Selection of welding process to fabricate butt joint of dissimilar metals using analytic hierarchic process

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Abstract*—Welding is a permanent joining technique uses heat and/ or pressure to fabricate high quality joints. There are numerous welding techniques, so selection of a welding is very crucial task for the industry. Decision of selection of a welding method can be made by high skill professional with consideration of qualitative and quantitative factors. The selection of a welding method for particular application is essential to fabricate high quality and low cost welding joint. Dissimilar metals have poor weldability. Dissimilar metals can be joined effectively by using Laser, Electron beam, Friction and Ultrasonic welding methods. Analytic Hierarchical Process (AHP) is one of the best Multi-Criteria Decision Making (MCDM) technique to select a best alternative based on some qualitative and quantitative factors/ criterion. AHP has been successfully implemented, results shows that Laser welding is best suited to weld butt joint of dissimilar metals (ferrous and copper/ aluminium alloy).

Index Terms— ***AHP, Dissimilar metals, Electron beam welding, Friction welding, MCDM, Laser welding, Ultrasonic welding,Welding.***

I. INTRODUCTION

Welding is technique used for joining metallic parts usually by application of heat. A weld can be defined as a combination of metals produced by heating to a suitable temperature with or without the application of pressure, and with or without the use of a filler material. Most metals, at elevated temperature, react with the atmosphere or other nearby metals. These reactions are very important in deciding the properties of a welded joint. Most metals, for example, rapidly oxidize when molten. A layer of oxide can prevent proper bonding of the metal. Molten-metal droplets coated with oxide become entrapped in the weld and make the joint brittle. Some valuable materials added for specific properties react so quickly on exposure to the air that the metal deposited does not have the same properties and composition as it had initially. These problems have led to the use of fluxes and inert atmospheres.Weldability is the capacity of a material to be welded under the fabrication conditions imposed, into a specific, suitably designed structure, and to perform satisfactorily in the intended service. [1]

Dissimilar metal joining in general has great potential in practical applications to replace riveted joints leading to huge cost and weight saving. [2] Joining dissimilar metals is very difficult, especially when the thermal conductivity of each is substantially different. Generally speaking, intersolubility is required in welding dissimilar metals. However, in some cases, a third metal which is soluble with the other two is needed to produce a successful joint. If the thermal expansion coefficients of dissimilar metals differ greatly, internal stresses will occur in the intermetallic zone during any temperature change of the weldment. [3].

II. LITERATURE SURVEY

For selecting the alternative to join dissimilar metals literature survey is carried out the consolidated list of research paper list given in **Table 1.**

Through exhaustive literature survey it is been found that friction welding, laser-beam welding, electron beam welding, ultrasonic welding are the most popular techniques for welding dissimilar metals. Metals combinations mostly used are Steel with non-ferrous metals like aluminium and copper alloys.

III. METHODOLOGY

Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method is selected for selection of welding process for dissimilar metals. Four factors/ criterion are identified based on the literature survey viz. Cost of Welding, Weld Quality, Availability of Welding Process and Welding Procedure. Four alternatives selected through literature survey to weld dissimilar metals are Friction welding, Electron Beam Welding, Laser welding and Ultrasonic welding. **Figure 1** shows the important factors which are considered for selecting the welding processes.

