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APPLICATION OF THE AHP FOR OPTIMIZATION OF MECHANICAL PROPERTIES OF Al-Mg-Si ALLOY USING PCTIG WELDING

Soumojit Dasgupta[1], Satadru Banerjee[2], Hares Hasan[3] and Santanu Das[4]

[1]Research Scholar, Department of Mechanical Engineering, Kalyani Govt. Engineering College, Kalyani- 741235, West Bengal and Assistant Professor, JIS College of Engineering, Kalyani.
Email: dasguptasoumojit29@gmail.com

[2]B.Tech Graduate, Department of Mechanical Engineering, Kalyani Govt. Engineering College, Kalyani- 741235, West Bengal. Email: satabanerjee786@gmail.com

[3]B.Tech Graduate, Department of Mechanical Engineering, Kalyani Govt. Engineering College, Kalyani- 741235, West Bengal. Email: hares23022000@gmail.com

[4]Professor, Department of Mechanical Engineering, Kalyani Govt. Engineering College, Kalyani- 741235, West Bengal. Email: sdas.me@gmail.com

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Abstract: This paper makes an attempt to investigate the influence of pulsed Tungsten Inert Gas (PCTIG) welding variables on the mechanical attributes like Impact Toughness, Hardness, Dilution as well as Notch Tensile Strength of welded specimen. The specimen used was Al-Mg-Si alloy. This alloy is extensively used in automotive manufacturing sector owing to its light weight which also helps to bring down the vehicular CO_2 emission. The addition of metalloid such as silicon in aluminum parent metal imparts high fluidity, good feeding characteristics and good hot cracking sensitivity to it. As opposed to normal Tungsten Inert Gas (TIG) welding, PCTIG welding applies variable current during operation. Peak current being higher in value facilitates sufficient penetration while base current helps in stabilizing the arc. However, owing to the development of inter-dendritic micro-structural features, PCTIG welding exhibits lower impact toughness and notch tensile strength compared to the parent metal. The Analytic Hierarchy Process (AHP) has been used in this work to maximize the mechanical properties and the related PCTIG welding parameters.

Keywords: Impact Toughness, Notch Tensile Strength, TIG, Inter-dendritic, Analytic Hierarchy Process

1. INTRODUCTION

Al-Mg-Si alloys are widely employed in automotive and aviation industries. The welding process commonly used for Aluminium alloys is Tungsten Inert Gas Welding. There are various techniques used in TIG welding process, such as magnetic arc oscillation and pulsed current. A number of difficulties were observed in achieving optimum attributes in as-welded condition. As the dilution obtained in the base metal is low, reduced strength and toughness were observed. To achieve improved results, various practices like injecting with heterogeneous nucleates and greater degree of dilution were implemented.

The Analytical Hierarchy Process is a multicriteria tool for decision making. In some of the research papers by Mohanty and Deshmukh [1], Wang et al. [2] and others, the application of the AHP was made to evaluate process plan and product plan to get optimized solution. In previous works using The Analytical Hierarchy Process (AHP), Saaty and Vargas [3], Harker and Vargas [4], Schnlederjans and Garvin [5], implemented the AHP in various fields like economics, political, social, engineering and technology.

In recent development, some of the break-through works were made [6, 7] using welding of aluminium and its alloys and composites [8, 9].

In the field of welding, one can also use the AHP to get optimum experimental results. Previous research works on optimization of welding process by using the AHP were published by several authors. Sabiruddin et al. [10] performed the parametric optimization in GMAW using CO_2 by analytical hierarchy process. The theoretical results were close to the experimental inferences. In another work by Jayant and Dhillon [11], the Analytic Hierarchy Process (AHP) was used for selecting the appropriate welding process for high pressure vessel manufacturing, depending on the qualitative factors of welding procedure given that the quantitative factors were equal. In this research work, a knowledge-base decision support system was developed for recognizing the suitable welding processes to conform to specific requirement of high pressure welding environment. In a similar fashion, Sarkar et al. [12] used the analytic hierarchy process (AHP) oriented Taguchi method for the choice of the foremost welding variables to produce submerged arc welding of plain carbon steel. In another investigation by Ravisankar et al. [13], the analytic hierarchic process (AHP) found its application in the selection of an appropriate weld method for making high strength butt joints of aluminium alloy of AA 7075 grade, considering the qualitative factors, when the quantitative factors of welding process appeared the same. The analytic hierarchic process was used by Mondal et al. [14], for optimization of parametric characteristics of spot welding of 17-4 Ph stainless steels.

In automotive applications, aluminium is largely used. Hirsch [15] studied on the application of aluminium in automotive sector and the newest development in it. 5xxx and 6xxx grade aluminium alloys were investigated which were upgraded for the increase in demands concerning high strength and improve in formability, producing mass reduction and enhanced crash worthiness.

