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AN INVESTIGATION OF TENSILE STRENGTH, HARDNESS AND HAZ OF DISSIMILLAR MATERIALS SS3041 & KOVAR ALLOY BY LASER WELDING

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Abstract — *Very less work has been done on laser welding of dissimilar material. Laser welding of KOVAR Alloy was studied in butt welding in SS304L. In order to decrease formation of intermetallic components during laser welding, effect of peak power, pulse duration and welding speed and was investigated. Tensile test, Hardness test and heat affected zone test was performed to identify the effect of each parameter on the weld. Results showed that increasing peak power (in constant pulse energy), pulse duration (in constant peak power) and welding speed (in constant pulse energy and peak power) will decrease tensile strength. On the other hand, decreasing the mentioned parameters will cause destructive effects such as inadequate penetration depth, spattering and cavity formation. Improvement in the tensile strength and decrement in hardness and Heat Affected Zone was attributed to low values of intermetallic components in weld metal.*

Keywords – *Tensile strength, Hardness, HAZ, Laser weldding.*

I INTRODUCTION

LASER BASICS

The word "LASER" is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The elements of a laser are –

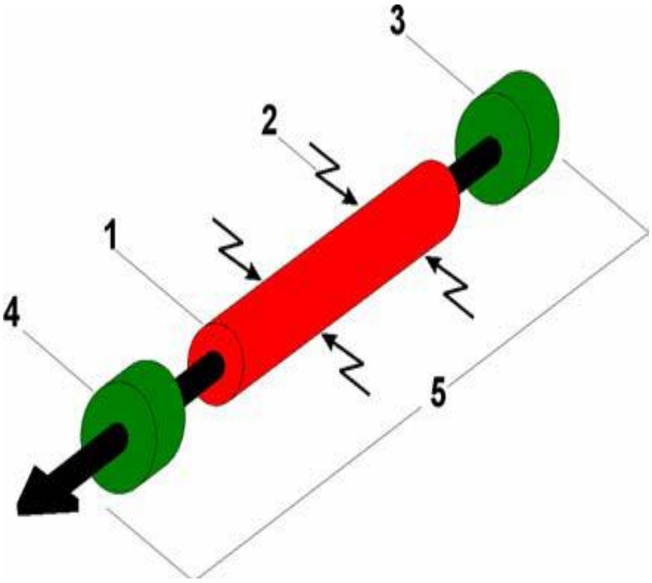

Figure 1. Elements of a laser

There are two of types of Nd:YAG laser welders; continuous wave and pulsed. As the name suggests continuous wave or CW is either on or off, whereas pulsed lasers create welds by individual pulses. The pulsed laser utilizes high peak power to create the weld, whereas the CW laser uses average power. This allows the pulsed laser to use less energy to create the weld, with a smaller heat affected zone. This provides the pulsed laser with unrivalled spot welding performance and minimal heat input seam welding. Unitek Miyachi lasers are pulsed welders.

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II LITERATURE REVIEW

[1] M.J. Torkamany et al In this paper dissimilar welding of carbon steel to 5754 aluminium Alloy, they used Nd:YAG to weld Al alloy and steel to using process parameter like Peak power 1-2.7 KW, Pulse duration 3.7- 10 ms, Velocity 5mm/sec, Pulse energy 10 J, Frequency 20/sec, Overlapping factor 40-90%, w/d ratio 1.5 mm, Power 200W. They observed OM, SEM, EDX, UTM . They found that High peak power cause mode dilution, Hardness is also increasing with increasing the peak power. Longer pulse duration cause large weld width and also penetration depth. Also they found that Welding efficiency increases with overlapping factor and Ideal parameter and of welding peak power is1.43KW, Pulse duration is 5 ms, Overlapping factor 80% Hardness value increases with increasing the penetration depth.

