The Effect of Tool Rotation Speed and Copper and Brass Addition in Foil Form on Tensile Properties of Friction Stir Welded Similar and Dissimilar Aluminium Alloy Weldments

G. Gopala Krishna[1], P. Ram Reddy[2], M. Manzoor Hussain[3]

[1] Associate Professor, Department of Mechanical Engineering, J.B. Institute of Engineering and Technology (Autonomous), Yenkapally, Moinabad Mandal, Hyderabad– 500 075, Telangana, India, e-mail: krishkans@gmail.com,

[2] Professor in Mechanical Engineering and Former Registrar, JNTU, Hyderabad, Telangana, India and

[3] Principal, JNTUH College of Engineering, Sultanpur, Medak District, Telangana, India.

ABSTRACT

Nowadays, aluminium and aluminium alloys are most widely used in many applications in which the combination of high strength and low weight is attractive. Friction Stir Welding (FSW) process is an efficient and cost-effective method for welding aluminium and aluminium alloys. FSW is a solid-state welding process in which the material is not melted during the process. Being a solid state process it overcomes many welding defects that usually happens with conventional fusion welding techniques which were initially used for low melting materials. Though this process is initially developed for low melting materials but now the process is widely used for a variety of other materials. In this present experimental investigation, initially, butt joining of similar aluminium alloy AA6351 with AA6351 and dissimilar aluminium alloy AA6351 with AA5083 of 5 mm thickness were carried out by FSW and compared tensile properties. To study the influence of another element such as copper and brass on both combinations have been carried out. FSW has been done by inserting 0.1 mm thickness of copper and brass foil separately in butt joint position for both similar and dissimilar aluminium alloy combinations by changing the rotational speed of the tool. Tensile properties studied for all these combinations and results were compared using with and without foil of copper and brass material.

Keywords: Friction Stir Welding, Tensile Properties, Aluminium Alloys AA6351 and AA5083, Copper and Brass Materials.

1.0 INTRODUCTION

Modern structural applications such as aerospace, shipbuilding and automotive industries demand a sound joint between similar and dissimilar materials. However, joining of dissimilar materials by conventional fusion welding technique leads to numerous welding defects such as voids, hot cracking, distortion, precipitate dissolution, hot cracking and lack of penetration [1]. Therefore, solid state welding process is forefront to solve these defects effectively.

Friction stir welding (FSW) is an appropriate solid state welding technique to join any combination of dissimilar aluminium alloys effectively and efficiently [2]. Friction Stir Welding (FSW) is a new solid state welding process which is developed and patented by The Welding Institute (TWI) in 1991. This process found suitable and accepted worldwide throughout the joining and welding community since its inception.

The basic principle of FSW process is simple. Instead of a conventional welding torch, friction stir welding process uses a non-consumable rotating tool usually harder than material to be welded, with a specially designed shoulder and the pin is inserted into the abutting edged of the two parts to be welded and traversed along the line of the joint as shown in **Fig.1.** The heating is localised and generated due to friction between the rotating tool and the workpiece material, with additional adiabatic heating from metal deformation. The shoulder and pin of the tool can be modified in a number of ways to influence the material flow and microstructural formation.

Joining of dissimilar aluminium alloys between AA5xxx and AA6xxx by FSW process was reported in references [3-6]. Elangovan et al. studied the mechanical characterisation of friction stir welded both similar and dissimilar combinations of aluminium alloys of AA6061 and AA5086. They found that the tensile strength of dissimilar combination is less compared to similar aluminium alloy combinations [3]. Leitao et al. investigated both similar and dissimilar aluminium alloy combinations of AA5182-H111 and AA6016-T4 by using FSW technique. They found that 10% reduction weld strength compared to similar combination but a considerable reduction in hardness not observed [4]. Peel et al. studied dissimilar aluminium alloys of AA5083 and AA6083 by FSW process and they concluded from the study that thermal histories and properties of weld joint influenced by the rotation speed of the tool is more strong and traverse speed of the tool is less strong [5]. Palanivel et al. investigated dissimilar aluminium alloys of AA6351-T6 to AA5083-H111 joined by friction stir welding process with various tool pin profiles. The best strength achieved with straight square profiled tool [6].

