The Tensile, Hardness and Impact Behaviour of Friction Stir Welded Similar and Dissimilar Aluminium Alloys

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Abstract

Nowadays structural application demands two important features in the fabrication and manufacturing of the materials. They are reduction of the weight and as well as cost. Aluminium (Al) alloys are the best choice for controlling these two features and perfectly replacing steel in many industrial applications. The Friction Stir Welding (FSW) technique is a good, powerful, and worthwhile method and one of the leading and appropriate joining techniques for Al alloys. The solid phase nature of this process controls many defects especially melt-related defects. Primarily, it is applied for low melting materials although the applications are extended for high melting point materials including steels and composites. The present study describes the tensile, hardness, and impact characteristics of Friction Stir (FS) welded butt joints of similar aluminium alloy groups of AA6351 with AA6351, AA5083 with AA5083 alloy, and dissimilar aluminium alloy group of Al AA6351 with Al AA5083.

Keywords: FSW, Aluminium alloys AA6351 and AA5083, Tensile, Hardness, Impact behaviour.

1.0 INTRODUCTION

Nowadays, the utilization of Al alloys increasing due to many outstanding characteristics. The properties like low weight and low cost attract the manufacturing industry. Moderate strength to low weight feature attracts many industries especially low weight feature has significant value in shipbuilding, aerospace, and automotive industries, etc. These features of Al alloy and other features like corrosion resistance attract many industries and readily replace steels in many applications. The joining techniques of Al alloys with traditional fusion welding techniques suffer many defects which include porosity, cracks and voids, and also many melt-related defects. Friction Stir Welding (FSW) [1] is rightly suitable for Al alloys. Recently developed this process is a solid phase in nature and overcomes numerous welding defects including melt-related defects. Though the technique is originally developed for Al alloys [2-10] and other low melting materials like magnesium [11,12], and copper [13,14], and now possible to weld for many other materials like steels [15,16], titanium [17], and composites [18].

This processing principle is simple and is illustrated in **Fig.1**. The rotating FSW tool consists of a shoulder and pin and which is non-consumable. In this process, this tool is required instead of a traditional welding torch. This tool is inserted into the abutting edges of the two welding materials and moved along the line of the joint. Heat due to friction is produced between the rotating tool and the workpiece.

Apart from Al similar group alloys, dissimilar Al alloy group of Al AA6351 alloy with Al AA5083 alloy are extensively useful in aerospace, automotive, shipbuilding, and other fabricate-related industries [19]. The corrosion resistance to seawater property of Al AA5083 alloy shows wide interest in marine-related industries.

Research work on FS welded dissimilar Al alloy combinations of 6 group Al alloys to 5 groups Al alloys is very less. Peel et al. [20] experimentally studied FS welded dissimilar Al alloy combination of Al AA5083 alloy with Al AA6083 alloy and they observed from the investigation that the more influenced parameter on properties and thermal histories of weldment is the tool rotational speed than the welding speed. Palanivel et al. [21] investigated dissimilar Al AA6351-T6 alloy with Al AA5083-H111 alloy FS weldments. These dissimilar welds were joined with different profiled tools and concluded that the strong weld joint was formed by the straight square tool. Leitao et al. [22] studied Al AA5182-H111 alloy with Al AA6016-T4 alloy FS welds of the similar and dissimilar group Al alloys. They concluded from experimental work that 10% weld strength is decreased in dissimilar Al group alloys compared to the similar Al group alloys but not much noticeable reduction is observed in the hardness. Elangovan et al. [23] investigated on mechanical properties of Al-grouped FS weldments of Al AA6061 alloy and Al AA5086 alloy. They concluded from the study that higher tensile strength is noticed for similar grouping weldments than the dissimilar grouping weldments.

So, in this work, an attempt is done to explore the influence of mechanical properties of FS welded Al AA6351 alloy and Al AA5083 alloy. These dissimilar Al grouped alloys FS weldment's mechanical properties were compared to similar Al grouped alloys of Al AA6351 alloy with Al AA6351 alloy and Al AA5083 alloy with Al AA5083 alloy FS welded mechanical properties. Influence of rotational speed of tool on these similar and dissimilar Al-grouped alloy FS weldments was studied in this experimental work. The tensile, hardness, and impact tests were performed and compared the values with these three grouped Al alloys.