Keeping in mind the recent development of automotive materials, Tisza and Czinege [16] made a comparison between application of steel and aluminium in the automobile sector from different viewpoints.

As it is a well known fact that although aluminium has many advantages like light weight, corrosion resistance [17] and many more, but when they are combined to make composites or joined by simple welding processes, it is found that the weld strength becomes very low. The best solution is to use pulse current tungsten inert gas (PCTIG) welding. Various research works on PCTIG welding were performed by Balasubramanian et al. [18], Kumar et al. [19], Balasubramanian et al. [20], Ravisankar and Balasubramanian [21], Balasubramanian et al. [22], Manti and Dwivedi [23], Ravisankar and Balasubramanian [24]. In these research papers why pulse current TIG welding is best suited for aluminium and its composites and the effects of pulse current in weld strength and its magnetic arc oscillation process parameters on weldments were discussed.

Some of the research works on aluminium metal matrix composites by Shorowordi et al. [25], Urena, Escalera and Gil [26], Jayashree et al. [27], Amirkhanlou et al. [28], highlighted the advantages of aluminium composites over normal aluminium material. Also the range of application which increased due to the incorporation of composites of aluminium was also explained.

Objective of this study is to choose a suitable combination of PCTIG welding process parameters using the AHP process so as to get the optimum mechanical attributes in the weld zone. The main process parameters in PCTIG welding which have significant impact on the weld zone are base current, peak current, welding speed and pulse frequency. The advantage of using pulsed current over constant current is that it produces refinement of grains in the fusion zone, reduced HAZ (heat affected zone), less degree of distortion, control of segregation, and less residual stresses. Peak current leads to greater weld penetration, while base current stabilizes the arc. Thus, overall pulsed current is also more efficient with respect to energy utilization than constant current. In comparison with grain refinement, dilution of the base metal into the fusion zone has more impact than using filler metal containing refining metals.

2. EXPERIMENTAL DETAIL

The substrate made of Al-Mg-Si alloy was used in this experimental investigation having 3.15 mm thickness. It was welded with 4043 filler. Elements present in the filler material do not affect mechanical properties of the welded joint. Constituents of the substrate and filler are shown in Table 1.

To determine working limits of the parameters on sample, multiple trial runs of PCTIG welding were done on a 3.14-mm plate of Al-Mg-Si alloy and the results were noted as reported by Kumar and Sundarrajan [29]. The welding machine used was a 350-W capacity AC welding machine. The process attributes which have a considerable effect on the weld quality are Base Current, Peak Current, Welding Speed and Pulse Frequency. Apart from this, flow rate of shielding gas and backup plate also have an impact on the weld-quality traits. The trial runs were performed by differing any one of the input variables within a range of values while

Table 1: Base Metal and Filler Composition

	Mg	Cu	Si	Cr	Mn	Zn	Ti	Al
Al-Mg-Si (Base material)	0.86	0.69	0.22	0.06	0.32	0.07	0.05	Balance
4043 alloy (Filler material)	0.05	4.8	0.17	0.05	0.24	0.05	0.05	Balance

keeping the other parameters constant. The limits of process attributes were investigated by detecting the bead appearance and penetration. The range of values of the process parameters selected for study is shown in Table 2.

The number of working attributes for optimizing the mechanical characteristics is four and the level of each parameter is two as shown in Table 2. Apart from this, there are also other parameters such as purging gas flow rate, shielding gas flow rate, pulse ratio, electrode material, filler rod diameter, etc., which were kept constant during this study. Each experimental condition was executed twice in order to rectify and eliminate the errors.

The characteristic quality such as impact toughness, hardness, notch tensile strength and dilution of the base metal into the weldment were tested for each experimental trial run. Ultimately, by studying the final values of the weld qualities, the optimum combination of input parameters was selected, in achieving the optimum mecha-nical properties.

Initially, base metal sheets were devised and then butt joints were welded making use of the experimental trial run values as depicted in Table 3.The metal sheets were pickled and preheated and then single pass welding was performed.

Samples for tensile testing (both notched and plain specimens) were selected at the middle of all weld joints and then fabricated to ASTM E8 standards. Notched Tensile Test was performed to highlight the weld metal properties. Impact testing of the sample was conducted on a Charpy impact testing machine.

Table 2: Range of Input Parameters

Process Parameters	Units	Lower Level	Higher Level
Peak Current	A	180	200
Base Current	A	60	72
Welding Speed	mm/min	120	150
Pulse Frequency	Hz	2	6

Table 3: Experimental Trial Runs

Experiment No.	Peak Current (A)	Base Current (A)	Welding Speed (mm/min)	Pulse frequency (Hz)
P1	180	60	120	2
P2	180	60	150	6
P3	180	72	120	6
P4	180	72	150	2
P5	200	60	150	6
P6	200	60	150	2
P7	200	72	150	2
P8	200	72	150	6

For metallographic observation, optical microscope was used to record the microstructure. Micro-hardness test was performed using a Vickers digital micro-hardness tester.