From the above literature review, it is observed that a very few research work is carried out in dissimilar FSW of aluminium alloys AA6351 and AA5083 which is widely used aerospace, ship building and other fabricated resulted in industries [7] especially in shipbuilding and marine related industries because aluminium alloy AA5083 is corrosion resistant to sea water. So, in this present research work, an attempt has been made to join not only similar alloy combinations of AA6351 with AA6351 but also dissimilar aluminium alloy combinations of aluminium alloy AA6351 with AA5083.

In this work, 5 mm thick similar and dissimilar aluminium alloy combinations joined by using FSW process and investigated experimentally, the effect rotational speed of the tool on tensile properties of both the combinations. In similar aluminium alloy combination, aluminium alloy AA6351 plate is friction stir welded to other AA6351 plate and in dissimilar aluminium alloy combination, aluminium alloy AA6351 plate is friction stir welded to the AA5083 plate in butt joint position.

Mechanical properties can improve by various techniques in FSW process such as post weld heat treatment [8, 9], pre-heating the weld during the process [10], different types of peening processes [11] and overlapping weld passes [12]. Though FSW process requires no additional material during the welding process but the addition of alloying elements influences microstructure and improves mechanical properties in aluminium alloys. The addition of a little percentage of copper and zinc improves the strength and hardness of aluminium [13]. In this work, one more effort has also been made to improve tensile properties of aluminium alloy by inserting 0.1 mm thickness of copper and brass foils separately during FSW in between two aluminium alloy plates of both similar and dissimilar alloy combinations.

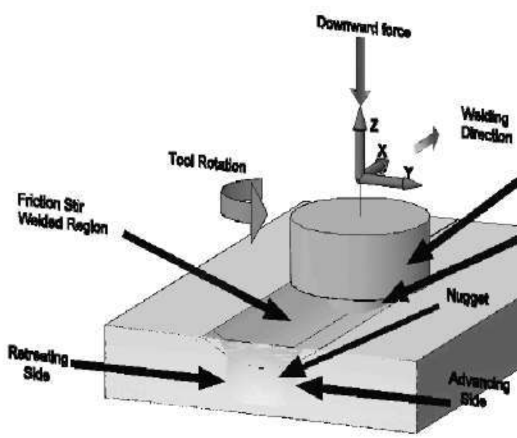

Fig.1. The Friction Stir Welding (FSW) process.

2.0 EXPERIMENTAL PROCEDURE

2.1 Material

In the present work, 5 mm thick aluminium alloy AA6351 and aluminium alloy AA5083 plates are used. Typical and experimental chemical composition of aluminium alloy AA6351 and aluminium alloy AA5083 are presented in **Table 1** and **Table 2** respectively. Friction stir welding of various combinations has been done in butt joint configuration.

Table 1 : Typical chemical composition and chemical composition of base material (Aluminium Alloy AA6351) used for experiments

Element	Typical	Base material used for experiments
Si	0.8	0.7
Fe	0.5	0.357
Cu	0.1	0.037
Mn	0.4	0.35
Mg	0.4	0.3
Zn	0.2 max	0.004
Ti	0.2 max	0.024
Ai	Balance	Balance

Table 2 : Typical chemical composition and chemical composition of base material (Aluminium alloy AA5083) used for experiments

Element	Typical	Base material used for experiments
Si	0.2	0.134
Fe	0.35	0.284
Cu	0.15	0.028
Mn	0.15	0.58
Mg	5	4.466
Zn	0.25	0.006
Ti	0.1	0.021
Al	Balance	Balance

The base material used for this study's mechanical properties of aluminium alloy AA6351 and AA5083 are presented in **Table 3**. It is clear from **Table 3**, that mechanical properties of aluminium alloy AA5083 are lower compared to aluminium alloy AA6351.

Table 3 : Mechanical properties of base materials used.