2.0 EXPERIMENTAL PROCEDURE

In this chapter, the materials used for experiments, the material used for the tool and its design details, and the FS welding procedure are discussed. The details of the tensile test, hardness test, and impact test are also presented.

2.1 Material

The basic materials utilized in this study are AA6351 and AA5083 aluminium alloys of 5 mm thickness. The standard and corresponding experimental chemical composition of these alloys are shown in **Table 1** and **Table 2**. Mechanical properties of them are shown in **Table 3**. Mechanical properties of AA5083 alloy are lower compared to AA6351 alloy.

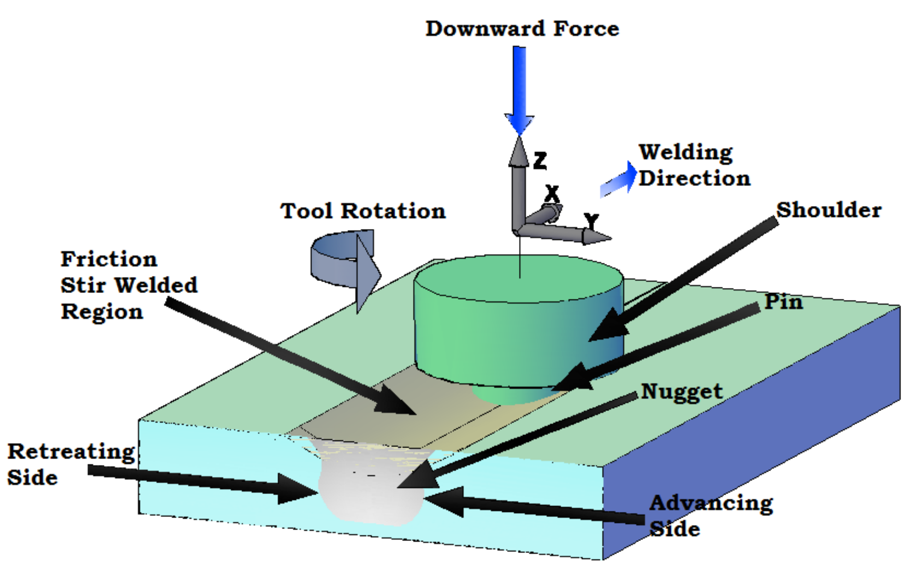

Fig.1 : Friction Stir Welding Process

Table 1 : Chemical composition of AA6351.

Element	Si	Fe	Mn	Mg	Cu	Zn	Ti	Al
Standard	0.8	0.5	0.4	0.4	0.1	0.2 max	0.2 max	Balance
Experimental	0.7	0.357	0.35	0.3	0.037	0.004	0.024	Balance

Table 2 : Chemical composition of AA5083

Element	Si	Fe	Mg	Mn	Cu	Zn	Ti	Al
Standard	0.2	0.35	5	0.15	0.15	0.25	0.1	Balance
Experimental	0.134	0.284	4.466	0.58	0.028	0.006	0.021	Balance

Table 3 : Mechanical properties of AA6351 and AA5083 alloys

	Yield Strength (MPa)	Tensile Strength (MPa)	Percentage Elongation	Brinell Hardness Number	Rockwell Hardness Number	Impact Energy (J)
Al AA6351 Alloy	251	278	11	78	58	19
Al AA5083 Alloy	215	253	9	72	55	17

2.1 FSW Tool

The design of the FSW tool and its material is very important and plays a vital role in deciding the strength of the weld joint. The material of the tool used for the FSW process should have sufficiently strong than the material used for the welding. The stronger material of the tool only can withstand the temperature at the weldment location. The material used for the tool in this investigation is high-speed steel (HSS). The tool consists of a shank and probe. The shape of the probe is conical and it does not have any threads. This tool undergoes a heat treatment process to get better hardness. The FSW tool hardness after completion of the heat treatment process is 54 HRC. **Fig.2** and **Fig.3** illustrated the image and the dimensions of the FSW tool respectively.

