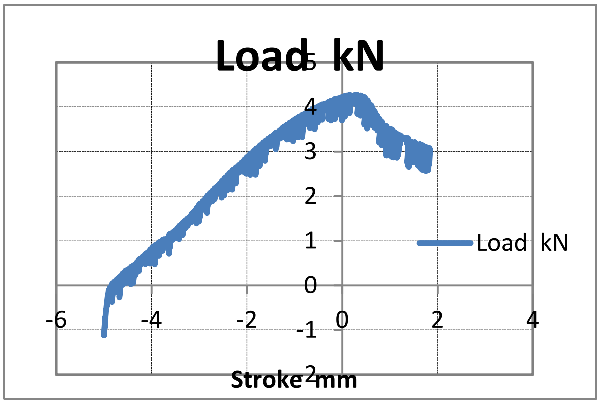
Case6;



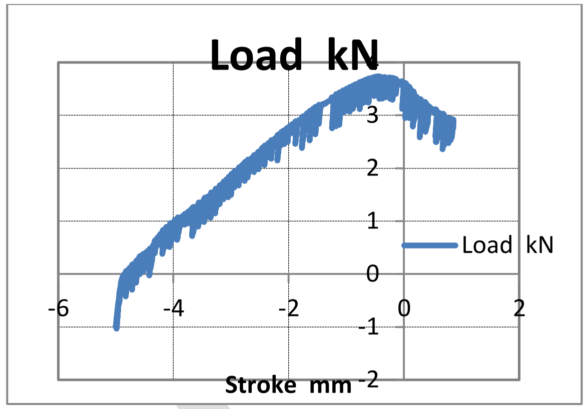
Case5: The graph shows the variation of load with stroke length. The stroke length varies from --5.007 to 4.986 mm, a total of 9.993 mm. The load varies from-0.8391 kN reaches a maximum of 4.35kN and then falls back to -1.3467 kN. The maximum load occurs at a stroke length of 1.0113 mm.

Case6: The graph shows the variation of load with stroke length. The stroke length varies from --5.0018 to 3.4639 mm, a total of 8.4657 mm. The load varies from-1.0464 kN reaches a maximum of 4.716kN and then falls back to 2.6373 kN. The maximum load occurs at a stroke length of 0.9981 mm.

Case7;



Case 8;



Case7: The graph shows the variation of load with stroke length. The stroke length varies from --5.002 to 1.673 mm, a total of 6.675mm. The load varies from-1.1195 kN reaches a maximum of 4.2504kN and then falls back to 2.5902 kN. The maximum load occurs at a stroke length of 0.0549 mm.

Case8: The graph shows the variation of load with stroke length. The stroke length varies from – 4.991 to 0.7259 mm, a total of 5.7169mm. The load varies from-0.9941 kN reaches a maximum of 3.7202kN and then falls back to 2.5615 kN. The maximum load occurs at a stroke length of -0.5126 mm.

6. Microstructure of the Experiments

6.1. Macroscopic and Microscopic structure of welds

Fig. 5 shown below is a macroscopic and microscopic structure of cross section of the welds made at the rotational speed of 2000 rpm and dwell time of 4 seconds. Fig.5a,b,c,d,e, are the cross sections of the FSSW joint which is divided into four main regions, mainly base material (BM), heat affected zone (HAZ),thermo-mechanically affected zone (TMAZ), and stir zone (SZ) respectively. From the fig.5 shown below we may note that the base material exhibits elongated grains and second phase particles parallel to the rolling direction due to work hardening effect. From the thermo-mechanically affected zone we can observe that it possesses highly deformed grains as compared to base material and heat affected zone. The stir zone has a refined and equiaxed grains. And the compact structure is observed in the stir zone and thermo-mechanically affected zone due to dynamic recrystallization occurred in the periphery of the tool pin because of the pin stirring and friction thermal cycle. In the present study, heat input during friction stir spot welding is dependent on tool rotational speed and tool dwell time. The appropriate heat input is obtained by using appropriate rotational speed and dwell time, the grain growth can be negligible even the second-phase particles becomes much finer and smaller with uniform distribution.