Area fraction was used to evaluate the weld dilution (i.e., volume fraction of the base metal into the weld bead).

3. METHODOLOGY

3.1 Application of the AHP

The AHP is a multi-criteria decision-making algorithm, developed by Thomas L. Saaty in the 1970s. It helps the user to make a final decision out of a spectrum of alternatives. In this process, the user can quantify a choice numerically w.r.t. others and a result is infrared based on the algorithm designed. For applying the AHP algorithm, the user needs three levels of data i.e., the goal, criteria and alternatives. Based on the effect of an individual criterion on the ultimate goal, it is first compared with other criteria. Then the alternatives are compared with respect to each other based on their individual effect on the criteria. In this paper, the AHP algorithm is used to make the optimum decision among the various experiments.

3.2 Hierarchy Structure

As per standard methodology of applying the AHP, the goal is selected at first. In this case the goal is "To Optimize the PCTIG Welding Process Parameters of Heat-Treated Aluminum Alloy Weldments for Maximizing the Mechanical Properties". Then four criteria were selected as Notch Tensile Strength, Dilution, Impact Toughness and Hardness and experimental runs were selected as eight alternatives after which the hierarchy structure was constructed as shown in Fig. 1.

3.3 Criteria Matrix

The pair wise comparison matrix between criteria is constructed (Table 5) by considering the goal. Higher the influence on the goal, higher number was allotted w.r.t. each other (for very high influence, values of 7 or 8 whereas for lower influence 2 or 3 and for similar influence value of 1 was assigned).

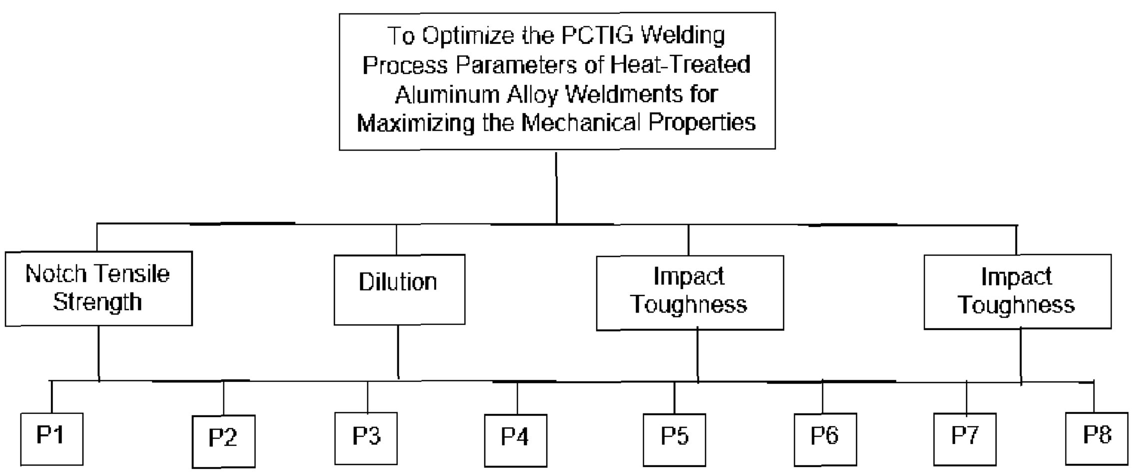

Fig. 1 : Hierarchy Structure

Consistency Ratio (CR) was checked and if it was less than 10% then it is acceptable.

CR=CI/RI **(1)**

CI= (λ_m-n)/(n-1) **(2)**

Where,

CI=Consistency Index, RI=Random Index (Table 4), n=order of the square matrix, λ_m=Maximum Eigen Value of the Corresponding Matrix.

Table 4: Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 5: Criteria Matrix

To Optimize Mechanical Properties of Weldment	Notch Tensile Strength	Dilution	Impact Toughness	Hardness	Geometric Mean	Criteria Weight
Notch Tensile Strength	1	1/5	1/3	3	0.6687	0.1177
Dilution	5	1	3	7	3.201	0.5636
Impact Toughness	3	1/3	1	5	1.4953	0.2633
Hardness	1/3	1/7	1/5	1	0.3124	0.0550
					5.6792	

