OPTIMIZATION OF PROCESS PARAMETERS FOR COLD METAL TRANSFER (CMT) WELDING OF DISSIMILAR MATERIALS

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Abstract: The study of optimization of process parameters of cold metal transfer (CMT) welding which serves the purpose of joining dissimilar metals using analysis of variance (ANOVA).The response variables of CMT welding have been examined for welding Aluminum 6061 with Mild Steel. CMT is advanced version of Metal Inert Gas Welding (MIG) welding. It welding depends on short circuiting process including low heat input rate and spatter free welding. Heat affected zone in this process is very less as compared to that of other. For increasing the weld quality, the selected process parameters are root gap, current, groove angle and the combined effect of these process parameters on response variables (tensile strength, micro-hardness, and heat affected zone) is observed with the help of ANOVA.

Keywords: CMT, ANOVA, Heat affected zone, Micro-hardness, Tensile strength

I. INTRODUCTION

CMT refers to Cold Metal Transfer. It is one of the modified metal inert gas welding process. This phenomenon is broadly based on the principle of short circuiting the transfer process which includes no heat input and no spatter-welding. During the short circuit, droplet detachment is assisted by the wire retraction motion. Thus the metal can be transferred into the welding pool without any source of the electromagnetic force. Then the heat supply and splashes can be decreased at large scale. Reducing weight for improving fuel efficiency ensuring the safety of a vehicle is one of the core challenges which automobile industry is going through now days. Automakers prefer thinner sheets made of steels having high strength with complimenting formability as a remedy of this problem statement. Here steel parts are replaced by those of aluminium for making car bodies light weight as this is one of the majors against pollution and for saving energy. So joining aluminium to steels provides trouble which should be overcome. As brittle intermetallic compounds are formed while welding the two metals which differ in their properties which damages mechanical properties of joints, it becomes very hard to use fusion welding methods for joining aluminium and steel. CMT fusion welding methods having low heat inputs and high efficiency may give the solution to realize aluminium used in automobile. This method consists low input characteristics so this method is more preferable. As excessive splashes during the process of welding also causes great problem to the producer. Cold Metal Process which is ideally suitable for aluminium and two dissimilar joints with almost without spatters and minimum thermal inputs is recently the development in welding technology and it is advance type of MIG welding. This CMT welding process is used mostly in defense technology, automobile industry etc.

II. LITERATURE SURVEY

Selvi et al. [1] performed and studied that for the laser or laser hybrid welding the CMT welding is preferred. For additive manufacturing in various sectors such as defence sector, automobile industries and power plants CMT welding is implemented. The welding of thicker materials and dissimilar metals is easily transformed by Cold Metal Transfer Technology. With low heat input and controlled metal deposition a better weld bead is produced by Cold Metal Transfer technology. In this study, the evaluation of ideas and information of the CMT process and applications of CMT is done. CMT welding provides better welding results of aluminium and steel with microstructure and weld characteristics which are even studied.

Furukawa [2] performed and studied the metal transfer, voltage and waveform of the welding current in CMT process. Bead-on-plate welding was carried out on pure aluminium to examine whether this process is applicable to thin aluminium sheets or not. A novel joining method which has satisfied the stringent demands is known as CMT welding. Process stability, reproducibility and cost effectiveness are the most important stringent demands. Short circuiting arc or dip arc is used to weld thin sheets frequently. Controlled pulsed welding current and voltage usually denies this CMT process. This CMT process is imitative of popular MIG\MAG process.

Robert et al. [3] studied and performed the experiments on welding of two dissimilar aluminium alloys in which load controlled fatigue behavior is observed. The aluminium material taken is 3mm thick Aural2 die casting sheet and 2mm thick AA575 wrought sheet. This welds are carried out with and without the adding the adhesive prior. Deformations and distortions are directly influenced by the heat input Q provided. The optimal heat input is essential for guarantee of joint penetration for thin metal sheet. The heat input range was 0.07-0.11 KJ/mm for welding the 2mm thickness stainless steel plate. For determination of heat input parameters study is to be conducted for all aluminium alloys.