[2] S.A.A. Akbari Mousavi et al Metallurgical investigations of pulsed Nd:YAG laser welding of AISI 321 and AISI 630 stainless steels of 0.6 mm thickness plate. They were focused on the effects of laser power, beam diameter and pulse duration on the depth and width of the welds. They measured Microstructures of the welded joints were investigated by optical and scanning electron microscopy. The results show that both weld depth and weld width increase with voltage. They also found that the pulse duration have bilateral effects on the weld bead depth and width and The maximum hardness resulted in the 630 stainless steel region and the minimum hardness occurred for the 321 stainless steel region. This was inferred from the micro hardness test.

[3] Jose´ Roberto Berretta et al Pulsed Nd:YAG laser welding of AISI 304 to AISI 420 stainless steels of 0.8 mm thick plate. They investigate to determine the influence of the laser beam position, with respect to the joint, on weld characteristics. They Prepared work pieces were welded with the laser beam incident on the joint. Joints attained under all the welding parametric conditions were constant. Changes in beam position had no effect on weld fillet geometry. If the laser beam is positioned on the joint or is shifted in the direction of AISI 304 steel, it will tend to favor the joint. If the laser beam is shifted to the opposite direction of AISI 420 steel, the structure becomes martensite The joints were examined in an optical microscope for cracks, pores and to determine the weld geometry. The microstructure of the weld and the heat affected zones were observed in a scanning electron microscope. An energy dispersive spectrometer, coupled to the scanning electron microscope, was used to determine variations in (weight %) the main chemical elements across the fillet weld. They used Vickers microhardness testing and tensile testing for determine the mechanical properties of the weld. The results of the various tests and examinations enabled definition of the best position for the incident laser beam with respect to the joint, for welding together the two stainless steels.

[4] Vicente Afonso Ventrella et al [4] A pulsed neodymium:yttrium aluminum garnet laser weld to examine the influence of the pulse energy in the characteristics of the weld fillet. The base material used for this study was AISI 316L stainless steel foil with 100mm thickness. The welds were analyzed by optical microscopy, tensile shear tests and microhardness. The results indicate that pulse energy control is of considerable importance to thin foil weld quality because it can generate good mechanical properties and reduce discontinuities in weld joints. The ultimate tensile strength of the welded joints increased at first and then decreased as the pulse energy increased. The process appeared to be very sensitive to the gap between couples. They found that the thin foil weld quality pulse energy control holds considerable because of tits capanility to create excellent mechanical properties and minimize.

III METHODOLOGY

SELECTION OF MATERIAL

Following material are widely used in coating of aerospace parts and ship such as relay switches. SS 304L stainless steel will cut to of 60 mm x 30 mm x 2.0mm for performing experimental study by company's hack saw machine. Chemical composition of SS304L has following in following table

Table 1 Chemical composition of SS304L

C Max	Si Max	Mn Max	Cr	Ni	P Max	S Max
0.03	0.75	2.00	18.00/20.00	8.00/12.00	0.045	0.030

Table 2 Chemical composition of KOVAR

Fe	Ni	Co	C	Si	Cr
Bal	29	17	0.02	0.20	0.20

Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

A. Full Factorial design for experiment

Full factorial design is used for simultaneous study of several factor effects on the process. By varying levels of factors simultaneously we can find optimal solution. Responses are measured at all combinations of the experimental factor levels. The combination of the factor levels represent the conditions at which responses will be measured. Each experiment condition is a run. The response measurement is an observation. The entire set of run is a design of experiment. It is used to find out the variables which are the most influence on the response and their interactions between two or more factors on responses.

The three-level design is written as a 3^k factorial design. It means that k factors are considered, each at 3 levels. These are referred to as low, intermediate and high levels. These levels are numerically expressed as 0, 1, and 2. One could have considered the digits -1, 0, and +1, but this may be confusing with respect to the 2-level designs since 0 is reserved for center points. Therefore, we will use the 0, 1, 2 scheme. Thus standard order (in terms of 0, 1 and 2 for coded test condition of -1, 0 and 1 respectively) 000 and 222 indicates all process parameters are at their low levels and higher levels respectively. The set of 27 tests have been performed randomly however some experimental limitation has been considered in randomization.