	Yield Strength (Mpa)	Tensile Strength (Mpa)	Percentage Elongation	Vickers Hardness Number (VHN)
Aluminium Alloy AA6351	251	289	11	111
Aluminium Alloy AA5083	215	253	7	89

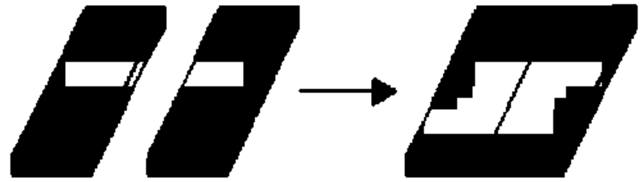

Fig.2 : Process FSW of AA6351 with AA6351 and AA6351 with AA5083.

Both aluminium alloys are friction stir welded with different combinations. Initially similar aluminium alloy combination, aluminium alloy AA6351 plate is friction stir welded with other aluminium alloy AA6351 plate and in dissimilar aluminium combination, aluminium alloy AA6351 plate is friction stir welded with aluminium alloy AA5083 plate as shown in **Fig.2**. Later both the similar and dissimilar aluminium alloy combination were FS welded with 0.1 mm thickness copper (99.95 % of copper) and brass (65% of copper and 35% of zinc) foils placed separately in between two aluminium alloy plates as shown in **Fig.3**.

Fig.3 : Process FSW of AA6351 with AA5083 with copper/brass thin sheet.

2.2 Tool

The design of tool influences heat generation, the power required for plastic flow and the uniformity of the weld joint. The rotating tool consists of the shoulder, shank and tool. The shoulder of the tool generates most of the heat and prevents the plasticised material flow escaping from the workpiece while both the shoulder and the tool pin affects the material flow. The design of the tool is a critical factor and a good tool design can improve both the quality of the weld and as well as the maximum possible welding speed. It is desirable that the material of the tool is sufficiently strong, hard and tough wearing at the welding temperature. The tool material used in this work was high-speed steel (HSS) with conical shape probe without threads. The tool is subjected to heat treatment to improve hardness, the hardness tool after the heat treatment process is 54 HRC.

2.3 Welding Procedure

A vertical axis Computer Numerically Controlled (CNC) milling is converted into friction stir welding machine to carry out welding process as shown in **Fig. 4** and **Fig. 5**. The two aluminium alloy plates were perfectly clamped in CNC milling machine bed on a backup plate. The welding tool consists of the shoulder, shank and pin are then rotated in specified speed, direction and oriented normal with respect to the workpiece. The tool is slowly plunged into the workpiece material at the butt line until the shoulder of the tool forcibly contacts the top surface of the material and pin is a short distance from the back plate. A downward axial force is then applied to maintain contact and a short dwell time observed to develop thermal fields for preheating and softening the material along the joint line. At this point, welding speed or feed is applied in lateral direction and tool is forcibly traversed along the butt line, until it reaches the end of the weld. After reaching the end of the weld, the tool is withdrawn, while it is still being rotated. A keyhole is formed at the end of the weld when the tool is withdrawn from the weld. The tool is plunged into the joint in the downward direction. Higher rotation of the tool generates temperature at weld zone because of higher frictional heating and resulted in the most intense stirring of mixing material.

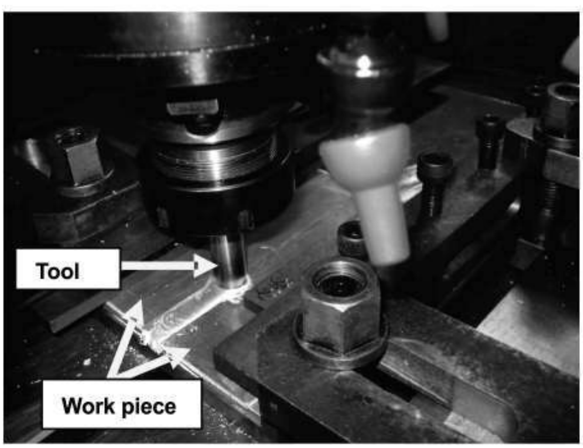

Fig.4 : FSW process under Progress.