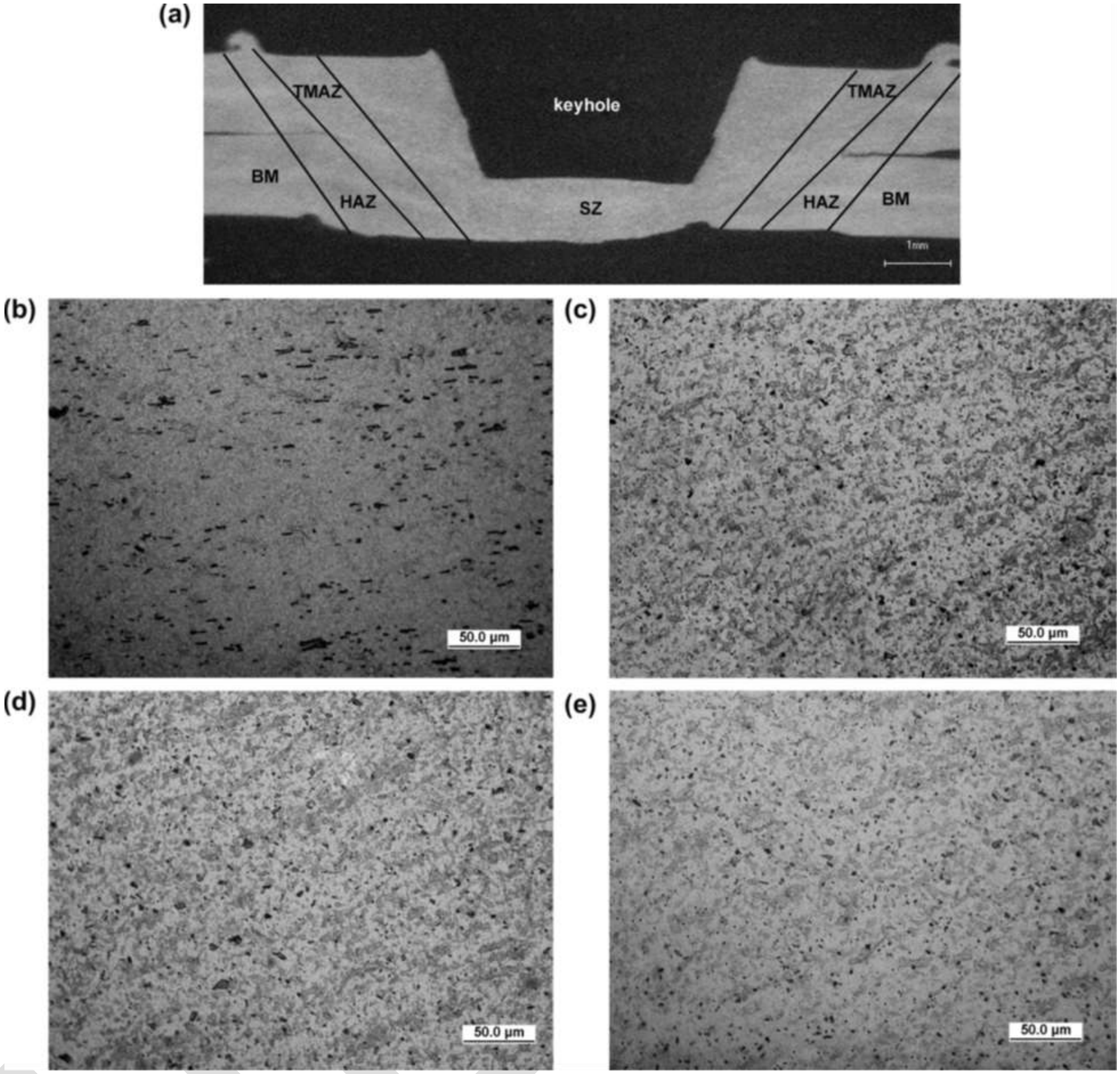
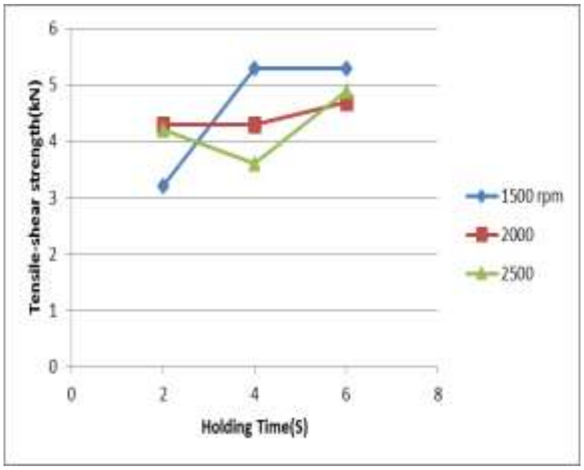


