Journal of Manufacturing Engineering, March, 2017, Vol. 12, Issue. 1, pp 49-54

OPTIMIZING THE MAGNETIC ARC OSCILLATION PROCESS PARAMETERS TO ATTAIN MAXIMUM TENSILE STRENGTH USING RSM

*** Subravel V[1], Padmanaban G[2] and Balasubramanian V[3]**

[1,2&3]Centre for Materials Joining and Research (CEMAJOR) ,Department of Manufacturing Engineering,
Annamalai University, Annamalai Nagar - 608 002 ,Tamil Nadu, India.

ABSTRACT

In this investigation, an attempt has been made to predict the tensile strength of magnetic arc oscillation welded(MAO) AZ31B magnesium alloy joints using RSM incorporating process parameters such as current, welding speed, arc amplitude and oscillation frequency as variables. The experiments were conducted based on a four-factors, five-levels, central composite design matrix. The developed empirical relationship can be effectively used to predict the tensile strength of MAO joints of AZ31B magnesium alloy at 95% confidence level. The results indicated that welding current has the greatest influence on tensile strength, followed by the oscillation frequency amplitude and welding speed. Response surface methodology (RSM) was used to optimize MAO parameters to attain a maximum tensile strength of 248MPa (91 % of base metal strength) in the AZ31B Magnesium alloy joints.

Key words: *AZ31B magnesium alloy; magnetic arc oscillation welding; response surface methodology; optimization; tensile strength.*

1. Introduction

Contemporary materials should possess high mechanical, physical and chemical properties to ensure long and reliable use. The above mentioned requirements and expectations regarding the contemporary materials are met by the non-ferrous metals and alloys such as magnesium alloys. Magnesium alloys and their derivatives, are materials from the lightweight and ultra-lightweight family, characterize of low density (1.5–1.8 g/cm3) and high strength in relation to their weight. Magnesium and its alloys have a wide prospect for application in the fields of automobiles, electronics and aerospace industry, not only for their lightweight but also for their excellent electromagnetic ability. Lightweight magnesium alloys have gradually shifted from military to civil applications during recent years. Especially the AZ series alloys, which contain Al and Zn as the major alloying elements are widely used [1-3].Gas Tungsten Arc Welding (GTAW) is a widely used material joining process, especially for nonferrous lightweight metals such as magnesium, aluminium and titanium. The quality of GTA welds ranks higher than that of other arc-welding processes, due to the reliability, clearance and strength of the weld [4]. Fusion zone of gas tungsten arc welded magnesium alloy typically exhibit coarse grains because of the prevailing thermal conditions during weld metal solidification. This often results inferior weld mechanical properties and poor resistance to hot cracking. While it is thus highly desirable to control solidification structure in welds, such control is often very difficult because of the higher temperatures and higher thermal gradients in welds in relation to castings and the epitaxial nature of the growth process. In general, the severity of a number of weld defects can be reduced if the solidification structure is refined. Certain novel welding technique like magnetic arc oscillation has been employed to improve hot cracking resistance and mechanical properties. Magnetic arc oscillation technique resulted in significant microstructural refinement in weld fusion zone [8]. Magnetic arc oscillation (MAO) is one of the effective techniques for refining the grain structure in the fusion zone of welds. In magnetic arc oscillation technique, the arc column is made to oscillate transverse to the welding direction using a two pole magnetic probe. Arc

**Corresponding Author - *Email: subra.vetri@gmail.com*

oscillation produces mechanical agitation in the weld fusion zone and breaks down the growing dendrite columns. As the broken dendrites act as nucleating sites and increase the cooling rate, microstructure is refined [9]. Recently few studies were carried out on effect of magnetic arc oscillation on aluminium alloys and steels. Fusion zone grain refinement in aluminium alloy welds through magnetic arc oscillation and its effect on tensile behaviour was studied by JanakiRam et al.[10]. Sivaprasad et al. studied the influence of magnetic arc oscillation and current pulsing on microstructure and high temperature tensile strength of alloy 718 (Nickel based precipitation hardenable super alloy) TIG weldments [11]. Effect of mechanical arc oscillation on the grain structure of mild steel weld metal was examined by Mahajan et al. [12]. Grain refinement in magnetically stirred GTA Welds of aluminum alloy was studied by Pearce et al. [13]. The available literatures are mainly focused on magnetic arc oscillation welding on aluminium alloy and steel only. However, there is no information available on the effect of magnetic arc oscillation and its parameters on magnesium alloys.