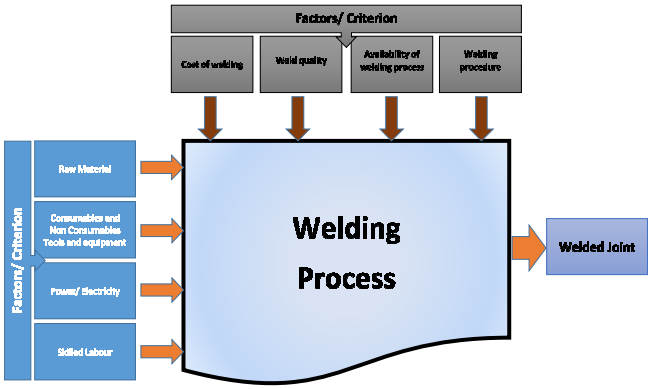

Figure 1:Factors for welding process

Table 1:Summary of Literature Survey

Year	Author(s)	Title,	Material welded	Welding Method used
2014	Paul Kah, Madan Shrestha Jukka Martikainen	Trends in Joining Dissimilar Metals by Welding	Dissimilar Metals	Various methods
2014	L. H. Shah & M. Ishak	Review of Research Progress on Aluminum–Steel Dissimilar Welding	Aluminum–Steel	Various methods
2013	Caiwang Tan, Liqun Li, Yanbin Chen, Wei Guo	Laser-tungsten inert gas hybrid welding of dissimilar metals AZ31B Mg alloys to Zn coated steel	AZ31B Mg alloys to Zn coated steel	Laser-tungsten inert gas hybrid welding
2013	M Aritoshi K Okita	Friction welding of dissimilar metals	Various matetals	Friction welding
2012	Zhengqiang Zhu & Kang Yong Lee & Xiaolong Wang	Ultrasonic welding of dissimilar metals, AA6061 and Ti6Al4V	AA6061 and Ti6Al4V	Ultrasonic welding
2010	Emel Taban, Jerry E. Gould, John C. Lippold	Dissimilar friction welding of 6061-T6 aluminum and AISI 1018 steel: Properties and microstructural characterization	6061-T6 aluminum and AISI 1018 steel	friction welding
2009	Thaiping Chen	Process parameters study on FSW joint of dissimilar metals for aluminum–steel	AA6061 aluminum alloy and SS400 low-carbon steel	friction stir welding
2009	San-bao Lin, Jian-ling Song, Guang-chao Ma, Chun-li Yang	Dissimilar metals TIG welding-brazing of aluminum alloy to galvanized steel	aluminum alloy to galvanized steel	TIG welding-brazing
2009	S Imaizumi	Welding of aluminium to dissimilar metals	Aluminium-copper and steel	Roll pressure welding, Explosive pressure welding, Friction welding, Flash welding
2008	Yajie Quan, Zhenhua Chen, Xiaosan Gong,	CO2 laser beam welding of dissimilar magnesium-based	magnesium alloys AZ31, AM60 and ZK60	CO2 laser beam welding

	Zhaohui Yu	alloys		
2007	SD Meshram, T Mohandas, GM Reddy	Friction welding of dissimilar pure metals	Fe, Cu, Ti and Ni	Friction welding
2007	Hitoshi Ozaki and Muneharu Kutsuna	Laser-roll welding of a dissimilar metal joint of low carbon steel to aluminium alloy using 2 kW fibre laser,	low carbon steel to aluminium alloy	Laser-roll welding
2006	Takehiko Watanabe, Hirofumi Takayama, Atsushi Yanagisawa	Joining of aluminum alloy to steel by friction stir welding	aluminum alloy to steel	friction stir welding
2006	K Furukawa	New CMT arc welding process – welding of steel to aluminium dissimilar metals and welding of super-thin aluminium sheets	steel to aluminium	Cold Metal Transfer arc welding
2005	Rattana Borrisutthekul, Yukio Miyashita, Yoshiharu Mutoh	Dissimilar material laser welding between magnesium alloy AZ31B and aluminum alloy A5052-O	magnesium alloy AZ31B and aluminum alloy A5052-O	laser welding
2004	S Katayama	Laser welding of aluminium alloys and dissimilar metals	aluminium alloys and dissimilar	Laser welding
1996	Z. Sun R. Karppi	The application of electron beam welding for the joining of dissimilar metals: an overview	Various materials	electron beam welding
1995	Z. Sun, j. C. Ion	Laser welding of dissimilar metal combinations	Stainless steel and carbon or low-alloy Steel, Steel and copper, Steel and aluminium, Steel and nickel, Aluminium and copper, Aluminium and lead	laser welding
1976	G. Metzger and r. Lison	Electron Beam Welding of Dissimilar Metals	Dissimilar Metals	Electron Beam Welding,

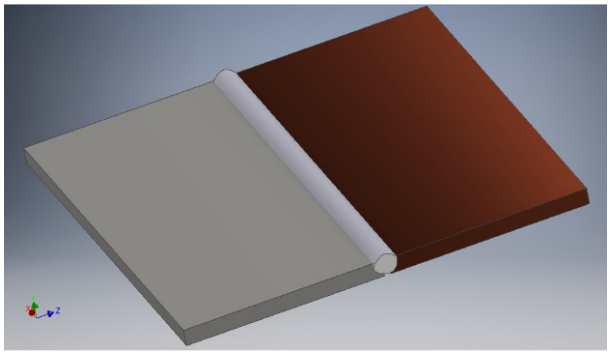

Figure 2: Representation of butt joint of dissimilar metals

IV. ANALYTICAL HIERARCHIC PROCESS

Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Prof. Thomas L. Saaty (1977 and 1994). It is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price, weight etc., or from subjective opinion such as satisfaction feelings and preference. AHP allow some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal Eigen vectors and the consistency index is derived from the principal Eigen value.