Fig. 2 : FSW tool

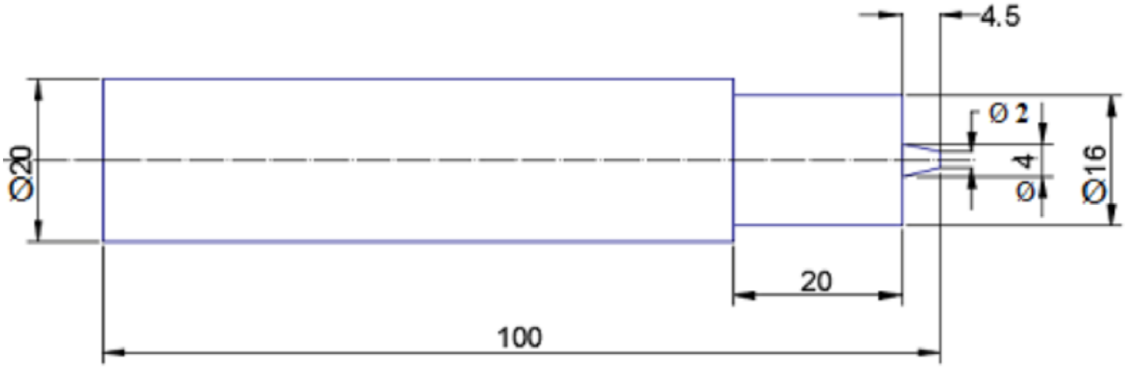

Fig. 3 : Detail of the FSW tool (All dimensions are in mm)

2.2 Welding Procedure

The similar combinations of Al alloy, AA6351 with AA6351 and AA5083 with AA5083 and dissimilar Al alloy combinations of AA6351 with AA5083 were FS welded in CNC (Computer Numerically Controlled) milling machine. The two Al alloy plates which are to be welded were firmly fixed with help of T bolts and clamps. The rotating tool was plunged into the joint and moved along the joint line and then formed welding on the two Al plates. The whole FSW process is illustrated in **Fig. 4(a)** and the weldment after completion of welding is illustrated in **Fig. 4(b)**.

The tensile test, The Brinell hardness, Rockwell hardness tests, and Charpy impact test were conducted to find out the tensile properties, hardness values, and impact behaviour of similar and dissimilar Al alloy groups of AA6351 and AA5083 that were friction stir welded at various tool rotational speed from 1000 rpm to 1500 rpm.

3.0 RESULTS AND DISCUSSIONS

In this chapter, to determine mechanical properties, the different combinations of FS Al alloy weldments were tested. The tensile, hardness, and impact strength tests were carried out by changing the tool rotational speed to evaluate the mechanical properties.

3.1. Tensile Test

A tensile test was carried out to find all the tensile properties (yield strength, tensile strength, and percentage elongation) of the weldment. A similar Al groups Al alloy AA6351 with AA6351, Al alloy AA5083 with AA5083, and a dissimilar Al group Al alloy AA6351 with AA5083 weldments were performed a tensile test by changing the tool rotational speed of 1000, 1200, 1300, 1400 and 1500 rpm. The tensile test results of all the combinations are illustrated in **Fig. 5, Fig. 6** and **Fig. 7**. The lower tool rotational speed results in lower

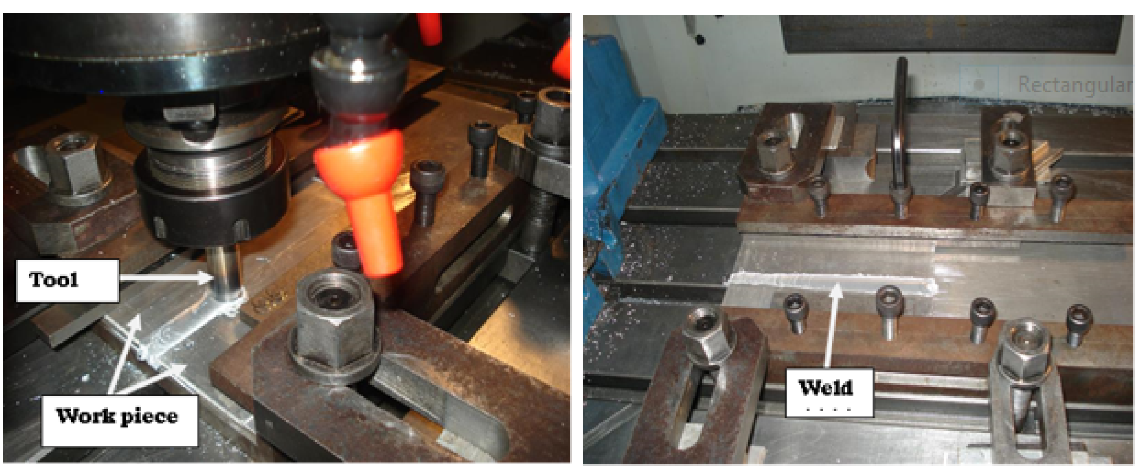

Fig.4 (a) : FSW process under progress, (b) FS welded piece after welding tensile properties. When the speed increases correspondingly tensile properties also increase and reach maximum properties at 1300 rpm of speed. The tensile property values decrease with a further increase in speed from 1300 rpm. This tendency was observed for all the combination welds.