CR= 0.043

Table 6: Alternative Matrix for NTS

Notch Tensile Strength (MPa)	P1	P2	P3	P4	P5	P6	P7	P8	Geometric Mean	Local Weight
P1	1	1/4	3	1	1/6	1/3	2	1/3	0.6389	0.0558
P2	4	1	5	4	1/4	2	5	1	1.9392	0.1694
P3	1/3	1/5	1	1/3	1/7	1/4	1/2	1/5	0.3072	0.0268
P4	1	1/4	3	1	1/7	1/3	2	1/3	0.6267	0.0547
P5	6	4	7	7	1	5	7	4	4.4881	0.3919
P6	3	1/2	4	3	1/5	1	4	1/2	1.2799	0.1118
P7	1/2	1/5	2	1/2	1/7	1/4	1	1/4	0.4158	0.0363
P8	3	1	5	3	1/4	2	4	1	1.7550	0.1533
									11.4508	

CR= 0.0366

Table 7: Aternative Matrix for Dilution

Dilution (%)	P1	P2	P3	P4	P5	P6	P7	P8	Geometric Mean	Local Weight
P1	1	1/4	2	1/2	1/6	1/3	2	1/2	0.5859	0.0515
P2	4	1	5	3	1/3	2	5	3	2.2247	0.1955
P3	1/2	1/5	1	1/3	1/7	1/4	1	1/3	0.3757	0.0330
P4	2	1/3	3	1	1/6	1/3	3	1	0.8717	0.0766
P5	7	3	7	6	1	4	7	6	4.4292	0.3892
P6	3	1/2	4	3	1/4	1	4	3	1.6465	0.1447
P7	1/2	1/5	1	1/3	1/7	1/4	1	1/3	0.3757	0.0330
P8	2	1/3	3	1	1/6	1/3	3	1	0.8717	0.0766
									11.3811	

CR= 0.0307

Table 8: Alternative Matrix for Impact Toughness

Impact Toughness (J)	P1	P2	P3	P4	P5	P6	P7	P8	Geometric Mean	Local Weight
P1	1	2	4	1/3	1	3	1/3	1/4	0.9506	0.0879
P2	1/2	1	3	1/4	1/2	2	1/3	1/5	0.6306	0.0583
P3	1/4	1/5	1	1/6	1/4	1/3	1/7	1/7	0.2477	0.0229
P4	3	4	6	1	3	4	3	1/3	2.3284	0.2153
P5	1	2	4	1/3	1	3	1/3	1/4	0.9506	0.0879
P6	1/3	1/2	3	1/4	1/3	1	1/3	1/6	0.4683	0.0433
P7	3	3	5	1/3	3	3	1	1/3	1.6094	0.1488
P8	4	5	7	3	4	6	3	1	3.6314	0.3357
									10.8170	

CR= 0.0384

Table 9: Alternative Matrix for Hardness

Hardness (HV)	P1	P2	P3	P4	P5	P6	P7	P8	Geometric Mean	Local Weight
P1	1	1/4	1/5	1/3	1/7	1/6	1/6	1/5	0.2456	0.0222
P2	4	1	1/2	2	1/5	1/3	1/3	1	0.7389	0.0667
P3	5	2	1	3	1/5	1/2	1/3	2	1.0901	0.0984
P4	3	1/2	1/3	1	1/6	1/3	1/3	1/2	0.5107	0.0461
P5	7	5	5	6	1	4	4	6	4.2212	0.3809
P6	6	3	2	3	1/4	1	1	3	1.7321	0.1563
P7	6	3	3	3	1/4	1	1	3	1.8221	0.1644
P8	4	1	1/2	2	1/6	1/3	1/3	1	0.7223	0.0652
									11.0830	

CR= 0.0324

4. RESULTS AND DISCUSSION

After final assessment, the 5th alternative was found to be the most optimum (Table 10) combination for optimized mechanical properties of the weldment. The global weight of individual alternatives was evaluated by the product of the criteria weight and the local weight of its corresponding alternative and finally summing them up.

The following were the numerical values of the input parameters for the optimum condition:

- Peak Current: 200 A
- Base Current: 60 A
- Welding Speed: 150 mm/min
- Pulse Frequency: 6 Hz

The global-weight corresponding to each of the alternatives denotes their relative influence in the UTS of the specimen. Higher is the global weight, better is the value of UTS.

Table 10: Results

Alternatives	Global Weight
P5	0.3096
P8	0.1532
P2	0.1491
P6	0.1147
P4	0.1088
P7	0.0711
P1	0.0600
P3	0.0332

5. CONCLUSION

The results obtained by using the AHP algorithm give the optimum numerical values of PCTIG welding parameters for desirable UTS of Al-Mg-Si composite. The optimized condition of PCTIG welding to have enhanced dilution of the base metal into the weld parameters has Peak Current of 200 A, Base Current of 60 A, Welding Speed of 150 mm/min and Pulse Frequency of 6Hz. Also, crystallographic analysis exhibits refined grain structure at the weld zone, that indicates better mechanical attributes. Finally, it can be concluded that the AHP is a good mathematical tool to analyze various case studies in different fields to obtain the optimum results.

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