A. Procedure of AHP

Basic steps in AHP model

The basic steps in the AHP are as follows:

1. Select the set of processes.
2. Identify the factors, which may be intrinsic as well as extrinsic, that might have an impact. For each of these impacts identify the criteria and the quantifiable indicators for the criteria.
3. Develop a graphical representation of the problem in terms of the overall goal, the factors, the criteria and the decision alternatives. Such a graph depicts the hierarchy for the problem.
4. Assign weights to each alternative on the basis of the relative importance of its contribution to each decision criterion. This is carried out through a pairwise comparison of the alternatives based on the decision criterion.
5. Once the pairwise comparison matrix has been formed for a criterion, the normalized priority of each alternative is synthesized. The procedure for this as follows: (a) sum the values in each column; (b) divide each element in the column by its column total, which results in a normalized pairwise comparison matrix, and (c) compute the average of the elements in each row of the normalized comparison matrix, thus providing an estimate of the relative priorities of the alternatives. **Table 2**shows Scale of relative importance and the **Table 3** shows RCI values to be consider as per number of factors.
6. In addition to the pairwise comparisons of the alternatives, use the same pairwise comparison procedures to set the priorities for all the criteria in terms of the importance of each in contributing towards the overall goal.
7. The priority is synthesized in a manner similar to step 5.
8. Calculate the overall priority for each alternative.
9. Select the alternative having the highest priority.

Table 2: Scale of Relative Importance (according to Saaty (1980))

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocal so f above non zero	If activity i has one of the above non zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Table 3: RCI values for different values of n.

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

B. Implementation of AHP

The general methodology for welding process selection for specific material is depicted in **Figure 3.**

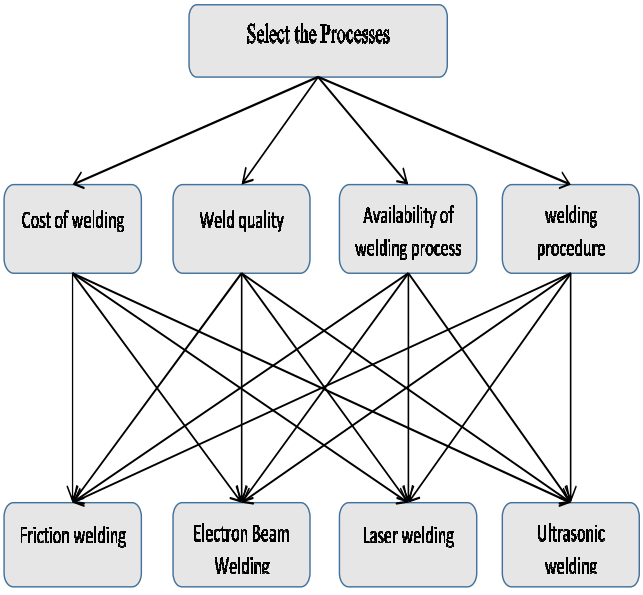

Figure 3:Schematic diagram of analytic hierarchic process model.

The following table shows Description of process Criterion considered

Table 4: Scale of Relative Importances (according to Saaty (1980))

Sr. No.	Criterion	Criterion Description
1	Cost of Welding	Cost of welding process includes cost of welding machine, equipment, tools, consumable and non-consumable materials, labor, power and miscellaneous.
2	Weld Quality	Weld bead appearance, percentage of rejects due to welding defects (e.g. distortion, misalignment, porosity, lack of penetration, etc.)
3	Availability of Welding Process	availability of welding process includes machine, equipment, tools, consumable and non-consumable materials and skilled labor availability
4	Welding Procedure	Pre-heating requirements, root pass requirements, number of passes required, interpass temperature maintenance, post-heating requirements and Clamping joints in fixtures, setting welding parameters (voltage, current, welding speed, gas flow rate, wire feed, etc.), electrode/filler metal preparation, cleaning the base metal

V. RESULTS AND DISCUSSION

Four criterion are finalized for selecting the welding process best suited for joining the dissimilar metals

Pair wise comparison matrix is formulated by considering the relative importance of the criterion shown in **Table 5**

Table 5: Pair wise comparison matrix

	Cost of welding	weld quality	availability of welding process	welding procedure
Cost of welding	1.00	2.00	2.00	3.00
weld quality	0.50	1.00	3.00	4.00
availability of welding process	0.50	0.33	1.00	2.00
welding procedure	0.33	0.25	0.50	1.00
Total	**2.33**	**3.58**	**6.50**	**10.00**

As discussed in the methodology normalized pair wise comparison matrix is formulated to obtained the Criteria weight (CW) shown in table no. 6.1, Table no. 6.2 shows the criteria weight for cost of welding.