B. Grey Relational Analysis

Through the grey relational analysis, a grey relational grade can be obtained to evaluate the multiple performance characteristic. As a result, optimization of the complicated multiple performance characteristic can be converted into the optimization of a single grey relation grade. For multiple performance characteristic optimizations using GRA, following steps are followed:

1. Normalization of experimental result for all performance characteristics.
2. Performance of grey relational generating and calculation of grey relational coefficient (GRC).
3. Calculation of grey relation grade (GRG) using, weighing factor for performance characteristics.
4. Analysis of experimental results using GRG and statistical analysis of variance (ANOVA).
5. Selection of optimal levels of process parameters

IV EXPERIMENTAL RESULT AND DISCUSSION

The experiment was conducted in company to measures the value of tensile strength, hardness, HAZ various combination of input parameter.

Table .3 L27 orthogonal array with Experimental Readings

Ex. No.	SNR of Tensile Strength	SNR of Hardness	SNR of HAZ
1	42.477	-47.712	24.43697499
2	42.211	-48.332	21.93820026
3	42.007	-48.974	18.41637508
4	43.22736004	-47.38431715	24.43697499
5	42.54209597	-47.92398694	23.0980392
6	42.21179421	-48.53022523	20
7	43.80663396	-47.15869694	27.95880017
8	43.40523431	-47.56795802	26.02059991
9	42.98438225	-47.99347443	23.0980392
10	44.50618563	-46.92705949	20.91514981
11	44.13651752	-47.64034085	17.72113295
12	43.69382862	-48.33281015	16.47817482
13	45.00840005	-47.19670965	23.0980392
14	44.24375209	-47.64034085	20.91514981
15	43.86249197	-48.36602583	19.1721463
16	44.76092206	-46.84845362	24.43697499
17	43.75041442	-47.15869694	23.0980392
18	43.10672075	-47.67630732	20.91514981
19	45.93330381	-46.3612667	18.41637508
20	45.1535715	-47.19670965	16.47817482
21	44.76092206	-47.99347443	14.8945499
22	46.14992076	-46.6487692	20.91514981
23	45.62066734	-47.53153914	20
24	45.39025888	-47.92398694	17.07743929
25	46.48564911	-46.31940691	23.0980392
26	46.06392115	-46.52671722	20.91514981
27	45.7560346	-47.2722396	19.1721463

A. Main Effects Plot of Tensile strength

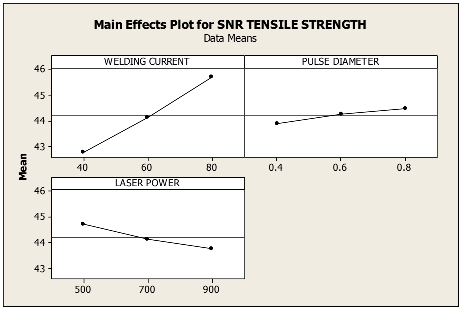

Figure 2. Effect of control factor on tensile strength

Fig 2 shows that it has been conclude that the optimum combination of each process parameter for high tensile strength is meeting at high welding current [A3], high pulse diameter [B3] and low laser power [C1].

B. Main Effects Plot of Hardness

Fig.3 shows that it has been conclude that the optimum combination of each process parameter for low hardness value is meeting at low welding current [A1], low pulse diameter [B1] and high laser power [C3].

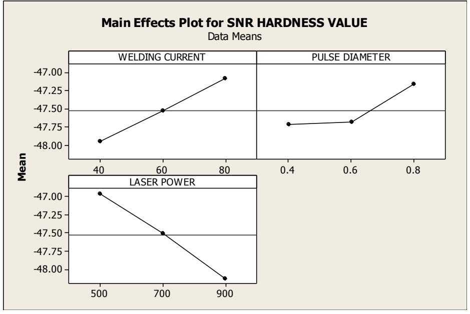

Figure 3. Effect of control factor on Hardness

C. Main Effects Plot of HAZ

Fig.4 shows that it has been conclude that the optimum combination of each process parameter for low heat affected zone is meeting at high welding current [A3], low pulse diameter [B1] and high laser power [C3].