Jian et al. [4] performed and studied the CMT brazed lap joint experiments done on thick plate of around 1.2mm of zinc coated steel and alloy of aluminum 6061in which observation of fusion line failure and high shear strength is done. A numerical method was developed for prediction of failure modes and shear strength occurred due to CMT lap joint. Maximum principal stress on joints and deformation energy on interface layer are the failure criteria for predicting the failure of the CMT joints. Plastic strain in base metal of aluminium, HAZ of CMT process and weld metal were equal to predicting failure category at fusion line

Kumar et al. [5] studied and performed the experiments on Cold Metal Transfer (CMT) welding of thin metal sheets of aluminium and stainless steel. Increasing productivity and reduction in distortions is beneficial due to which CMT welding can be used instead of TIG welding. Varying electrode forces, electrode diameters and welding currents cause controlled movement of electrode which is achieved due to low heat input. Taguchi experimental design method was used to determine and set the welding parameters.

Amin [6] performed and studied the simulation of effect of metal deposition phenomena and recurrent and periodic arcing in CMT welding which was proposed on heat source model. Resultant mechanical properties and weld pool behavior is studied in detail through this heat source model. A double ellipsoidal heat source model is utilized by the proposed model as basis and is made geometrical.

Cao et al. [7] performed and studied the experiments that aluminum alloys and zinc coated steel are joined easily by cold metal transfer method. To perform CMT welding on aluminium galvanized steel of 120x50x5mm various process variables are required such as root gap, voltage, and groove angle. Joint strength is usually affected by softening of aluminum heat affected zone and thickness of intermetallic zone. Control of heat input in range of 100-200J/min can reduce the thickness of intermetallic layer and reduction of HAZ property. This leads to production of hybrid aluminium to steel joint which has the equivalent strength as that of aluminum to aluminum CMT joints.

III. EXPERIMENTATION AND ANALYSIS

CMT welding process is performed by combining the process parameters and the universal effect of these parameters in the type of response variables on the weld quality is experimented here for study and optimization of CMT process. Determination of influence of process parameters such as root gap, groove angle and current for increasing the quality of welded joints as response variables on HAZ, hardness and weld strength. Experimental result shows the performance of experiments based on experiments factorial design. For nullifying the effect of factors like human error and environmental condition random performance of design of experiments is carried out. Effect of extrinsic factors is reduced while the experiments are performed by randomly performing the experiments. When the process parameters are set to required level then the experiments are conducted. Before starting the experiments setting of desired value is done of constant process parameters. For reduction of effect of noise parameters, the experiments are carried out at different intervals of time. The test piece size 120x50x5 of aluminium AA6061 and galvanized steel is used were cut down by power hack saw machine.
A bevel angle of 15, 22.5,30 degrees is provided on each plate and therefore total 30, 45, 60 degree groove angle is obtained. Angles are cut on milling machine using angular cutter. V groove angle and different terms related to it shown in Fig.1