Table 6: Normalized pair wise comparison matrix

	Cost of welding	weld quality	availability of welding process	welding procedure	Criteria weight (CW)
Cost of welding	0.43	0.56	0.31	0.30	**0.40**
weld quality	0.21	0.28	0.46	0.40	**0.34**
availability of welding process	0.21	0.09	0.15	0.20	**0.17**
welding procedure	0.14	0.07	0.08	0.10	**0.10**
Total	**1.00**	**1.00**	**1.00**	**1.00**	

Table 7: Criteria weight for cost of welding

Cost of welding	Cost of welding	Criteria weight (CW)
Friction welding	600000	0.23
Electron Beam Welding	650000	0.25
Laser welding	1000000	0.38
Ultrasonic welding	400000	0.15
Total	2650000	

For calculated criteria weights consistency is calculated and tabulated in Table no. 7. Where

Λmax – Maximum value of igen vector

CI – Consistancy Index

RI – Random index

CR – Consistency ratio

All values are found consistence.

Table 8: Consistency calculation matrix

	Cost of welding	weld quality	availability of welding process	welding procedure	Weighted sum value (CSV)	CSV/CW
Cost of welding	0.40	0.68	0.33	0.29	**1.70**	**4.26**
weld quality	0.20	0.34	0.50	0.39	**1.42**	**4.20**
availability of welding process	0.20	0.11	0.17	0.19	**0.67**	**4.07**
welding procedure	0.13	0.08	0.08	0.10	**0.40**	**4.08**
Total	**0.93**	**1.21**	**1.07**	**0.97**	λmax	**4.15**

CI	RI	CR=CI/RI	CR<0.1	CONSISTENT
0.05	**0.90**	**0.06**	**TRUE**	**CONSISTENT**

Similar calculations are carried out criteria wise for all four welding methods selected. For weld quality, Table no. 9, 10 and 11. For availability of welding process, Table no. 12, 13 and 14. For welding procedure, Table no. 15, 16 and 17.

Table 9: Pair wise comparison matrix for weld quality

weld quality	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding
Friction welding	1.00	0.17	0.20	2.00
Electron Beam Welding	6.00	1.00	2.00	7.00
Laser welding	5.00	0.50	1.00	6.00
Ultrasonic welding	0.50	0.14	0.17	1.00
Total	**12.50**	**1.81**	**3.37**	**16.00**

Table 10: Normalized pair wise comparison matrix for weld quality

weld quality	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding	Criteria weight (CW)
Friction welding	0.08	0.09	0.06	0.13	**0.09**
Electron Beam Welding	0.48	0.55	0.59	0.44	**0.52**
Laser welding	0.40	0.28	0.30	0.38	**0.34**
Ultrasonic welding	0.04	0.08	0.05	0.06	**0.06**
Total	**1.00**	**1.00**	**1.00**	**1.00**	

Table 11: Consistency calculation matrix for weld quality

weld quality	Friction welding	Electron Beam	Laser welding	Ultrasonic welding	Weighted sum value	CSV/CW

	g	Welding			(CSV)	
Friction welding	0.09	0.09	0.07	0.12	**0.36**	**4.02**
Electron Beam Welding	0.53	0.52	0.67	0.40	**2.13**	**4.13**
Laser welding	0.45	0.26	0.34	0.35	**1.39**	**4.12**
Total	**1.11**	**0.93**	**1.13**	**0.92**	λmax	**4.07**

CI	RI	CR=CI/RI	CR<0.1	CONSISTENT
0.02	**0.90**	**0.03**	**TRUE**	**CONSISTENT**

Table 12: Pair wise comparison matrix for availability of welding process

availability of welding process	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding
Friction welding	1.00	7.00	3.00	2.00
Electron Beam Welding	0.14	1.00	0.50	0.20
Laser welding	0.33	2.00	1.00	0.33
Ultrasonic welding	0.50	5.00	3.00	1.00
Total	**1.98**	**15.00**	**7.50**	**3.53**

