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ARTICLE

Behaviour of Friction Stir Dissimilar Welded Blanks and The Role of Different Tool Pin Profiles

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ABSTRACT

In this study, the forming behaviour of dissimilar welded blanks was studied. Welded blanks were prepared with friction stir welding processwith different types of tool pin profiles. Welded blanks were developed with fixedfriction stir welding process parameters by varying the tool pin profiles. The forming behaviour of welded blanks were analyzed with the limiting dome height test in biaxial stretch forming condition.The results reveal that the formability of welded joints are made with the square pin tool exhibited a better formabilitybehaviour when compared with other profiled tools, this is due to sufficient amount heat generation and high static volume to dynamic volume ratio.

1. Introduction

The application of Tailor welded blanks (TWBs) are generally found in the aerospace and automotive industries, where theneed of a high strength to weight ratio parts for the fabrication purpose with local required stiffness at some part of the components. Aluminium metal matrix composites are capable to fulfill the requirement of high strength and low weight for particular applications. Friction stir welding (FSW) is a metal joining technique and is widely used in making of aluminium alloys welded banks. It is a basically a solid state process, the base materials are welded together in plastic deformation condition, so that the process avoids many problems that are commonly encounteredwith the conventional welding techniques such as porosity, cracks etc.TWBs can be made with same or different materials. In some cases, TWBs made with weak and strong material combination to form a component and there is a need of different strengths at different places of the component with less weights. It is not that much easy to deform a high strength material as compared withless strength material. The less strength material normally gives a better response to the applied load and not the high strength material because of difference in the ductility of materialsthat results in uneven deformation.Many researchers have used different kinds of metal joining techniques viz. arc welding, gas welding and friction stir welding to make welded blanks [1,2] and are formed into required shapes [3-5]. In the past research, FSW was applied to weld similar [6] and dissimilar [7-9] aluminium alloys. With this process they obtained a refined ho-

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mogenized structure in the weld zone withsuperior mechanical properties. This isbecause of stirring action of the tool pinand extrusion of plasticized material during welding [3].Tool pin is considered as an important parameter [4,10] in the FSW process, because ofit stirs the material around in the joining area and develops a fine grain structure. It also avoid the voids in stir zone [5] and also dictates the flow of plasticized material during welding [6,7]. For good quality of TWBs,it's necessary to use a proper FSW tool pin to develop the required amount of heat by sweeping huge quantity of plasticized metal [8]. Xu et al.[11] studied the influence of tool pin profiles and process parameters of welded joints made with AA2219 aluminium alloys through FSW.Vijay et al. [12]achieved a better tensileproperties with use of a square profiled tool is mainly due to flat faces of tool pin and holding dynamic volume to static volume ratio.Morteza et al. [13] developed welded joints using H13 tool and the rupture was observed at heat affected zone in the low strength alloy side on welded blanks during limiting dome height test. Lietao et al. [14] analyzed the formability of FSWwelded blanks made with similar and different kind of alloys using threaded tool revealed that the base material size and their properties are the main influencing parameters on the formability. According to Palanivel et al. [15] a better welded joints can developed using FSW process with a square pin tool and revealed that thetool profile is better to develop a good refined structure through sufficient heat development during welding.In this paper, an attempt was made to study the effect of different tool pin profileson the properties and formability through the Limiting Dome Height (LDH) test.

2. Experimental Procedure

The base aluminium alloys used for the work were AA6061 and AA2014 alloys with blank thickness of 3mm.The composition (wt%) for AA6061-T6 aluminium alloy blank is Al- 0.8Mg- 0.45Si- 0.025Cu- 0.017Ti- 0.04Cr- 0.15Mn and for AA2014 aluminium alloy blank is Al- 3.98Cu- 0.46Mg- 0.75Si- 0.026Ti- 0.017Cr.First the two base material sheets are sliced to size of 300mm x 75mm. Friction stir welding was conducted on the vertical axis milling machine with different tool pin profiles viz. Straight Cylindrical (SC), Taper Cylindrical (TC), Stepped Cylindrical (ST), Straight Square (SS), and Straight Hexagonal (SH). FSW experiments were conducted with tool rotational speed of 900 rpm, welding speed of 24 mm/min and tool tilt angle of 1^{o}. After welding, testing specimens were extracted from welded sheets and tensile test specimens were prepared as per standards of ASTM and tests were performed on universal tensile testing machine.