The fracture locations of weld joints and hence tensile properties depend on the tool rotational speed. Other factors like feed, tool tilt angle, the axial force also affect fracture locations. The heat generation at weld locations is low at lower speeds (1000 to 1200 rpm). This lower heat results in crack and pinhole defects and hence results in lower tensile properties. Whereas heat generation is more due to a rise in temperature at higher speeds (1400 to 1500 rpm) which results again lower tensile properties. This is due to an increase in grain growth, metallurgical changes like re-precipitation at the weld zone, and a reduction of dislocation density [24].

The tensile values of Al AA6351 alloy with Al AA6351 alloy combination showed better performance than the Al AA5083 alloy with Al AA5083 alloy combination because of the superior mechanical properties of Al AA6351 alloy than Al AA5083 alloy. The tensile values of the Al AA6351 alloy with Al AA5083 alloy combination show lower performance than the Al AA6351 alloy with Al AA6351 alloy. This is due to the different melting points of Al alloy AA6351 and AA5083. The melting point of AA6351 alloy at liquidus state is 649°C and at solidus state is 554°C. The melting point of AA5083 at liquidus state is 638°C and at solidus state is 591°C. These different melting points of material affect the improper mixing of materials at the location of the weld. The Al AA6351 alloy with Al AA5083 alloy combinations shows the least performance than the other two similar combination joints.

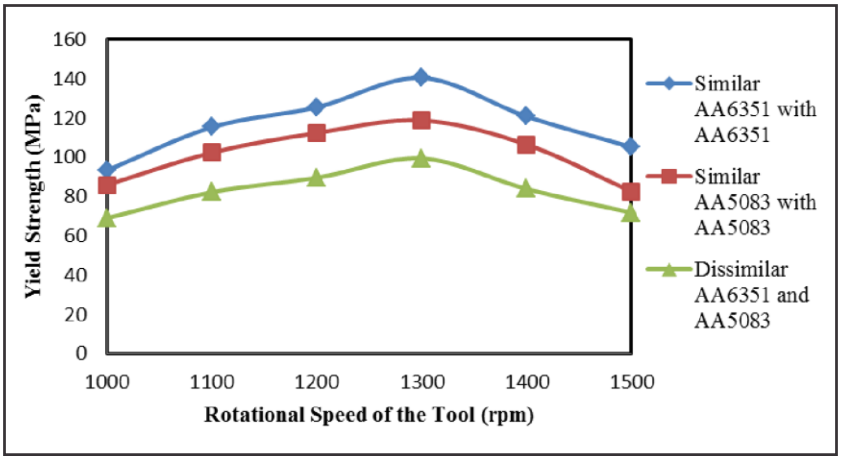

Fig.5 : Effect of rotational speed of tool on yield strength.

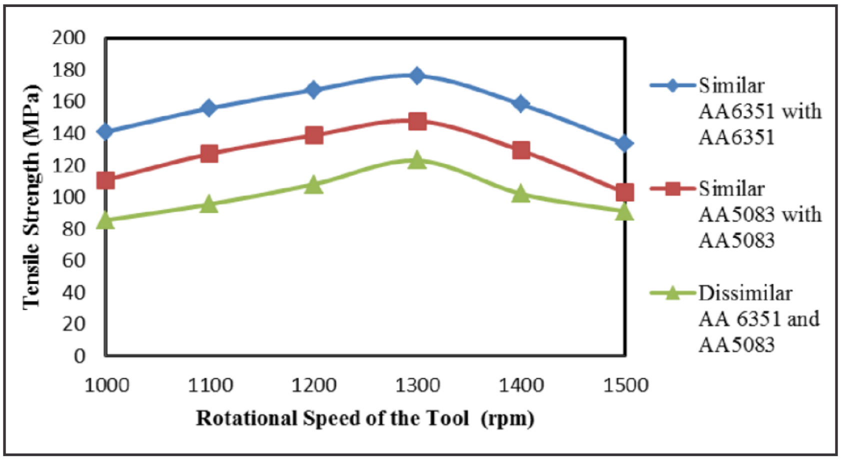

Fig.6 : Effect of rotational speed of tool on tensile strength.