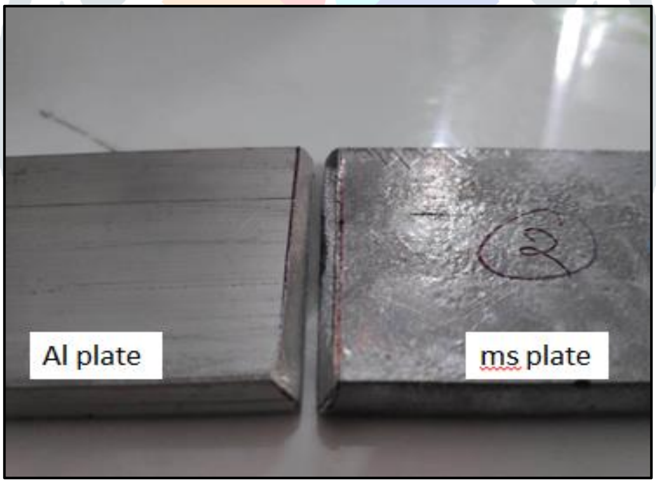

Fig.1: v notch specimen

All the experiments were performed on Fronius 320i CMT welding machine by selecting manual mode option for selected parameters according to DOE. Basic experimentation was done by varying the root gap, groove angle, current. Whereas base material thickness, gas flow rate kept constant throughout the experiments. Total four trial experiments are performed to check input parameter and machine capability. Current varies from 110-140 A, root gap 1-2mm, groove angle 30-60 welded joint.
After visual examination of trial experiments final experiments are done according to the Taguchi Orthogonal Array and Analysis of final experiment is discussed. CMT welding specimens are done by using CMT Welding machine with varying process parameter Groove angle, Root gap, Current for optimization. The specimens are prepared for tensile testing of welded plates as per the ASTM standards

i. Weld Strength Analysis

In weld strength Analysis firstly all the specimens are cut according to ASME standards considering the gauge length as 100 mm. The tensile Test was performed on "computerized Universal Testing Machine-TUF-C-1000 SERVO. Nomenclature of tensile test specimen is shown in table 1.Tensile Test specimen after tensile strength is shown in fig.2

Table 1: tensile specimen section and its sizes

Tensile specimen section	Size(mm)
Overall Length	240mm
Gage length	100mm
Length of grip section	80mm
Width of grip section	25mm
Gage width	18mm

Fig.2: final experiments after tensile strength

The experimental results obtained during CMT welding using L18 orthogonal array for AA6061-galvanised steel alloy material shown in table 2.

Table 2: response parameter value

Expt. No.	**Root gap (mm)**	**Current (Ampere)**	**Groove angle (^{0})**	Tensile strength (Mpa)	Micro Hardness	HAZ (Micron)
1	1	110	30	61.010	79.970	463.57
2	1	110	45	65.398	83.442	518.179
3	1	110	60	67.184	87.102	548.44
4	1	125	30	71.290	89.034	592.74
5	1	125	45	71.884	89.692	593.67
6	1	125	60	76.148	92.400	699.85
7	1	140	30	82.884	93.096	705.55
8	1	140	45	86.982	102.100	832.99
9	1	140	60	93.778	95.232	806.89
10	2	110	30	54.356	77.255	345.16
11	2	110	45	64.526	81.669	310.18
12	2	110	60	65.254	84.018	530.91
13	2	125	30	69.492	88.383	558.18
14	2	125	45	70.990	89.692	589.9
15	2	125	60	75.276	90.358	607.0

16	2	140	30	81.018	93.096	659.71
17	2	140	45	85.736	93.801	713.69
18	2	140	60	92.094	96.697	832.5

The main purpose of ANOVA is to investigate significant process parameters which affect the quality characteristics of welded joint. Table 3 shows ANOVA analysis performed on MINITAB 17 software. Determination of sum of variance and squares takes place in ANOVA analysis. In this study 95% confidence level is preferred for determination of tensile strength percentage contribution and most useful parameters. Large effect on characteristics of process parameters shows the higher F-value.