Various optimization methods can be applied to define the desired output variables through the development of mathematical models to specify the relationship between the input parameters and output variables. One of the most widely used methods to solve this problem is the response surface methodology (RSM), in which the experimenter tries to approximate the unknown mechanism with an appropriate empirical model.

A few investigations on the effect of MAO welding process parameters and optimization of mechanical and metallurgical properties of aluminium alloy have been reported [8-10]. Very countable number of studies on optimization of MAO arc welding process parameters to attain maximum tensile strength in AZ31B magnesium alloy was available. Hence, in this investigation an attempt was made to develop an empirical relationship to predict tensile strength of MAO welded AZ31B magnesium alloy joints using statistical tools such as design of experiments, analysis of variance and regression analysis.

2. DEVELOPING AN EMPIRICAL RELATIONSHIP

In order to achieve the desired aim, the present investigation was planned in the following sequence:

(i) Identifying the important MAO parameters that influence tensile strength of the joints

(ii) Finding the upper and lower limits of the identified parameters.

(iii) Developing the experimental design matrix.

(iv) Conducting the experiments as per the design matrix.

(v) Developing an empirical relationship using response surface methodology.

(vi) Checking the adequacy of the developed relationship.

2.1 Conducting the Experiments

Rolled sheets of AZ31B magnesium alloy of 3 mm thickness were cut into required size of 300 mm×150 mm×3 mm by machining. Square butt joint configuration was prepared to fabricate PCGTAW joints. The joint configuration is shown in Fig.1.

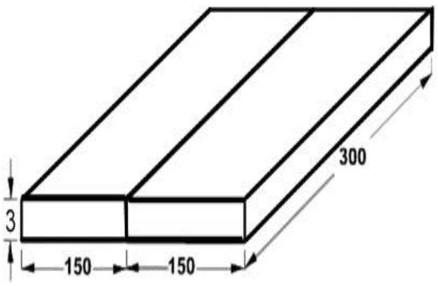

Fig.1 Joint configuration

The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction. Single pass welding procedure was used to fabricate the joints. Argon (purity 99.99%) was used as shielding gas.

Tensile test was carried out in an electro-mechanical controlled universal testing machine (FIE-Bluestar, UNITEK−94100) and the average values of three results are presented in Table 1.

3. RESULTS AND DISCUSSION

3.1 Analysis of Response Graphs and Contour Plots

By generating the response graphs and contour plots using the design expert software for analysis of surface response, it is easy to ascertain the optimum conditions with logical precision. Fig.2.4 (a) shows the 3 dimensional response surface plot for the response tensile strength attained from the regression model, assuming a welding current of 75 Amps and oscillation frequency of 2 Hz.

Table 1. Design matrix and experimental results

Exp No.	Coded value				Actual value				Tensile strength of the joint (MPa)
	R	**F**	**T**	**S**	**I**	**S/ Mm /min**	**A/mm**	**F/Hz**	
1	-1	-1	-1	-1	70	115	0.4	1.5	180
2	1	-1	-1	-1	80	115	0.4	1.5	152
3	-1	1	-1	-1	70	115	0.8	1.5	219
4	1	1	-1	-1	80	115	0.8	1.5	152
5	-1	-1	1	-1	70	115	0.4	2.5	206
6	1	-1	1	-1	80	115	0.4	2.5	174
7	-1	1	1	-1	70	115	0.8	2.5	195
8	1	1	1	-1	80	115	0.8	2.5	176
9	-1	-1	-1	1	70	135	0.4	1.5	199
10	1	-1	-1	1	80	135	0.4	1.5	150
11	-1	1	-1	1	70	135	0.8	1.5	193
12	1	1	-1	1	80	135	0.8	1.5	142
13	-1	-1	1	1	70	135	0.4	2.5	195
14	1	-1	1	1	80	135	0.4	2.5	183
15	-1	1	1	1	70	135	0.8	2.5	180
16	1	1	1	1	80	135	0.8	2.5	166
17	-2	0	0	0	65	125	0.6	2	177
18	2	0	0	0	85	125	0.6	2	144
19	0	-2	0	0	75	125	0.2	2	179
20	0	2	0	0	75	125	1	2	188
21	0	0	-2	0	75	125	0.6	1	155
22	0	0	2	0	75	125	0.6	3	174
23	0	0	0	-2	75	105	0.6	2	168
24	0	0	0	2	75	145	0.6	2	221
25	0	0	0	0	75	125	0.6	2	231
26	0	0	0	0	75	125	0.6	2	248
27	0	0	0	0	75	125	0.6	2	245
28	0	0	0	0	75	125	0.6	2	242
29	0	0	0	0	75	125	0.6	2	244
30	0	0	0	0	75	125	0.6	2	240