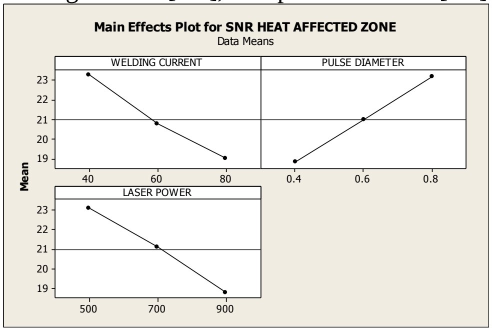

Figure 4. Effect of control factor on HAZ

D. Analysis of Variance for Tensile strength

Table 4. ANOVA table of tensile strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Welding current	2	38.9167	38.9167	19.4584	160.81	0.000
Pulse diameter	2	1.5674	1.5674	0.7837	6.48	0.007
Laser power	2	4.1563	4.1563	2.0781	17.17	0.000
Error	20	2.4201	2.4201	0.1210		
Total	26	47.0605				
R-Sq = 94.86%				R-Sq(adj) = 93.31%		

From ANOVA result it is observed that the welding current, pulse diameter and laser power of weld influencing parameter for tensile strength as they are all less than 0.05 p.

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E. Analysis of variance for Hardness

From ANOVA result it is observed that the welding current, pulse diameter and laser power of weld influencing parameter for tensile strength as they are all less than 0.05 p.

Table 5. ANOVA table for Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Welding current	2	3.3840	3.3840	1.6920	48.59	0.000
Pulse diameter	2	1.7028	1.7028	0.8514	24.45	0.000
Laser power	2	6.1381	6.1381	3.0691	88.13	0.000
Error	20	0.6965	0.6965	0.0348		
Total	26	11.9215				

F. Analysis of variance for HAZ

From ANOVA result it is observed that the welding current, pulse diameter and laser power of weld influencing parameter for tensile strength as they are all less than 0.05 p.

Table 6. ANOVA table for HAZ

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Welding current	2	82.952	82.952	41.476	100.29	0.000
Pulse diameter	2	84.595	84.595	42.298	102.28	0.000
Laser power	2	82.516	82.516	41.258	99.77	0.000
Error	20	4.5998	4.5998	0.2300		
Total	26	26.8332				
R-Sq = 96.80%				R-Sq(adj) = 95.84%		

V GREY RELATIONAL ANALYSIS

Table 7. Normalization, GRC and GRG of experimental data

No	Normalization data			Grey relational coefficient			GRG
	Tensile strength	Hardess value	HAZ	Tensile strength	Hardess value	HAZ	
1	0.104	-28.346	0.269	0.826	-0.017	0.649	0.486
2	0.045	-28.113	0.460	0.916	-0.018	0.520	0.472
3	0.278	-27.871	0.730	0.999	-0.018	0.406	0.462
4	0.272	-28.470	0.269	0.647	-0.017	0.649	0.426
5	0.119	-28.267	0.372	0.807	-0.018	0.573	0.454
6	0.045	-28.038	0.609	0.916	-0.018	0.450	0.449
7	0.401	-28.555	0.248	0.554	-0.017	0.999	0.512
8	0.312	-28.401	0.148	0.615	-0.017	0.771	0.456
9	0.218	-28.240	0.372	0.696	-0.018	0.573	0.417
10	0.557	-28.642	0.539	0.472	-0.017	0.481	0.311
11	0.475	-28.373	0.783	0.512	-0.017	0.389	0.294
12	0.376	-28.113	0.878	0.570	-0.018	0.362	0.304
13	0.670	-28.540	0.372	0.427	-0.017	0.573	0.327
14	0.499	-28.373	0.539	0.500	-0.017	0.481	0.321
15	0.414	-28.100	0.672	0.546	-0.018	0.426	0.318
16	0.614	-28.672	0.269	0.448	-0.017	0.649	0.360
17	0.389	-28.555	0.372	0.562	-0.017	0.573	0.372
18	0.245	-28.360	0.539	0.670	-0.017	0.481	0.377
19	0.876	-28.855	0.730	0.363	-0.017	0.406	0.250
20	0.702	-28.540	0.878	0.41578	-0.017	0.362	0.253
21	0.614	-28.240	1.000	0.448	-0.018	0.333	0.254
22	0.925	-28.747	0.539	0.350	-0.017	0.481	0.271