Table 3: analysis of variance for tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	% contribution
Root gap	1	17.63	17.63	17.634	4.57	0.054	0.86%
Current	2	1771.48	1771.48	885.742	229.54	0.02	86.49%
Groove angle	2	205.75	205.75	102.876	26.66	0.007	10.08%
Error	12	46.30	46.30	3.859	-	-	2.27%
Total	17	2041.18	-	-	-	-	100.00%
RSq=97.73%							

Table 3 shows that Current is most influencing parameter for tensile strength in all final experiment. Root gap and Groove angle are having less influence as compared with Current. Again the percentage of contribution of individual factor is shown in Table 3. Main effect plot for means pertaining to tensile strength is plotted against the respective process parameters selected for experimentation and shown in Fig.3.The graphs shows that the current and groove angle are directly proportional to tensile strength. Main effect plot for Means for tensile strength shows that current process parameter have more contribution as compare to other process parameter. R-Sq. value for tensile strength response variable is 97.73%

For root gap 1mm tensile strength is more than that of 2mm.Tensile strength at 140A current is maximum. Tensile strength increases with increasing groove angle. Tensile strength is maximum at 60 groove angle.

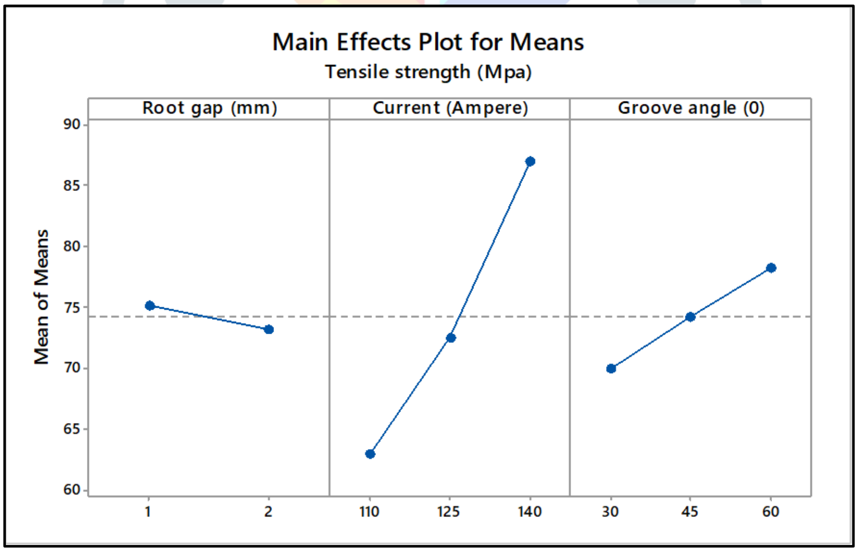

Fig.3: main effect plot for means for tensile strength

ii. Experimental Result for Micro Hardness

The Fig.4 shows indentation mark in welding zone of two dissimilar metals. After taking indentation mark on micro Vickers hardness tester two horizontal and vertical distance measures between the two points. Using this horizontal and vertical distance total area of indentation is calculated. 50 gm. load is selected for micro hardness testing. Using these values Vickers micro hardness is calculated.

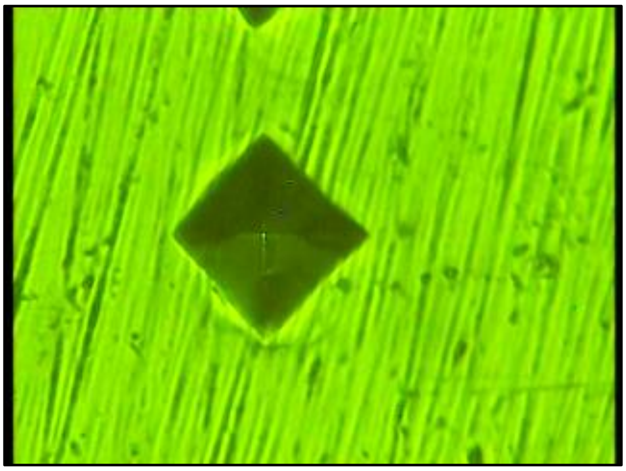

Fig.4: micro hardness indentation

Table 4 shows that Current is most influencing parameter for micro hardness in all final experiment. Root gap and Groove angle are having less influence as compared with Current. Again the percentage of contribution of individual factor is shown in Table 4. Main effect plot for means pertaining to is plotted against micro hardness the respective process parameters selected for experimentation and shown in Fig. 5.The graphs shows that the current and groove angle are directly proportional to micro hardness. Main effect plot for Means for micro hardness shows that current process parameter have more contribution as compare to other process parameter.