The optimum tensile strength is showed by the vertex of the response surface. From the response graph, it is distinguished that at the welding current of 75 amps, the tensile strength of MAO joints is higher. The tensile strength of the MAO joints were increased due to fine equiaxed grains formed in the fusion zone. When the welding current is increased from of 75 amps, decreases the tensile strength. This happens because of increased heat input consorted with the use of higher current. The tensile strength of the MAO joints were decreased due to fine coarsening of grains formed in the fusion zone. This phenomenon can be also interpreted by the change in cooling rate. It is well known that the increases in heat input will results in slower the cooling rate. Moreover, slower the cooling rate during solidification, longer the time available for the grain coarsening. In differ, decrease in welding current tends to the decrease in heat input which leads to the faster cooling rate and happening of finer grains in the fusion zone (Padmanaban et al 2011).

Fig.2.4 (b) it is indicate that at the Amplitude of 0.6 mm, the tensile strength of the MAO joints is higher. The fine grains were adhered in the fusion zone may be reason for the higher tensile strength of these joints. This is generally due to optimum heat input. The Amplitude decreases farther, which develops the grain growth in the weld region. This is because as the Amplitude decreases, the arc density is increases. When the Amplitude is decreased, the welding heat has more time to conduct into the fusion zone, which develops grain coarsening (Padmanaban et al 2011). The grains in the fusion zone get coarser, with decreasing amplitude, and the tensile strength of these joints decreases.

Fig.2.4 (d) shows the 3 dimensional response surface plots for the response tensile strength attained from the regression model, assuming a welding speed of 125 mm/min and welding current of 75 Amps. From the response graph, it indicated that at the welding speed of 125 mm/min the tensile strength of MAO joints is higher. When the welding speed is decreased from of 125 mm/min, the tensile strength also decreases. This is the result of the increased heat input associated with the use of slower welding speed.

The tensile strength of the MAO joints were decreases due to formation of coarser grains in the fusion zone. This phenomenon can also be interpreted by the change in cooling rate. It is known that an increases in heat input will results in slower cooling rate. Moreover, the slow the cooling rate during solidification, the longer time available for the grain coarsening. In differ, the increase in welding speed tends to the decrease in heat input, which leads to the faster cooling rate and happening of finer grain size in fusion zone (Kumar et al, 2007).

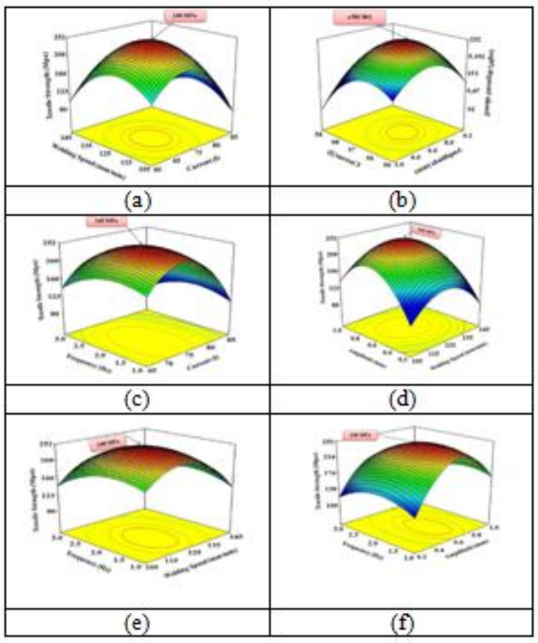

Fig.2 Response graphs for MAO welded AZ31B magnesium alloy

Fig.2.4 (e) shows the 3-dimensional response surface plots for the response tensile strength obtained from the regression model, assuming a oscillation frequency of 2 Hz. Oscillation frequencies higher than the optimum, little time is available during a half-cycle before the direction of fluid flow is reversed, the stirred liquid is then able to reach only a lesser velocity, thus decreasing the effectiveness of magnetic field (Pearce et al, 1981), and it drops the amplitude vibrations on molten path and simultaneously stops agitation of the molten path and it results the less refinement on the weld metal. Due to less grain refinement the coarser grains in the fusion zone was observed in the joint fabricated using a arc oscillation frequency of 3 Hz.