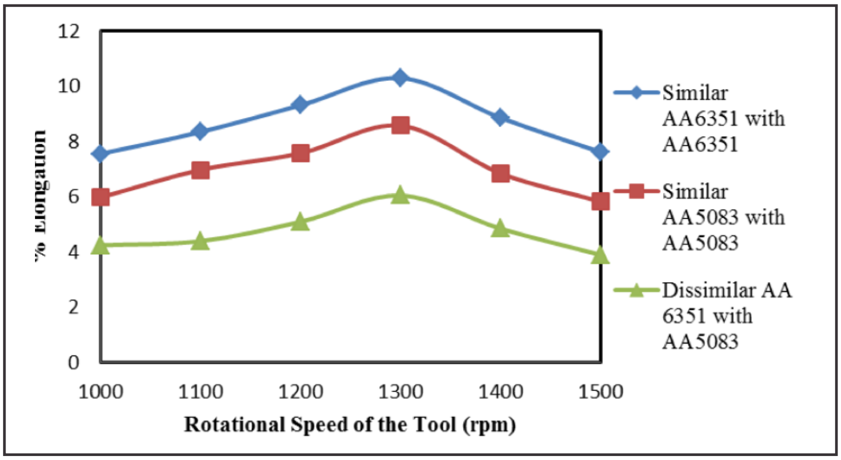

Fig.7 : Effect of rotational speed of tool on percentage elongation.

3.2. Hardness Test

The two hardness tests were carried out to find the BHN (Brinell Hardness Number) and RHN (Rockwell Hardness Number) values of the Al alloy AA6351 with AA6351 alloy, Al alloy AA5083 with AA5083, and Al alloy AA6351 with AA5083 by changing tool rotational speed. **Fig. 8** and **Fig. 9** illustrate the effect of the tool rotational speed on Brinell and Rockwell hardness numbers. From the figures, it is clear that both hardness values show the same trend. At lower speeds, the hardness values are lower. When speed increases correspondingly hardness values increase. After reaching maximum values at 1300 rpm, the trend is reversed i.e. hardness values decrease with further increase in speed.

Al AA6351 alloy with Al AA6351 alloy combination shows better hardness values as compared to Al AA5083 alloy with Al AA5083 alloy combination and Al AA6351 alloy with Al AA5083 alloy combination because Al AA5083 alloy hardness values are lower than Al AA6351 alloy so Al AA6351 alloy with Al AA5083 alloy results lower hardness values. The Al AA6351 alloy with Al AA6351 alloy combinations shows better performance than Al AA5083 alloy with Al AA5083 alloy and Al AA6351 alloy with Al AA5083 alloy combinations. The Al AA6351 alloy with Al AA5083 alloy combinations shows the lowest values of the other two similar combination joints.

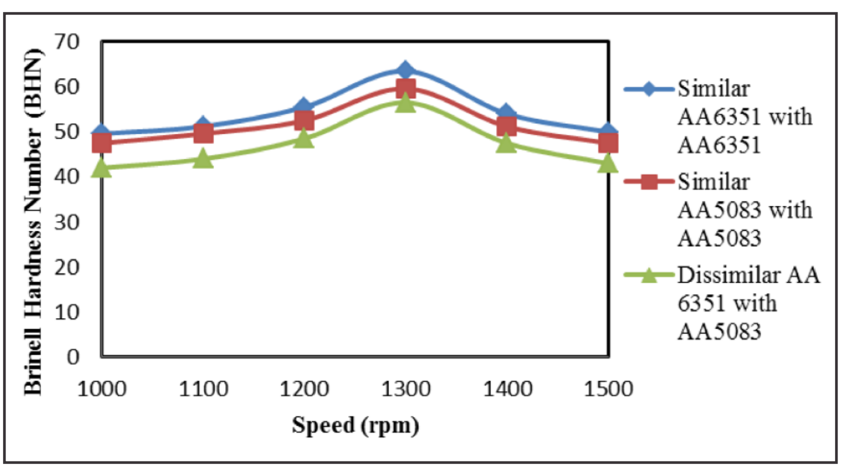

Fig.8 : Effect of rotational speed of tool on BHN.