3.0 RESULTS AND DISCUSSIONS

Tensile tests were performed to determine the tensile properties (yield strength, tensile strength and percentage elongation) for friction stir welded all aluminium alloy combination samples. Transverse tensile specimen cut from friction stir welded sample according to ASTM-E8 standards.

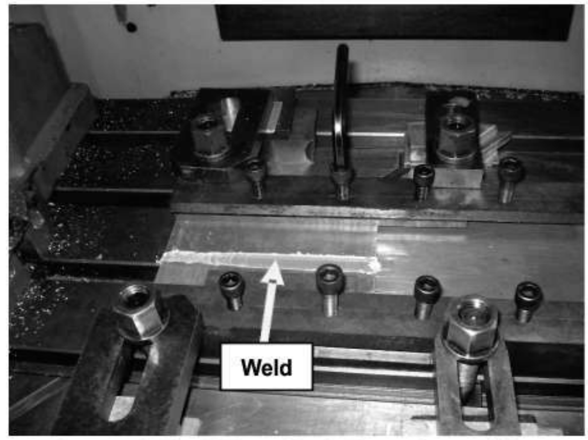

Fig.5 : Friction Stir Welded Piece after welding.

Tensile properties were lower at lower rotational speeds of the tool and increase with increase in rotational speeds and after reaching optimum value, a reverse trend has been observed i.e., tensile properties decrease with increase in rotational speed of the tool. This type of trend is common for all types of combinations of alloys i.e., similar aluminium alloy, dissimilar aluminium alloy, similar aluminium alloy and dissimilar alloy using copper and brass foil material combinations.

Fig. 6-8 show the effect of rotational speed of the tool on yield strength, tensile strength and percentage elongation of similar aluminium alloy combination of AA6351 with AA6351 and dissimilar aluminium alloy combination of aluminium alloy AA6351 with AA5083 respectively. It is clear from these figures that at lower rotational speed (1000 rpm) of the tool, tensile properties of both similar and dissimilar aluminium alloy combination were lower and reaches a maximum at 1300 rpm. After reaching an optimum value at 1300 rpm rotational speed of the tool, tensile properties decreases with increase in rotational speed of the tool. This type of trend coincided with authors Elangovan and Palanivel [14 , 15].

Lower rotational speeds of the tool lower the heat input during FSW which results in lower tensile properties because of wavy zigzag pattern formation on weldment cross section [16] and crack or pinhole defect formation [14]. Higher rotational speed of the tool results higher temperature at weld joint [17] which results in large size defect like tunnel [14]

Similar aluminium alloy combination of aluminium alloy AA6351 with AA6351 shows higher tensile properties compared to dissimilar aluminium alloy combination of aluminium alloy AA6351 with AA5083 because weaker aluminium alloy (AA5083) dictates the performance of the weld joint [18].

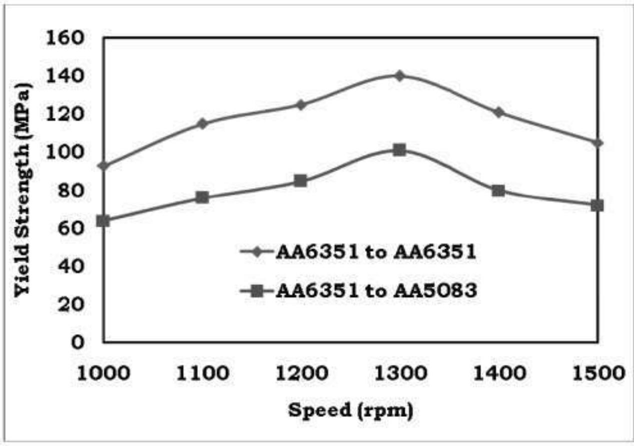

Fig. 6 : Effect of the rotational speed of tool on yield strength for both similar and dissimilar aluminium alloy combination.

