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HYPERGEOMETRY SERIES IN FRICTION STIR WELDING OF AA 6061 AND AZ61

J.Jayapriya[1*] , Muruganadam.D[1]
Assistant Professor, Department of Mathematics, Sathyabama University, Chennai, Tamilnadu.
Asst.Professor, Department of Mechanical Engineering, Jeppiaar Institute of Technology,Sriprembudur, Chennai.
Email: murudurai@gmail.com

Abstract

Friction stir welding (FSW) is found as an modern welding approach in automobile, aerospace and ship bulding. This paper is concentrated on initiating a numerical approach for Friction Stir Welding (FSW) in AA 6061 – AZ 61. Use of Hypergeometry series is adopted as a numerical approach.

The various process parameters like density, rotational speed, transverse speed and axial load are considered for the numerical approach. Using concave tapered tool the various weld parameters are carried on five welded specimen with different process parameters combination. The mechanical strength of experimental results was correlated with numerical approach.

Keywords: Friction Stir Welding, AA 6061, AZ 61, Hypergeometry.

Introduction

Friction stir welding is a process of joining similar and dissimilar metal. The metals are not joined in liquid state, instead during solidus state metals are joined together with combined forces of torque, axial force and transverse force. These forces are generated by the parameters such as rotational speed, axial load and transverse speed. Since the metal joining is affected by the combination of forces which is developed by the respective process parameters, it is required to choose the optimal combination of parameters which will produce a quality weld. The different process parameter combination can be made on the friction stir welding machine and the specimen (combination of two metals – similar/non-similar) is welded for that parameter.

So an infinite number of parameter combination will lead to infinite number of specimens which will lead to increase in cost for both material and testing. Hence it is required to initiate a numerical approach that will identify the optimal combination.

The already existing design of experiments procedure are deals with individual variables (single parameter). But we used a numerical approach that combines different process parameters. The Schematic illustration of Friction Stir Welding is represented in Fig.1.
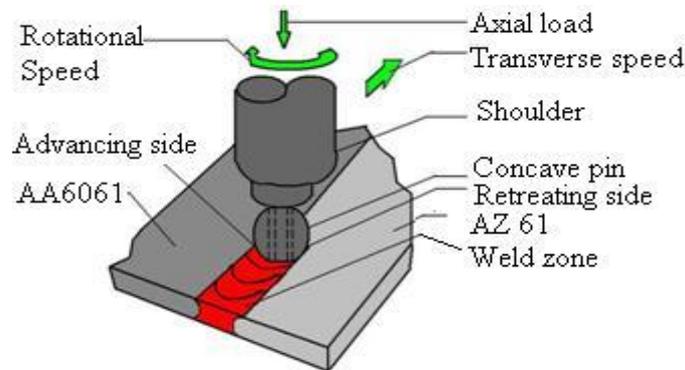
Fig.1 Representation of Friction Stir Welding with concave slotted pin.

During the stirring process the weld centre is subjected to high temperature composes fine – equiaxed grains and large deformation sets up on the nugget zone[1]. TMAZ is the region that is surrounding the nugget zone, where the nugget zone usually have more heat deformation compared to the TMAZ zone [2]. The simultaneous translational and rotational motion of the welding pin during the Friction Stir Welding process creates a remarkable symmetry between both the advancing and retreating sides. The side where the tool pin coincides with the direction of translation of the pin with the rotation of the welding tool is called the advancing side (AS), while the other side, where the two motions, translation and rotation counteract is called the retreating side (RS) [3].

Taguchi's technique is a powerful tool in quality optimization. Taguchi's technique makes use of a special design of orthogonal array (OA) to examine the quality characteristics through a minimal number of experiments[4]. Taguchi's technique is not following any distribution it is using analysis of variance on a particular parameter. So a numerical approach which makes the combination of parameters to follow a distribution is initiated by approaching a hyper geometric series. A hyper geometric series, in the most general sense, is a power series in which the ratio of successive coefficients indexed by 'n' is a rational function of 'n'. The series, if convergent, will define a hyper geometric function, which may then turn out to be defined over a wider domain of the argument by analytic continuation[5].

The series 2F1 are called Gauss's hyper geometric functions, classical standard hyper geometric or often simply hyper geometric series [6].