3.2 Developing the empirical relationship

Response surface methodology (RSM) is a group of statistical and mathematical techniques that is used for modelling and analysing the problems, in which the response of interest is authorised by many variables and the objective is to optimise this response. The response function of the joint tensile strength (σ) is a function of Welding Current (I), Oscillation Frequency (F), Amplitude (A) and Welding Speed (S), and it can be prescribed as:

$$\sigma=f\,(I, F, A, S) \qquad (1)$$

The IInd order polynomial equation is used to describe the response surface ‘Y’ is given as:

$$Y=b0+\sum bixi+\sum biixi2+\sum bijxixj+er \qquad (2)$$

and for 4 factors, the selected polynomial could be expressed as:

$$\sigma=b_0+b_1(I)+b_2(F)+b_3(A)+b_4(S)+b_{11}(I^2)+b_{22}(F^2)+ b_{33}(A^2)+b_{44}(S^2)+b_{12}(IF)+b_{13}(IA)+b_{14}(IS)+ b_{23}\,(FA)+b_{24}\,(FS)+b_{34}\,(AS) \qquad (3)$$

Where b_0 is the responses average; b_i and b_{ij} are the coefficients that based on the respective main and influencing effects of the parameters. In order to evaluate the regression coefficients, a number of experimental design techniques are available. In this work, central composite design which exactly fits the second order response surface was used. All the coefficients were attained by applying the central composite design using the design expert statistical software package tool. After finding the significant coefficients, the final relationship was derived using only these coefficients. The final empirical relationship is developed by the above procedure to predict tensile strength of MAO AZ31B magnesium alloy joints is given below:

$$TS= [247.67-15.83(I)-6.33(F)+4(A)-5.92(S)+2.75(I*F)+6.63(I*A)+1.25(I*S)\ S-2.62(F*A)+2.25(F*S)-2.12(A*S)-21.52(I2)-15.77(F2)-20.52(T2^{)}-7.65(S^2)]\ MPa \qquad (4)$$

Where,

Ts= Tensile strength in MPa
I= Welding Current Amps
A= Amplitude (mm)
F= Oscillation Frequency Hz
S= Welding Speed mm/min

3.3 Checking acceptability of developed relationship

The acceptability of developed relationship was subjected to using the analysis of variance technique (ANOVA). In this technique, if the calculated F value of the developed model is less than the standard F ratio (from the F-table) value at a desired confidence level (95%), the model is acceptable within the confidence range. It is stated that the developed relationship is acceptable at 95% confidence level. The model F value of 1272 express that the relationship is significant. There is only a 0.01 percentage chance that this large "model F-value" could occur owing to noise. Values of "prob>F" < 0.05 mention that the relationship is termed as significant. In this case, I, F, A, S, IF, IA, IS, FA, FS, AS, I^2, F^2, A^2 and S^2 are significant model terms. Values > 0.05 mention that the relationship is termed as not significant. The "lack of fit F-value" of 3.77 implies that the lack of fit is not significant compared to the pure error. There is a 7.78% chance that a large "lack of fit F-value" could occur due to noise.

Coefficient of determination "R^2" is used to find how close the predicted and experimental values lie. The value of "R^2" for the above-developed relationship is also presented in Table 6.3, which indicates high correlation existing between the experimental values and predicted values. The "Pred. R-squared" of 0.9956 is in reasonable agreement with the 'adj R-squared' of 0.9984. "Adeq precision" measures the signal to noise ratio. The normal probability plots of the residuals for tensile strength are shown in Fig.6.2 which reveals the residuals are falling on the straight line, indicating the errors are distributed normally (Kumar et al, 2007). All the above consideration indicates an excellent adequacy of the developed empirical relationship.

3.4 Validation of Optimization procedures

The confirmatory experiments were conducted with the welding parameters as suggested by the numerical modelling (suggested solutions) and keeping the welding current, oscillation frequency, amplitude and welding speed at 72, 3.5 Hz, 0.41 and 117 mm/min respectively. A very small difference was found between the predicted values and experimental values (Table 2).

MAO parameters							
Expt. No.	Current (I)	Freq (F)	Ampl (A)	Welding speed (S)	By Expt	By Model	Variation (%)
1	63	1.75	0.1	110	221	218.6	-2.4
2	77	2.25	0.5	120	241	243.56	-2.56
3	82	3.5	0.9	130	198	201.3	-3.32

Table 2. Validation results for developed empirical relationships

4. CONCLUSIONS

1) An empirical relationship was developed to predict tensile strength of pulsed current gas tungsten arc welded AZ31B magnesium alloy joints using response surface methodology. Incorporating welds parameters the developed relationship can be effectively used to predict the tensile strength of PCGTAW joints of AZ31B magnesium alloy at 95% confidence level.

2) A maximum tensile strength of 214MPa(78% 0f base metal strength) was obtained under the welding condition of current ratio of 2.2, pulse frequency of 5Hz, pulse on time of 50% and welding speed of 135 mm/min which is the optimum PCGTA welding condition for AZ31B magnesium alloy.