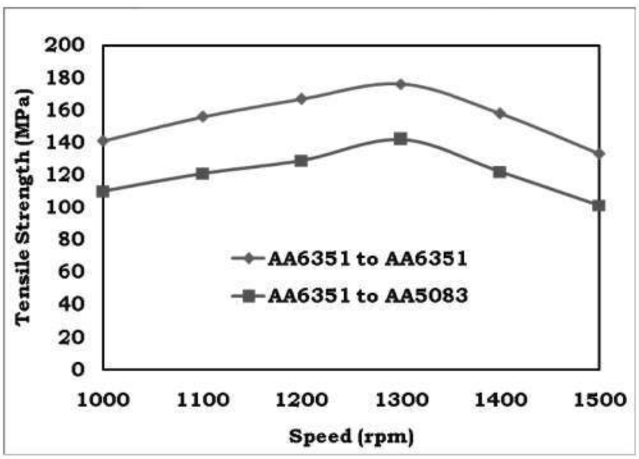

Fig.7 : Effect of the rotational speed of tool on tensile strength for both similar and dissimilar aluminium alloy combination.

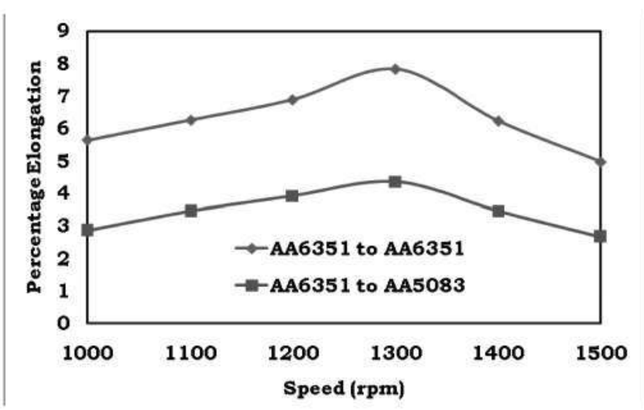

Fig.8 : Effect of the rotational speed of tool on percentage elongation for both similar and dissimilar aluminium alloy combination.

Fig. 9-11 show the effect of rotational speed of the tool on yield strength, tensile strength and percentage elongation of similar aluminium alloy combination of aluminium alloy AA6351 with AA6351, similar aluminium alloy combination of AA6351 with AA6351 with the addition of copper and brass foils separately. It is clear from these graphs that at lower rotational speed (1000 rpm) of the tool, tensile properties of all the combinations were lower at lower rotational speeds of the tool and reaches a maximum at 1300 rpm. After reaching an optimum value at a rotational speed of 1300 rpm, tensile properties for all combinations decreases with further increase in rotational speed of the tool. The tensile values of similar aluminium alloy combination with copper and brass foil addition are lower than the pure similar aluminium alloy combination alloys because complete melting and intermixing of copper and brass foil were not taken place at the bottom side of the plates though the thickness of copper and brass foils are too small. This is due to the melting point of copper and brass are more compared to aluminium alloy and in friction stir welding process takes below the melting point of the aluminium alloy. The tensile values of copper foil addition in similar aluminium alloy combination are more than that of brass foil addition because the thermal conductivity of copper is more than brass due to this more heat flow takes place with the copper addition this additional heat helps more intermixing of copper than the brass.

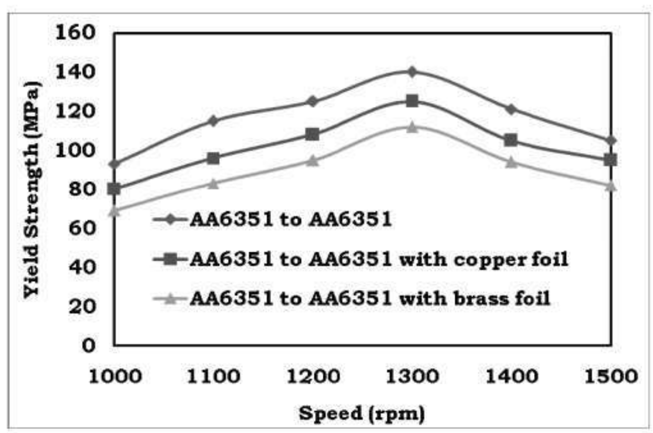

Fig.9 : Effect of the rotational speed of tool on yield strength for pure similar aluminium alloy, and the effect of copper and brass addition on similar aluminium alloy combinations.