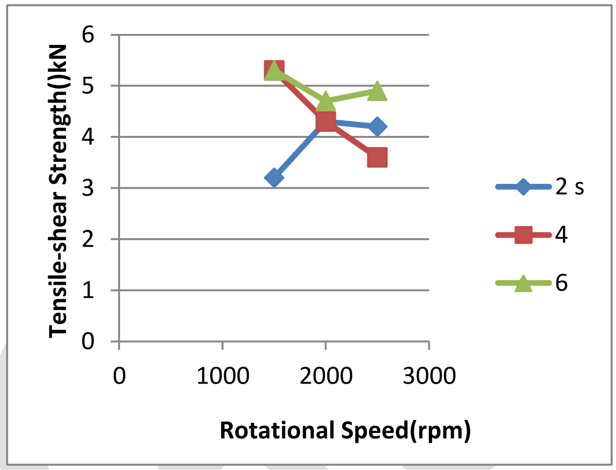
Figure5: Macroscopic and Microscopic structure welds.

7. Discussions:

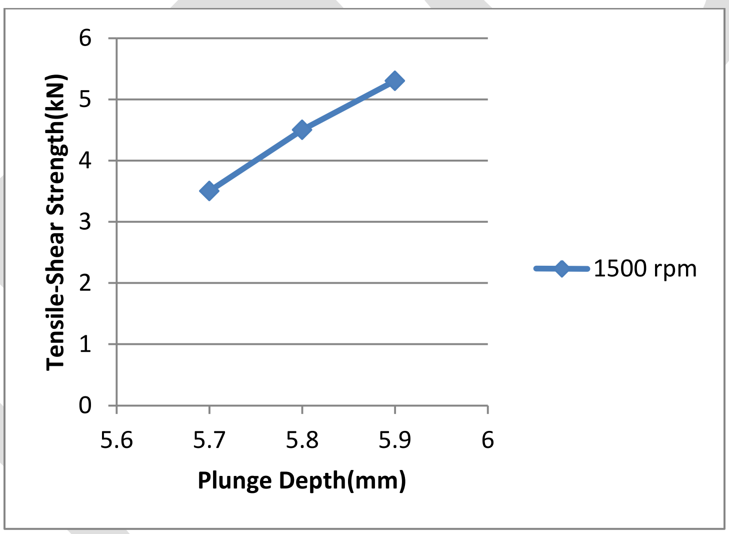
The following are the graphs obtained from the tensile tests of the specimen



Graph tensile – shear strength Vs holding time



Graph Tensile –shear strength Vs rotational speed



Graph Tensile –shear strength Vs plunge depth

8. Conclusions:

1) For Lower speed, lower holding time for the given tool failure mode observed is shear fracture.

2) Higher speed, higher holding time and higher plunge depth causes good stirring effect, grain refinement and material mixing at the interface of the workpiece. So it was observed that plug fracture occurred in this case.

3) At lower value of parameters, the stirring to eliminate the material mixing area is less. i.e. Stirring affected area at lower parameters is less and may be material flow at these parameters is less.

4) High speed, high holding time causes good stirring effect, grain refinement and due to high shoulder force material flow is more.

5) Increasing the plunge depth causes the expansion of stirring zone and the upward flow of the material in the lower sheet occurs.

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