Figure 1. FSW arrangement

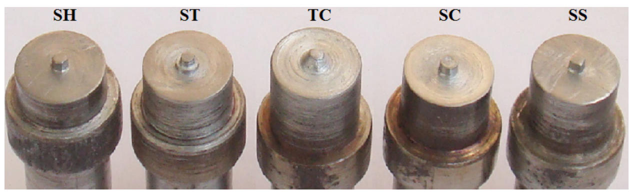

Figure 2. Photograph ofdifferent tool pin profiles

Forming test on welded sheets were conducted through LDH test and samples were prepared as square in size (100 mm x 100 mm). LDH test was conducted on a 50 tons hydraulic press and forming was made with 36 mm diameter hemispherical punch. the data logger which is attached to press was recorded the dome height and applied load data during forming and the arrangement of hydraulic press with punch, dies and welded blankis shown in Figure 3. It can be observed that the welded blanks made with dissimilar aluminium alloys was generally less and on the other hand, a huge weld line movement was observed. This is mainly due to difference in ductility of the two alloys. AA2014 alloy alloy was heated in the furnace at 495 ^{o}C for one hour and immediatelyquenched in water. And then solutionized blanks are naturally aged for five days at room temperature. The welding was carried out with the heat treated AA2014 and as received AA6061 alloys and forming test was carried. The microstructural examination of base materials and also weld zone of the joined sheets was done with scanning electron microscope after applying the Keller's reagent to reveal the microstructures.

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Figure 3. Arrangement of hydraulic press with punch, dies and welded blank

3. Results and Discussions

3.1 Formability Analysis

Figure 4 shows the effect of different tool pins on the formability of welded blanks. The material flow and developed heat are controlled with stirring action of the tool geometry [15]. The action of the tool dictate by the ratio of dynamic to the static volume of the geometry. The values for the ratio is equal to 1 for SC tool, 1.09 for TC tool, 1 for ST tools, 1.56 for SS tool and 1.21 for SH tool [15,17,18]. Out of five pin profiles, SS tool is holding high ratio of 1.56 with tool pin pulsating action of 60 pulses/sec is enough to develop sufficient heat to make the welding zone material soft and sweeping a huge amount of plasticized material around the pin of rotating tool, which results in a better formation of weld and led to formability enhancement.ST and TC pin profile tools holding almost a same ratio and there is possibility of less flow of plasticized material and led to decrease in the formability. The SC pin profiled tool holding the ratio of 1.0 and generates less flow of plasticized material around the pin and attained a lesser formability. This is because of the absence of pulsating action of the tool pin was experienced. Although, the SH pin tool holds ratio of 1.21 and the highest number of pulsating action, this tool pin resembles almost as a cylindrical profile tool leads to less properties.

It can be noted that, a high LDH (16.8 mm) value is obtained for welded blank developed with SS pin profiled tool and confirmed the effect of SS profiled tool is more on the weld zone properties, similar kind of observations were made by some researchers [15,19,20]. The SH and SS pin profiled tools hold flat faces on the tool pin and developed a localized pulsating stir action to plasticize the materials around during welding. At tool rotational speed of 900 rpm, the SS profiled pin produces 60 pulses/sec, due to high pulses/sec produced is sufficient heat at weld zone and leds to better properties.The SH pin profiled tool produced a low LDH (10.8 mm) formability characteristics is due to at higher rotational speed, the SH tool flat faces are resembles as almost SC tool pin profiled tool, and developed a insufficient heat during welding. The yield strength and formability of welded blanks are relates inversely with each other. Forming behaviour of an material is a function of fundamental material propertiessuch as strain hardening exponent (n) and work hardening capacity (1/YR) of that material, and exisisting a relation with the formability [21,22]. Higher values 'n' are required for better welded blanks formability and are correlated with LDH values and also with 1/YR values. 1/YR values are obtained from inverse of the Yield Ratio (YR= yield strength/tensile strength), which is good indicator for the formability behaviour [23]. It can be observed from Figure 5, the LDH has almost a linear relation with the elongation (e), strain hardening exponent (n) and also with the work hardening capacity (1/YR). On otherside, higher'n'value was obtained for welded blanks made with SS pin profiled tool, this is mainly due favourable heating condition through pulsating action of the tool pin. These relationships are showing a good agreement of formability with tensile results.

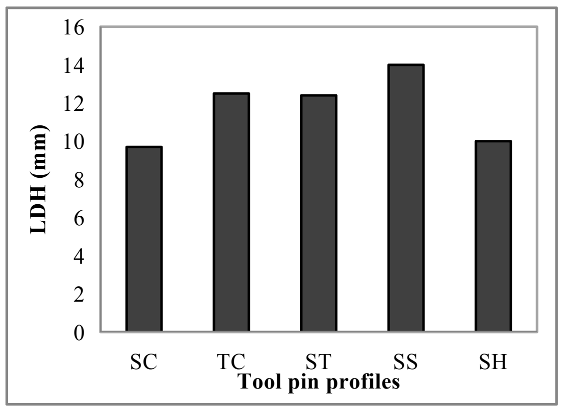

Figure 4. Effect of different tool pin profiles on the formability of the welded blanks