Table 13: Normalized pair wise comparison matrix for availability of welding process

availability of welding process	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding	Criteria weight (CW)
Friction welding	0.51	0.47	0.40	0.57	**0.48**
Electron Beam Welding	0.07	0.07	0.07	0.06	**0.07**
Laser welding	0.17	0.13	0.13	0.09	**0.13**
Ultrasonic welding	0.25	0.33	0.40	0.28	**0.32**
Total	**1.00**	**1.00**	**1.00**	**1.00**	

Table 14: Consistency calculation matrix for availability of welding process

availability of welding process	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding	Weighted sum value (CSV)	CSV/CW
Friction welding	0.48	0.46	0.40	0.63	**1.98**	**4.08**
Electron Beam Welding	0.07	0.07	0.07	0.06	**0.26**	**4.03**
Laser welding	0.16	0.13	0.13	0.11	**0.53**	**4.01**
Ultrasonic welding	0.24	0.33	0.40	0.32	**1.28**	**4.05**
Total	**0.96**	**0.98**	**0.99**	**1.12**	λmax	**4.04**

CI	RI	CR=CI/RI	CR<0.1	CONSISTENT
0.01	**0.90**	**0.02**	**TRUE**	**CONSISTENT**

Table 15: Pair wise comparison matrix for welding procedure

welding procedure	Friction welding	Electron Beam	Laser welding	Ultrasonic welding
		Welding		
Friction welding	1.00	9.00	7.00	2.00
Electron Beam Welding	0.11	1.00	0.33	0.14
Laser welding	0.14	3.00	1.00	0.20
Ultrasonic welding	0.50	7.00	5.00	1.00
Total	**1.75**	**20.00**	**13.33**	**3.34**

Table 16: Normalized pair wise comparison matrix for welding procedure

welding procedure	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding	Criteria weight (CW)
Friction welding	0.57	0.45	0.53	0.60	**0.54**
Electron Beam Welding	0.06	0.05	0.03	0.04	**0.05**
Laser welding	0.08	0.15	0.08	0.06	**0.09**
Ultrasonic welding	0.29	0.35	0.38	0.30	**0.33**
Total	**1.00**	**1.00**	**1.00**	**1.00**	

Table 17: Consistency calculation matrix for welding procedure

welding procedure	Friction welding	Electron Beam Welding	Laser welding	Ultrasonic welding	Weighted sum value (CSV)	CSV/CW
Friction welding	0.54	0.41	0.64	0.65	**2.24**	**4.18**
Electron Beam Welding	0.06	0.05	0.03	0.05	**0.18**	**4.02**
Laser welding	0.08	0.14	0.09	0.07	**0.37**	**4.03**
Ultrasonic welding	0.27	0.32	0.46	0.33	**1.37**	**4.19**
Total	**0.94**	**0.91**	**1.22**	**1.09**	λmax	**4.11**

CI	RI	CR=CI/RI	CR<0.1	CONSISTENT
0.04	**0.90**	**0.04**	**TRUE**	**CONSISTENT**

Criteria weight obtained by criteria comparison is multiplied by criteria weight obtained for individual process and sum for each welding process is calculated. Rating is given to the process according the sum. The calculations are summarized in table no. 18.

Table 18: Final composite rating of the welding processes

Criteria	Criteria weight (CW)	Process priority weights							
		Friction welding		Electron Beam Welding		Laser welding		Ultrasonic welding	
Cost of welding	0.40	0.23	**0.09**	0.25	**0.10**	0.38	**0.15**	0.15	**0.06**
weld quality	0.34	0.09	**0.03**	0.52	**0.17**	0.34	**0.11**	0.06	**0.02**
availability of welding process	0.17	0.48	**0.08**	0.07	**0.01**	0.13	**0.02**	0.32	**0.05**
welding procedure	0.10	0.54	**0.05**	0.05	**0.00**	0.09	**0.01**	0.33	**0.03**
Total			0.25		0.29		0.30		0.16

Rating	3		2		1		4

CONCLUSION

For joining dissimilar metals friction welding, electron beam welding, laser welding and ultrasonic welding are most popular welding processes. The important criteria decided for selecting best suitable welding processes are cost of welding, weld quality, availability of welding process and welding procedure.

AHP technique is applied for selecting the best suited method. AHP gives final process priority weights for welding methods. Laser welding gets the highest value of 0.30, closely followed by electron beam welding (0.29), and followed by friction welding (0.25) and ultrasonic welding (0.16).

So laser welding is best suitable process for joining the dissimilar metals and ultrasonic welding is least suitable. In case laser welding is not available Electron beam welding is good alternative

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