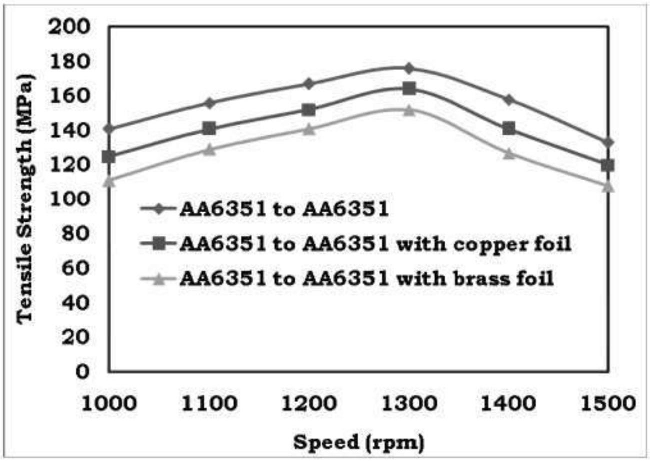

Fig.10 : Effect of the rotational speed of tool on tensile strength for pure similar aluminium alloy, and the effect of copper and brass addition on similar aluminium alloy combinations.

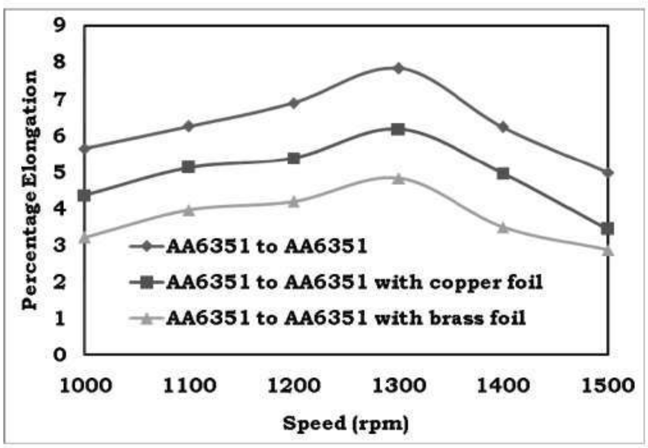

Fig.11 : Effect of the rotational speed of tool on percentage elongation for pure similar aluminium alloy, and the effect of copper and brass addition on similar aluminium alloy combinations.

Fig. 12-14 show the effect of rotational speed of the tool on yield strength, tensile strength and percentage elongation of dissimilar aluminium alloy combination of aluminium alloy AA6351 with AA5083, dissimilar aluminium alloy AA6351 with AA5083 with the addition of copper and brass foil material respectively. It is clear from all these figures that at lower rotational speed (1000 rpm) of the tool, tensile properties of all the combinations were lower and reaches a maximum at 1300 rpm. After reaching an optimum value at 1300 rpm rotational speed, tensile properties decreases with increase in rotational speed of the tool. Tensile values of dissimilar aluminium alloy combination with copper and brass foil addition are lower than the pure dissimilar aluminium alloy combination alloys because a complete melting and inter-mixing of copper and brass foil were not taken place at the bottom side of the plates though the thickness of copper and brass foils are too small. This is due to the melting point of copper and brass are more compared to aluminium alloy and friction stir welding process takes place below the melting point of the aluminium alloy. The tensile values of copper foil addition in dissimilar aluminium alloy combination are more than that of brass foil addition because the thermal conductivity of copper is more than brass due to this more heat flow takes place with copper addition, this additional heat helps more intermixing of copper than the brass.