Table 4: analysis of variance for micro hardness

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	% contribution
Root gap	1	16.24	16.24	16.243	3.63	0.081	2.42%
Current	2	544.67	544.65	272.335	60.83	0.000	81.03%
Groove angle	2	57.53	57.53	28.767	6.43	0.013	8.56%
Error	12	53.73	53.73	4.477	-	-	7.99%
Total	17	672.17	-	-	-	-	100.00%
RSq=92.01%							

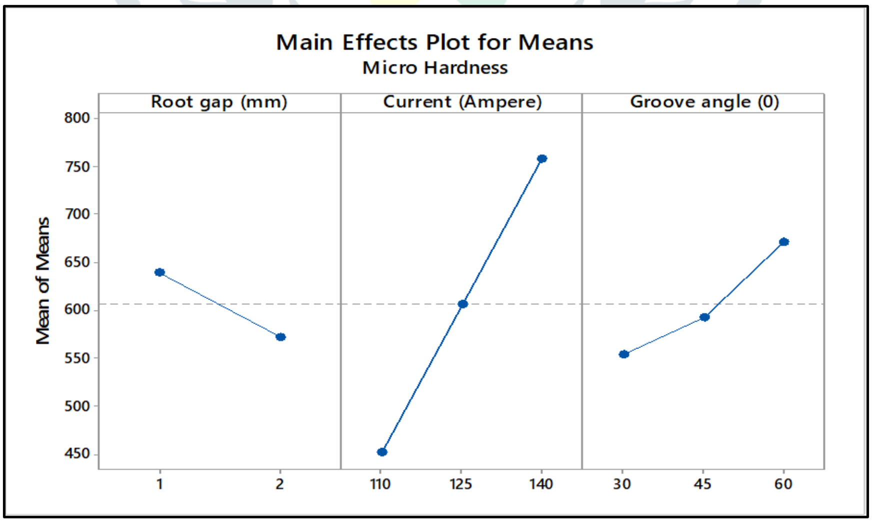

Fig.5: main effect plot for means for micro hardness

iii. Experimental Result and Discussion for HAZ

Fig.6 Shows the Microstructures from Sample 17 which represents different sub zones i.e. Base metal, Heat Affected Zone and Weld Metal. All the images taken from Metallurgical Optical Microscope having image size 1mm.with magnification of 100X.there are four zones in CMT welding Zinc rich zone, heat affected zone, base material zone, welding zone. HAZ is most contributing on the CMT welding as compare to other zone. The structural change can been seen in heat affected zone shown in Fig.6