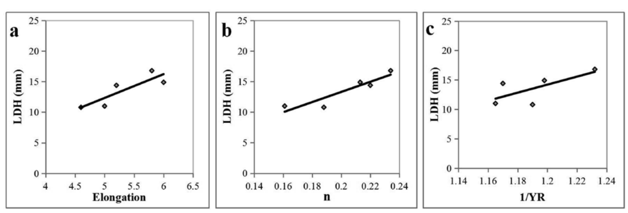

Figure 5. Variations of LDH for (a) elongation (b) strain hardening component (c) work hardening capacity of welded blanks

The recorded punch loads and dome heightsduring forming are plotted in Figure 6. It can be observed that the welded blank made with SS profiled toolattain high dome height with underwent more load as compared with the welded blanks made with other pin profiles.

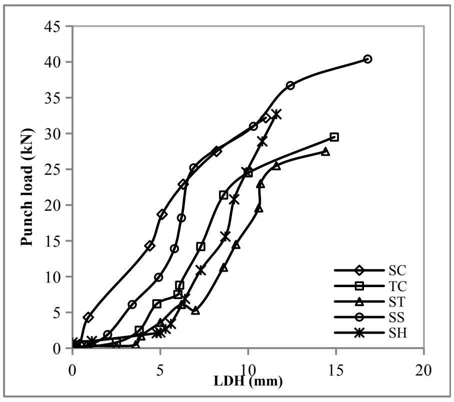

Figure 6. Punch load and limiting dome height diagram for welded blanks made with different tool pin profiles

3.2 Microstructural analysis

The microstructures of the base materialsare shown in figures 7a and b respectively. Base alloy AA6061 mainly consist of particles of Al, Fe, Mn with some Mg_2Si (white) precipitates.AA2014 alloyconsists of $CuAl_2$ precipitates (white) in aluminium matrix and also consists of some insoluble such as Fe, Mn, Si particles.The micrographs of welded zones made with different tool pin profiles are shown in Figure 8a-e. ThroughFSW process, homogenized and fine grains are formed at the weld zone [3,5,19], at the appropriate heat generation is result of severe plastic deformation [20,24,25]. A homogeneous and fine grained structure can observed in the case of welded blanks made with SS profiled tool. This is due to appropriate heat generation through pulsating action of the SS tool pin. A less homogenized microstructure obtained with usage of TC and ST pin tools and on otherside, coarse and unhomogenized grains were obtained with SH and SC profiled tools. This is mainly due to insufficient heat generation of the tool. This gives an effect of decreasing the formability of welded blanks.

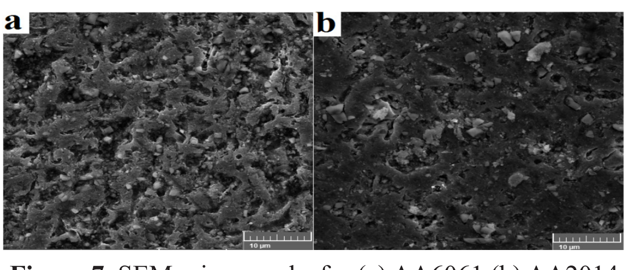

Figure 7. SEM micrographs for (a) AA6061 (b) AA2014 base materials

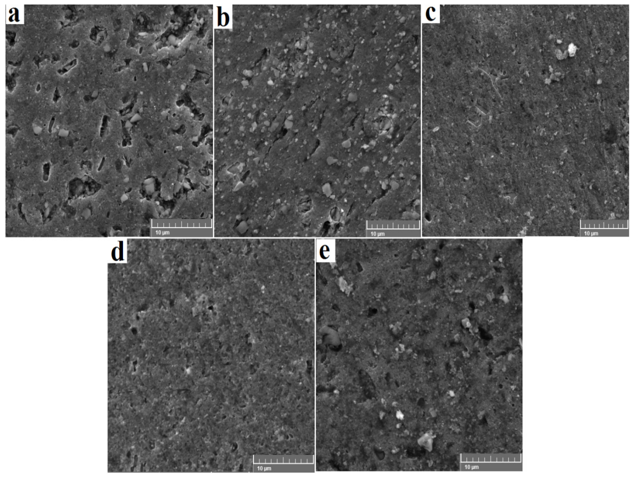

Figure 8. SEM micrographs ofweld zonesof (c) SC, (d) TC, (e) ST, (f) SS, (g) SH tool pin profiles

4. Conclusions

The dissimilar welded joints were developed using FSW process by using different tool pin profiles and then formability behaviour was studied with the LDH test. From the results,it can be observed that the welded joints developed using a square profile pin tool gives a better formability is due to the pulsating action of the tool produced a fine and uniform distributed grains throughout the structure and this results were confirmed from the obtained microstructure.

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