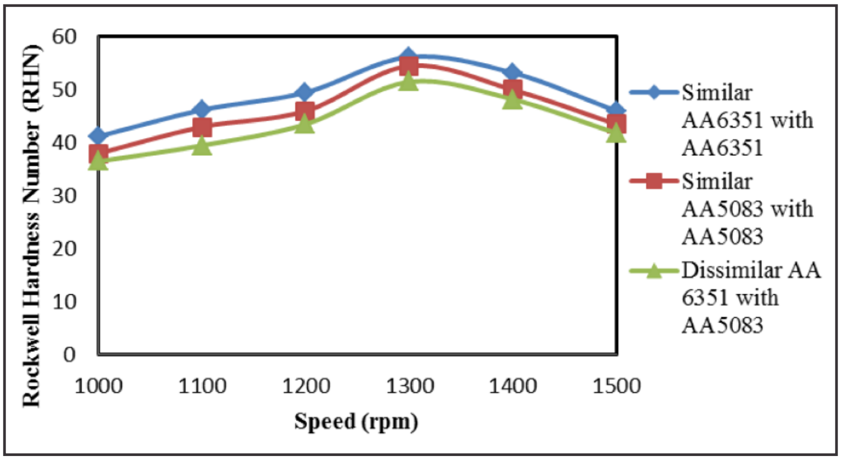

Fig. 9 : Effect of rotational speed of tool on RHN.

3.3. Impact Test

A Charpy impact test was done to find out impact energy of various combinations of FS weldments. **Fig. 10** illustrates the effect of the tool rotational speed on the impact energy of FS welded AA6351 with AA6351, AA5083 with AA5083, and AA6351 with AA5083 combinations. Impact energy of FS weldment is less when speed is less (1000 rpm). As the speed increases from 1000 rpm the impact energy of the weld material also increases and reaches its optimum value at 1300 rpm. After reaching the maximum value, the trend is reversed i.e. impact values decrease with a further increase in speed. All the combinations show the same trend. The Al AA6351 alloy with Al AA6351 alloy combinations shows better performance than Al AA5083 alloy with Al AA5083 alloy and Al AA6351 alloy with Al AA5083 alloy combinations. The Al AA6351 alloy with Al AA5083 alloy combinations shows the least performance than the other two similar combination joints.

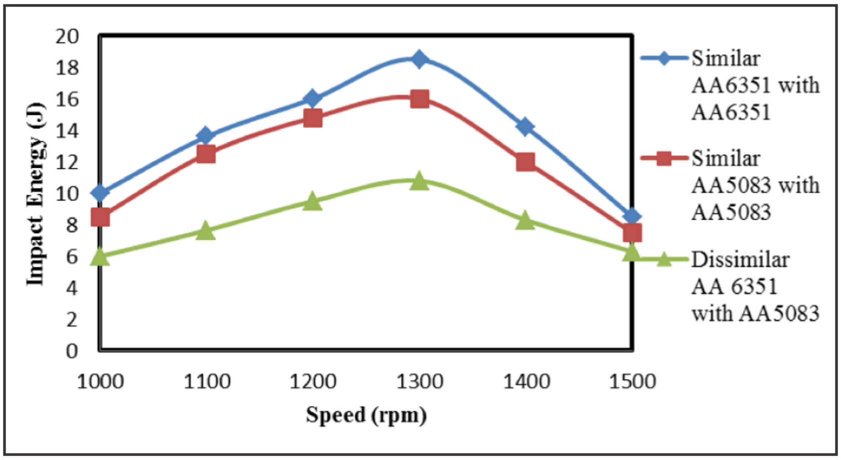

Fig.10 : Effect of rotational speed of tool on Impact energy.

4.0 CONCLUSIONS

- The tensile properties of weldments increase with the increase in speed of the tool. After attaining optimum values at a particular speed, the tensile values decrease with a further increase in the speed.
- The Rockwell and Brinell hardness values reveal that hardness increases with an increase in the speed of the weldment. The value comes down with the increase in the speed after reaching the optimum value at a particular speed.
- The Charpy impact strength increases in impact strength of weldment with an increase in speed and reaches a maximum value at a particular speed and decreases with the further increase in speed of the tool.
- Tensile, hardness, and impact properties of Al alloy AA6351 with AA6351 combination got better performance than AA5083 with AA5083 and AA6351 with AA5083. Lower mechanical properties of AA5083 alloy play a key role in obtaining lower properties in AA5083 alloy with AA5083 alloy and AA6351 alloy with AA5083 alloy combination weldments.

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