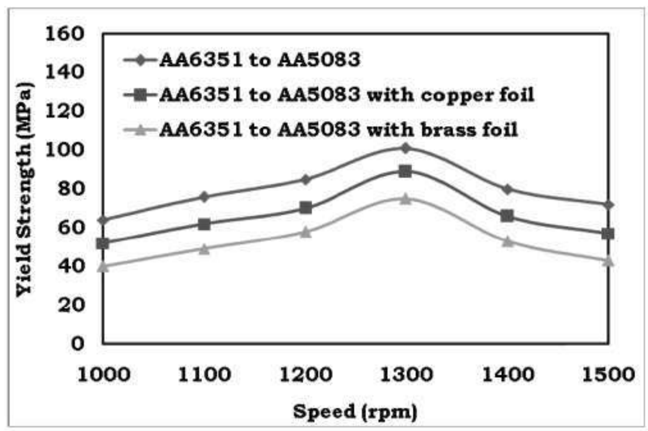

Fig.12 : Effect of the rotational speed of tool on yield strength for pure dissimilar aluminium alloy and the effect of copper and brass addition on dissimilar aluminium alloy combinations.

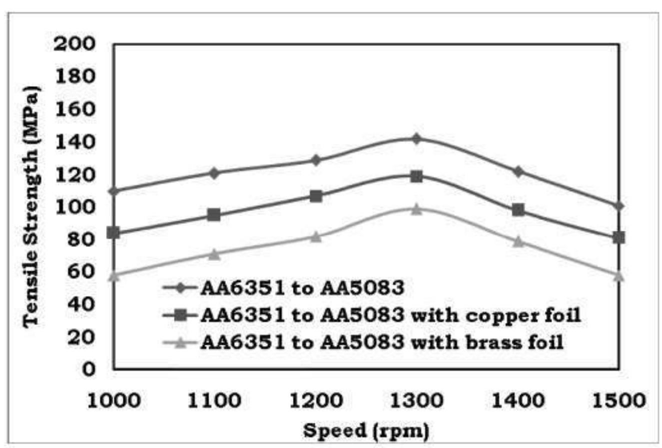

Fig.13 : Effect of the rotational speed of tool on tensile strength for pure dissimilar aluminium alloy, and the effect of copper and brass addition on dissimilar aluminium alloy combinations.

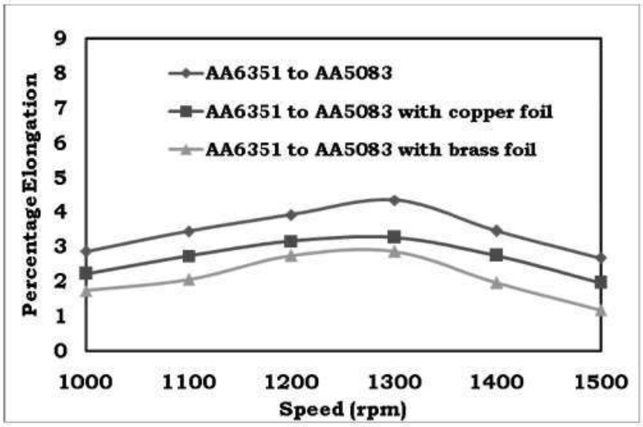

Fig.14 : Effect of the rotational speed of tool on percentage elongation for pure dissimilar aluminium alloy and the effect of copper and brass addition on dissimilar aluminium alloy combinations.

4.0 CONCLUSIONS

The following conclusions arrive from the present work :

- Tensile values (yield strength, tensile strength and percentage elongation) are lower at lower rotational speed of the tool and increase with increase in rotational speed of the tool and reaches maximum at a particular value of the speed (1300 rpm) and thereafter, tensile values come down with increase in rotational speed of the tool. This trend is common for all types of combinations.
- Tensile values of similar aluminium alloy combination of aluminium alloy AA6351 with other aluminium alloy AA6351 are greater than the dissimilar aluminium alloy combination of aluminium alloy AA6351 with aluminium alloy AA5083.
- Tensile properties of copper and brass foil addition on similar aluminium alloys are lower compared to pure similar aluminium alloy combinations but the copper foil addition in the similar aluminium alloy are more than that of brass foil addition in same similar aluminium alloy combination of aluminium alloy of AA6351 with AA5083.
- Tensile values of copper foil addition in dissimilar aluminium alloy combination of AA6351 with AA5083 are lower than that of pure dissimilar aluminium alloy combination of AA6351 with AA5083 but greater than that of brass foil addition in dissimilar aluminium alloy combination of AA6351 with AA5083.

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