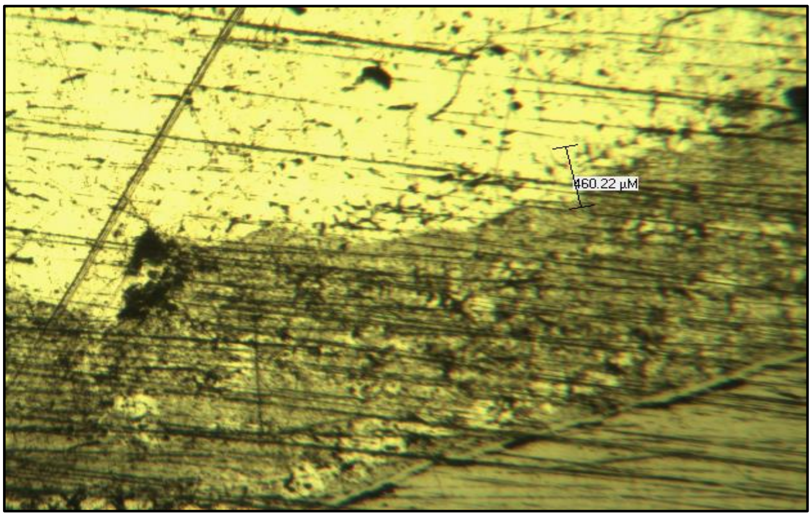

Fig.6: micro structure of specimen no. 17

Table 5 shows that current is most influencing parameter for heat affected zone in all final experiment. Root gap and groove angle are having less influence as compared with current. Again the percentage of contribution of individual factor is shown in Table 5.Main effect plot for means pertaining to tensile strength is plotted against the respective process parameters selected for experimentation and shown in Fig.7.The graphs shows that the current and groove angle are inversely proportional to HAZ. Main effect plot for Means for HAZ shows that current process parameter have more contribution as compare to other process parameter.

Table 5: analysis of variance for HAZ

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	% contribution
Root gap	1	20989	20989	20989	9.07	0.011	5.65%
Current	2	280575	280575	140287	60.63	0.000	75.47%
Groove angle	2	42424	42424	21212	9.17	0.004	11.41%
Error	12	27768	27768	2314	-	-	7.47%
Total	17	371756	371756	-	-	-	100.00%
RSq=92.53%							

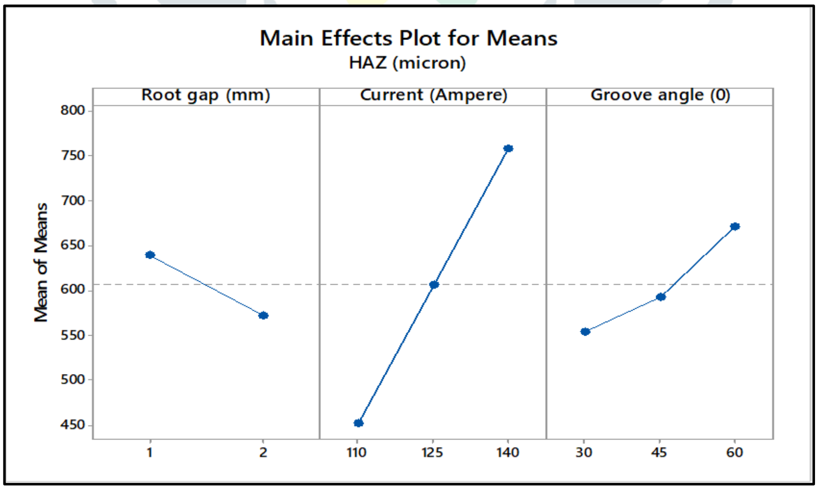

Fig.7: main effect plot for means for HAZ

'Smaller is better' taguchi loss function is selected for HAZ calculation. Heat affected zone is smaller for 2mm root gap. With increasing the current HAZ is increases. Therefore heat affected zone is optimum for the values of current 110A, groove angle 30 and root gap 2mm.

IV. CONCLUSIONS

i. Maximum Tensile strength 93.778 Mpa is observed for the experiment number 9 for which welding current is 140 A, root gap 1 mm and groove angle 60.

ii. Based on Analysis of variance (ANOVA), the welding current is most significant parameters that control the tensile strength whereas root gap is comparatively less impact on tensile strength.

iii. In case of Hardness current is the most efficient factor which has effect on hardness. Percentage contribution of current is 81.03%, root gap 2.42% and groove angle 8.56%.

iv. Higher hardness value is obtained at current is 140 A, root gap 1 mm and groove angle 45 for the experiment number 8 and which is found to be optimum.

v. Current is the mostly effect on HAZ. Contribution for current is 75.47% and has a highest effect on hardness. Whereas groove angle has 11.41% Contribution and root gap has contribution of 5.65%.

vi. Minimum HAZ width means the stronger weld and which is observed at optimum parameter.

vii. CMT process meets the target in terms of cost and easiness of automation of the process.

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