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Optimization of Process Parameters for Friction Stir Spot-Welded AA2024-Al/Polycarbonate and AA2024-Al/Polypropylene

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Abstract. The aim of the present work is to optimize the welding parameters for friction stir spot welding on heat treatable AA2024 aluminium alloy/Polycarbonate and Polypropylene sheets using analysis of variance (ANOVA). The optimum welding parameters for the peak temperature of the joints were predicted, and the individual importance of each parameter on the temperature of the friction stir spot weld was evaluated by examining the analysis of variance (ANOVA) results. The optimum levels of the dwell time and tool rotational speed were found to be 6 s and 1500 rpm, respectively. The ANOVA results indicated that the dwell time has the higher statistical effect with 56.16% on the peak temperature, followed by the rotational speed and tool respectively.

Keywords: Aluminium alloy, Friction stir spot welding, Temperature, Welding parameters, ANOVA.

1. INTRODUCTION

Polymer–metal hybrid structures are widely used in automotive, aerospace and electronic industries. These structures are attractive due to their high strength-to-weight ratios, thermal and electrical insulation and excellent corrosion resistance, as well as design flexibility[1]. Modern thermoplastic materials are used in an expanding range of engineering applications, such as the automotive industry, due to their better stress-to-weight ratios, a very short time of solidification, toughness, and low thermal conductivity [2]. The utilize of aluminum alloys for auto body panels leads to a lessening in the vehicle body weight which translates into reduced emissions as well as increased performance. After the body panels are formed into the desired shapes they will require joining to other parts of the automobile[3]. Although, joining polymers to metals is difficult due to very large differences in their mechanical and physical properties. Conventional methods for joining polymer–metal structures are mostly mechanical joining and adhesive bonding [4], [5]. However, the two methods have some limitations. Adhesive bonding imposes obstacles due to high difference between surface energy of metals and polymers. In addition, strength of the adhesively bonded joint is disposed to temperature and other environmental conditions[1]. On the other hand, mechanically joined polymer–metal structures generally show high susceptibility to stress concentration due to high notch sensitivity and crazing of polymeric parts[6].

Recently, a new solid-state joining technology of the friction stir spot welding (FSSW), which is a derivative process of the friction stir welding (FSW), has been developed as an extensive technique and effectively applied for producing lap-joints[7]. In 2001, Friction stir spot welding (FSSW) was developed in the automotive industry to replace resistance spot welding (RSW) for aluminum sheets[3]. Easiness of joining materials, excellent mechanical properties, low distortion, low cost and more economical are some advantages of FSSW than RSW. The friction stir spot welding process consists of three phases; plunging, stirring and retracting[8]. The process starts with the spinning of the tool at a high rotational speed. Then the tool's shoulder is forced into the weld spot until it contacts the top surface of the upper workpiece. When the tool reaches the predetermined depth, the plunge motion ends and the stirring phase starts by the tool's pin[9]. Frictional heat is generated in the plunging and the stirring phase and, hence, the material adjacent to the tool is heated and softened. The softened upper and lower workpiece materials mix together in the stirring phase. The shoulder of the tool creates a compressional stress on the softened material. A solid-state joint is formed in the stirring phase. When a predetermined bonding is obtained, the process stops and the tool is retracted[10].

Parameters of friction stir spot welding are optimized by using the analysis of variance (ANOVA). ANOVA is the statistical treatment that is widely applied to the results of experiments to determine the percentage contribution of each parameter. ANOVA helps in properly testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specific confidence levels [11]. To determine the relative effect of the welding parameters, the standard ANOVA procedure was performed using the mean values.

The present study aims to fulfill two objectives, to use the Taguchi method for determining the efficiency ratio FSSW parameters, and to estimate the contribution of individual welding parameters to the peak temperature of the weld joint.

1.2 Materials and experimental procedures

AA2024 aluminium alloy sheets with dimensions of 120 × 25 × 1.5 mm^3, polycarbonate and polypropylene polymer sheets with dimensions of 120 × 25 × 3 mm^3 were the primary materials in this study. Table 2 shows the chemical composition of AA2024 aluminium alloy. Table 3 and Table 3 show the mechanical properties of the primary materials. Two tools designs with different pin configurations were used to perform the FSSW for the AA2024Al/polycarbonate and AA2024Al/polypropylene sheets. The tools have conical pins. The pin of tool (T1) has slope angle of 16.69°, where tool (T2) has slope angle of 6°. The pin height and diameter of shoulder are kept constant at 5 mm and 15 mm, respectively, for both tools. The tools were made from heat-treated K110 steel with a hardness of ~58-60 HRC. The specimens were welded on a CNC milling machine. In order to develop the FSSW tests, a designed clamping fixture was utilized to fix the specimens. Fig 1 shows a properly designed clamping fixture. Fig 2 illustrates a cross sectional view of the tools used in the welding.