23	0.806	-28.414	0.609	0.382	-0.017	0.450	0.271
24	0.755	-28.267	0.832	0.398	-0.018	0.375	0.251
25	1	-28.8714	0.372	0.333	-0.017	0.573	0.296
26	0.905	-28.793	0.539	0.355	-0.017	0.481	0.273
27	0.8	-28.512	0.672	0.384	-0.017	0.426	0.264

The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. Experiment 25 has the best multiple performance characteristic among 27 experiments, because it has the highest grey relational grade shown in table. The higher the value of the grey relational grade, the closer the corresponding factor combination is, to optimal. A higher grey relational grade implies better product quality, therefore, on the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

A. Main Effect of Factors on Grey Relational Grade (GRG)

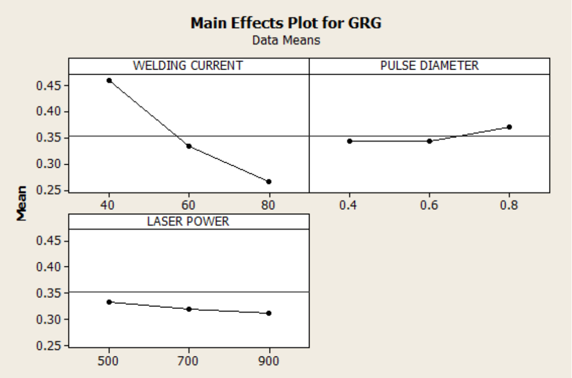

Figure.5. Effect of control factors plot of SNR of GRG

For the combined response maximization or minimization, fig.5.5 gives optimum value of each control factor. It interprets that level A1, B2, and C1 gives optimum result. The mean of grey relational grade for each level of the other machining parameters can be computed in similar manner. The mean of grey relational grade for each level of the machining parameters is summarized and shown in following table

Table 8. Main effect of factors on Grey Relational Grade

Symbol	Control Factor	Level-1	Level-2	Level-3
A	WELDING CURRENT	***0.459738***	0.332513	0.26529
B	PULSE DIAMETER	0.343575	***0.343608***	0.330000
C	LASER POWER	***0.360322***	0.352255	0.344633

As we know that higher grey relational grade value will give optimum value of TENSILE STRENGHT, HARDNESS VALUE AND HEAT AFFECTED ZONE. Thus it is revealed that response will be optimum at WELDING CURRENT AT 45 A^0, PULSE DIAMETER at 0.6 mm and LASER POWER at 500 watt.

VI CONFIRMATION TEST

The final step is to confirm the validity of the optimization technique and verify the improvement of the performance characteristics by welding same sample with predicted optimized level setting. That means again laser welding was done for the specified sample with welding current kept at 40 Amp., pulse diameter kept at 0.6 mm and laser power 500 Watt. The same procedure was followed to find tensile strength, hardness value and heat affected zone. The tensile strength was found to be 145.25 N/mm^2, hardness value 233.89 N/mm^2 and 0.06 mm.

Again considering the predicted optimized parameters and using Equation 1, 2 and Equation 3, tensile strength was calculated to 145.17 N/mm^2, hardness value calculated to 234.31N/mm2 and heat affected zone 0.0501

Table Conformation result

Responses	Actual value	Predicated value	Percentage error[%]
Tensile strength	145.25	145.17	0.05
Hardness value	234.00	234.31	0.13

Heat affected zone	0.06	0.0501	16.5

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