Whipple's theorem for terminating generalised hypergeometric series:

For five parameter combination by whiple formula for terminating generalised hypergeometric series is formulated as

$$
{}_3F_2 \left|\begin{matrix} -n, b, c; \\ 1 - b - n, 1 - c - n; \end{matrix}\, x\right| = (1 - x)^n \; {}_3F_2 \left[\begin{matrix} -\frac{1}{2}n, -\frac{1}{2}n + \frac{1}{2}, 1 - b - c - n; \\ 1 - b - n, 1 - c - n; \end{matrix}\; -\frac{4x}{(1-x)^2} \right]
$$

Whipple's theorem for non-terminating generalised hypergeometric series:

For five parameter combination by whiple formula for non-terminating generalised hypergeometric series is

formulated as

$$
{}_3F_2 \left|\begin{matrix} a, b, c; \\ 1 + a - b, 1 + a - c; \end{matrix}\, x\right| = (1 - x)^{-a} \; {}_3F_2 \left[\begin{matrix} \frac{1}{2}a, \frac{1}{2}a + \frac{1}{2}, 1 + a - b - c; \\ 1 + a - b, 1 + a - c; \end{matrix}\; -\frac{4x}{(1-x)^2} \right]
$$

Clearly, for non-terminating the "-n" parameters are replaced by parameter "a".

Dixon's Theorem:

If $(1 + a - b)$ or $(1 + a - c)$ is neither zero nor negative integer and $\Re\ (a - 2b - 2c) > -2$, then

$$
{}_3F_2 \begin{bmatrix} a & b & c \\ 1 + a - b & 1 + a - c & \end{bmatrix}; 1
$$

$$
= \frac{\Gamma\left(1 + \frac{a}{2}\right)\Gamma(1 + a - b)\Gamma(1 + a - c)\Gamma(1 + \frac{a}{2} - b - c)}{\Gamma(1 + a)\Gamma\left(1 + \frac{a}{2} - b\right)\Gamma\left(1 + \frac{a}{2} - c\right)\Gamma(1 + a - b - c)}
$$

We currently chosen this theorem for numerical approach.

Experimental work

Friction Stir Welding process were selected for manufacturing dissimilar joints of Aluminium alloys AA 6061-T6 and Magnesium alloys of AZ 61. The thickness for both AA 6061-T6 and AZ 61 weld plates were 5.8 mm.The weld plates were placed with a butt joint configuration and the welding process was carried out normal to the rolling direction of the plates. The dimensions for the weld plates length and breadth of the plates are 240 and 120mm. The chemical compositions of AZ 61and AA 6061-T6 are given in Table 1. The mechanical properties of the both base metals AA 6061 and AZ 61 are shown in Table 2. Geometry of the tool pin profile and photograph of tool used to perform the welding process is shown in Fig.3. The Friction Stir Weld tool is made up of M_2 high speed steel and which was tempered and hardened to 60 HRC. The welding process was accomplished at five combination of welding speeds 12,15,18,21 and 24 mm/min with rotational speeds of 600,800,1000,1200 and 1500 rpm respectively. The net angle is set to 0º for all tests keeping constant axial load 6 kN.

Table.1. Chemical composition for Aluminium and Magnesium alloys (Base metals % by mass)

Material	Al	Mg	Zn	Fe	Si	Cu	Ni	Mn	Cr
AA6061-T6	95.8 to 98.6	0.8 to 1.2	Max 0.25	Max 0.7	0.4 to 0.8	0.15 to 0.4	-	Max 0.15	0.04 to 0.35
AZ 61	5 – 7	Balance	0.8-1	< 0.01	< 0.01	< 0.03	< 0.005	-	-

Table.2. Mechanical properties of the base metals.

Material	Yield stress Mpa	Ultimate stress Mpa	Percentage of Elongation	Hardness (Vickers)
AA6061-T6	276	310	17 %	107
AZ 61	190	295	55 %	70
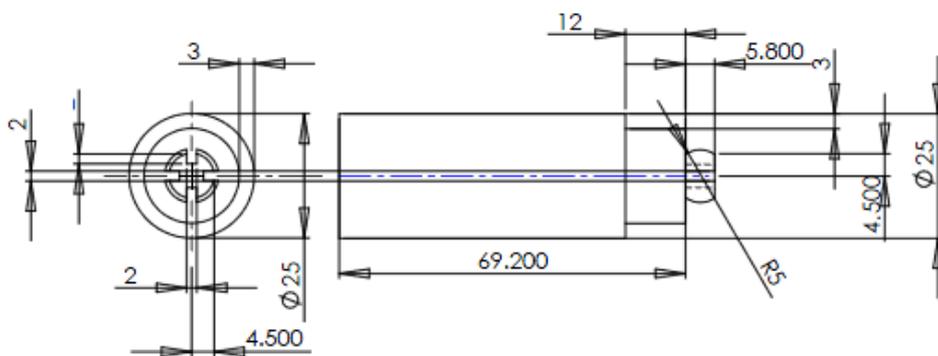
(a)