Table 1 Chemical composition of AA2024 aluminium alloy

Element	Cu	Mg	Fe	Si	Cr	Zn	Al
Weight, %	3.73%	1.17	0.33	0.23	0.24	0.56	Bal.

Table 2 The mechanical and thermal properties of AA2024 Al alloy

Parameter	Value
Density	2.78 g/cm^3
Melting point	502 - 638 °C
Thermal conductivity (W/m-K)	151 W/m-K
Coefficient of thermal expansion	24.7 µm/m-°C
Tensile strength	Min 427 MPa
Specific Heat Capacity	875 J/kg.°C

Table 3 Thermal characteristics of the polypropylene and polycarbonate sheets

Material	Coeff. of thermal expansion (10-6/ºK)	Specific heat (J /K^{-1} kg)	Thermal conductivity (W/m.K)	Melting Temp. (ºC)	Tensile strength (MPa)	Density (g/cm^3)
Polycarbonate	66-70	~1200	0.19-0.22	288-316	59	1.15-1.52
Polypropylene	100-180	1700-1900	0.1-0.22	163.8	48	0.97-1.25

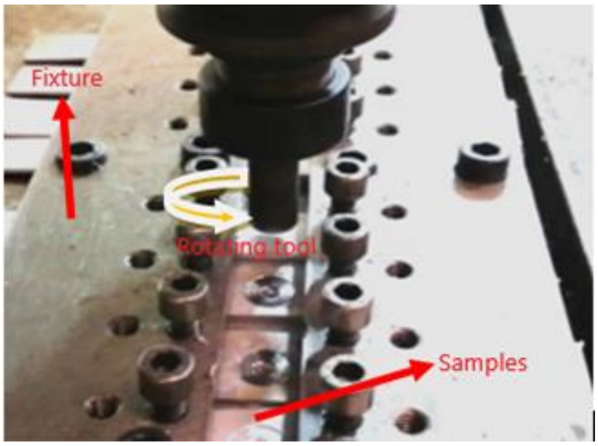


Fig 1 Properly designed clamping fixture

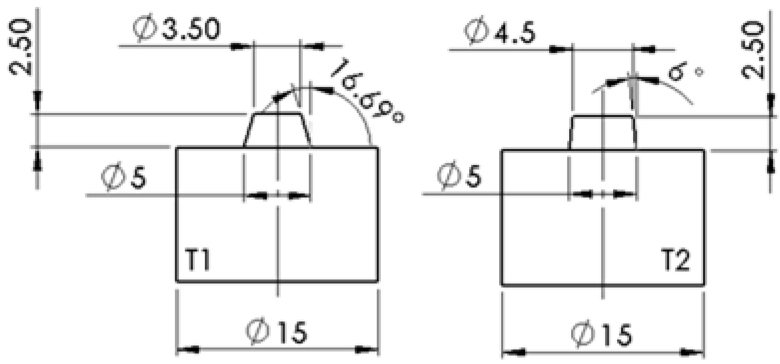


Fig 2 A cross sectional view of the tools

Joining was performed at constant plunge depth of 3.5 mm, three rotational speeds of 500, 1000 and 1500 rpm, three dwell time of 4,5 and 6 sec.

FLUKE Ti32 infrared camera was used to record the temperature during FSSW. The camera was aimed, to capture the temperature images at the top surface of the AA2024 Al sheet of the welded joint since it is very difficult to measure the temperature at the metal/polymer interface region. The thermal images was captured immediatly, after the retracting of the tool. It has a thermal senstivity of 0.045˚C and a powerful 320×240 resolution. The temperature range of the camera varies from -20 to 600˚C.

1.3 RESULTS AND DISCUSSION

Main effect plots show how each factor affects the response characteristic. As shown in Fig 3 the trend of the peak temperature means which increase by increasing the dwell time and rpm. This finding indicates that welding parameters revealing higher mean values resulted in higher variability. It is clear that the highest peak temperature was obtained at the average value of the levels for dwell time and rotational speed. So, the optimal combination of welding parameters is a dwell time of 6 s, and a tool rotational speed of 1500 rpm and using tool 2. The ANOVA table indicates the order of importance of the welding parameters for the peak temperature of the welded joints was: dwell time > rotational speed > tool (Table 4). The most significant parameter is the dwell time with a contribution of 56.19 percent. The dwell time and rotational speed parameters greatly affect the heat input during the process, which affect the weld quality.