3) From the analysis of variance (ANOVA) test results and from the F ratio it is found that the welding speed has the greatest influence on tensile strength, followed by current ratio, pulse on time and pulse frequency.

ACKNOWLEDGMENTS

The authors wish to place their sincere thanks to University Grant commission (UGC), New Delhi for financial support rendered through Major Research Project No: 39-864/2010.

References

1. *Dobrza´nski L A Ta´nski T and Cızek L (2007), "Journal of Materials Processing Technology", Vol. 192–193 ,567–574.*

2. *Zhang Zhi-min XU Hong-yan and WANG (2008), "Corrosion and mechanical properties of hot-extruded AZ31 magnesium alloys", transactions of nonferrous metals society of china, Vol. 18 s140-s,144.*

3. *Scintilla L D Tricarico L Brandizzi M Satrianoc A A (2010), "Nd:YAG laser weldability and mechanical properties of AZ31 magnesium alloy butt joints", Journal of Materials Processing Technology, 2206–2214.*

4. *Padmanaban G and Balasubramanian V (2007), "Optimization of pulsed current gas tungsten arc welding process parameters to attain maximum tensile strength in AZ31b magnesium alloy", transactions of nonferrous metals society of china, 21467-476.*

5. *Razal Rose A Manisekar K Balasubramanian V and Rajakumar S (2012), "Prediction and optimization of pulsed current tungsten inert gas welding parameters to attain maximum tensile strength in AZ61A magnesium alloy", Materials and Design, Vol. 37, 334–348.*

6. *Balasubramanian T S Balakrishnan M and Balasubramanian V and MuthuManickam M A (2011), "Influence of welding processes on microstructure, tensile and impact properties of Ti-6Al-4V alloy joints", transactions of nonferrous metals society of china, Vol. 21, 1253-1262.*

7. *Kou S Le Y (1986), "Nucleation mechanism and grain refining of weld metal", Welding Journal, Vol. 65(4), 65–70.*

8. *Senthil Kumar T Balasubramanian V and Sanavullah M Y (2007), "Influences of pulsed current tungsten inert gas welding parameters on the tensile properties of AA 6061 aluminum alloy", Materials and Design, Vol. 28, 2080–92.*

9. *Koteswararao S R and Madhusudhanareddy G (2005), "Grain refinement through arc manipulation techniques in Al–Cu alloy GTA welds", materials science and engineering, Vol.404, 227–234.*

10. *Sivaprasad K Ganesh S and sundararaman (2007), "Influence of magnetic arc oscillation and current pulsing on fatigue behavior of alloy 718 TIG weldments", materials science and engineering, Vol.448, 120–127.*

11. *Janaki ram G D and Murugesan R (1999), "Fusion Zone Grain Refinement in Aluminum Alloy Welds through Magnetic Arc Oscillation and Its Effect on Tensile Behavior", Journal of materials engineering and performance, Vol. 8, 513-520.*

12. *Pearce B P and kerrbp H W (1981), "Grain Refinement in Magnetically Stirred GTA Welds of Aluminum Alloys metallurgical transactions", Vol.480 (12b).*

13. *Liu M Zhang z D Song G and Wang L (2006), "Mechanism and microstructure of oxide fluxes for gas tungsten arc welding of magnesium alloy", Metallurgical and Materials Transactions A, Vol. 38, 649−658.*

14. *Afrin N Chen DL Cao X and Jahazi M (2008), "Microstructure and tensile properties of friction stir welded AZ31B magnesium alloy", Materials Science and Engineering A, Vol.472, 179–86.*

15. *Box g E P Hunter W H and Hunter J S (1978), "Statistics for experiments", New York, John Wiley Publications.*

16. *Kumar S kumar P and Shan H S (2007), "Effect of evaporative casting process parameters on the surface roughness of Al-7%Si alloy castings", Materials Processing and Technology, Vol.182, 615−623.*

17. *Montgomery D C (2001), "Design and analysis of experiments", New York, John Wiley & Sons.*

18. *Kou S and Le Y (1986), "Nucleation mechanism and grain refining of weld metal", Welding Journal, 65−70.*

19. *Padmanaban G and Balasubramanian V (2011), "Influences of Pulsed Current Parameters on Mechanical and Metallurgical Properties of Gas Tungsten Arc Welded AZ31B Magnesium Alloys", Metals and Materials International, Vol. 17(5), 831-839.*

20. *Munitz A Cotler C Stern A and Kohn G (2001), "Mechanical properties and microstructure of gas tungsten arc welded magnesium AZ91D plates", Materials Science and Engineering A302, 68–73.*