Fig.3 Concave slotted tool pin profiles (a) line sketch with dimensions
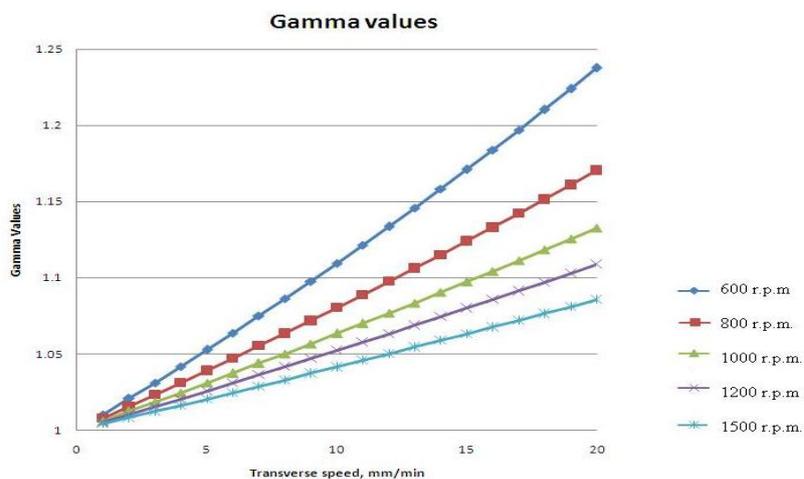
(b) Photographic view

Fig.4. Gamma values for the different combinations of rotational speed and transverse speed.
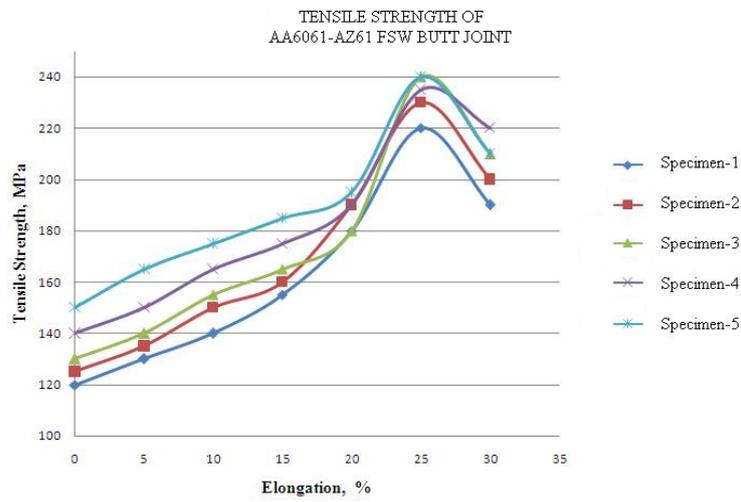
Fig.5. Tensile strength for the different combinations of rotational speed and transverse speed.

Table-3. Weld speimens with different parameter combinations.

Specimen No.	Rotational speed (r.p.m.)	Transverse Speed(mm/min)	Axial Load (KN)
Specimen-1	600	12	6
Specimen-2	800	15	6
Specimen-3	1000	18	6
Specimen-4	1200	21	6
Specimen-5	1500	24	6

Result & Discussion:

The experimental result for sepecimen-3 and specimen-5 the tensile strength is attained a maximum value. The gamma values calculations condidering these three parameters without inclusion of density values predicted the the higher rotational speed and transverse speed will result closer unity gamma values. If gamma values closer to unity the weld strength will be good. But it is required to consider the densities of AA 6061 and AZ 61 as fourth and fifth parameters to predict the optimal combination of rotational speed as well as transverse speed.

According to Dixon's theorem,

$$d = a - b + 1, \quad e = a - c + 1$$

The parameter of density is assigned to 'd' and 'e' for our numerical approach.

AA6061- density value of 2700 Kg/m^3 assigned to 'd' and AZ 61- density value of 1800 Kg/m^3 is assigned to 'e'.

Then Dixon's theroem equation becomes,

$$2700 = 1+a-b \text{ -- } (1)$$

$$1800 = 1+a-c \text{ -- } (2)$$

By calculations, 'a' value of 1400 r.p.m and 'b' value of 24 mm/min is found as optimum parameter and 'c' value of '6' KN is calculated as optimum parameter.

Conclusion:

The experimental value of the tensile strength for rotational speed of 1000 r.pm and 18 mm/min transverse speed (specimen-3), is attained a maximum value.Similarly, For specimen-5, having rotational speed of 1500 r.pm and 24 mm/min transverse speed (specimen-3),the tensile strength is attained a maximum value. According to Dixon's theorem it is found that the combination of rotational speed of 1400 r.p.m and weld transverse speed of 24 mm/min. will yield a good weld strength. This is clear that for conducting experiments for the identification of strength it requires cost for doing test as well as failure of materials. Also it takes number of samples to conduct test which is time consuming. By adopting a numerical approach it saves money as well as time. The hypergeometry series identifies the right combination of process parameters without going for number of experiments.

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Corresponding Author:

J.Jayapriya[*] ,

Email: murudurai@gmail.com