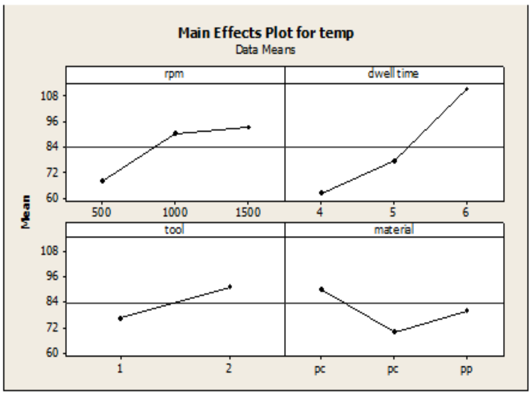
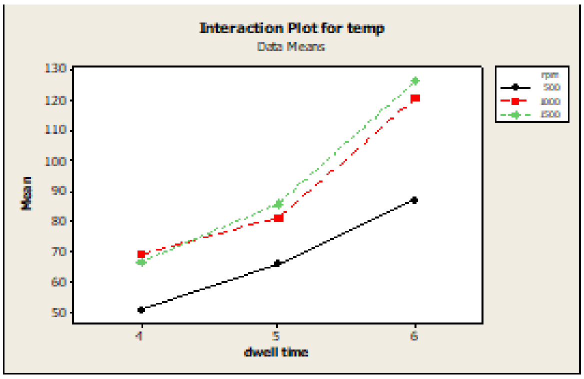


Fig 3 Main effects plot for the peak temperature of the welded joints.

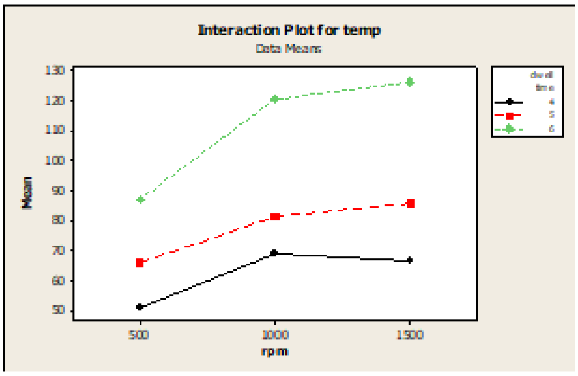
Table 4 ANOVA table for means

	DF	SS	MS	F	P	Contribution %
Rpm	2	4506.4839	2253.2419	0.855	0.471	16.02
Dwell time	6	15807.9083	2634.6514	9.634	0.002	56.19
Tool	9	2461.2	273.4667	0.919	0.531	8.75
Material	18	5358.05	297.6694			19.05
Total	35	28133.6422				100

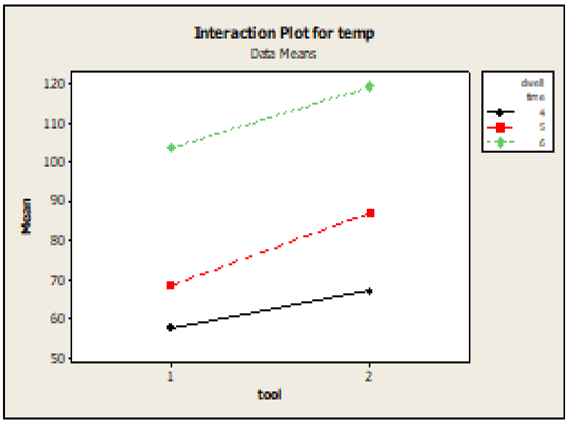
Fig 4 shows the interaction plot for average peak temperatures with the different friction stir spot welding parameters. In Fig 4c and d it is clear that tool 2 recorded higher mean temperature than tool at constant dwell time and rpm, this means that it generates more heat input at the weld which affect the weld quality.



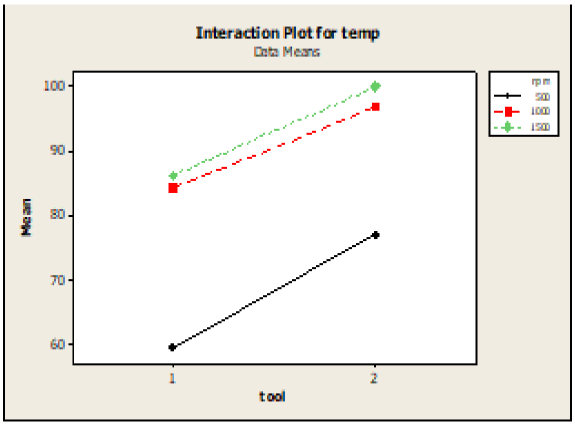
(a)



(b)



(c)



(d)

Fig 4 Interaction plot of average peak temperature (a) for dwell time at constant rpm (b) for rpm at constant dwell time (c) for tools at constant dwell time (d) for tools at constant rpm.

1.4 CONCLUSION

The results revealed that for friction spot welding of AA2024-Al/polycarbonate and AA2024-Al/polypropylene welds are as follows:

1- The dwell time is the most contributive factor by 56.19 percent.

2- The most optimum condition which gives the highest mean peak temperature is of dwell time 6 s, 1500 rpm and with tool 2.

3- Tool 2 generates more heat input in the weld at constant dwell time and rpm which affect the weld quality.

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