Optimization of laser welding parameters for Copper and aluminum joint

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***Abstract*—Aluminum and Copperhas more significance in electrical and electronic application such as solar energy collectors or light weight electric motors and actuators. It combines comparably good thermal and electrical properties with attractive price and low material weight. However the main difficulty for widespread use of aluminum is the lack of reliable joining process to connect it with copper. The problem during welding of copper and aluminum are caused by large misalignment in physical properties and even more poor metallurgical affinity of both materials and therefore crack sensitivity and formation of brittle intermetallic phase during fusion welding.**

Wide range of materials can be welded by laser, especially the alloys that are normally difficult to weld by conventional welding. Since absorption of the laser power is crucial for melting, conductivity and reflectivity are important key factors for achieving better melting. In this effort we have investigated laser welding of aluminum and copper of 2mm thk with literature studies in past. This paper also concentrates on review of current processes for joining Aluminum and copper with disadvantages and feasibility of laser welding the same metals with higher efficiency.

***Index Terms*—Laser Welding, Copper and Aluminum, 2 mm thickness, Analytical**

I. INTRODUCTION

Generally aluminum is a reactive material that oxidizes easily, but in practice it has proved to offer good corrosion resistance. This characteristic is due to a chemical reaction that takes place when in contact with atmospheric oxygen resulting in a very thin but also very resistant oxide layer being formed. (oxide barrier). When metals are connected to those with a higher electrical potential such as copper in the presences of an electrolyte (condensed water) will result in an electrochemical reaction taking place. During this process the differences caused in electrochemical potential can have a significant impact.

Connection has its needs in batteries and electrical transformation. The unique combination of light weight and relatively high strength makes aluminum the second most popular metal that is welded.Application of Copper and Aluminum joint includes cable lugs, electromagnetic coils, medical devices, batteries and jointing clamp wire terminals, PCBs, CRTs, transformer plates and accumulator plates Aluminum is not difficult to join but aluminum welding is different from welding copper.

Major objective of this study is to

- Current welding processes for Al-Cu weld joint and issues
- Compatibility between copper and Aluminum
- Evaluate Laser welding parameters for optimum joint efficiency between dissimilar metals Copper and Aluminium
- Using factorial design approach statistical design of experiment (DOE) technique for optimizing the selected welding parameters in terms of maximizing tensile strength using statistical software Minitab.

Further aluminum and Copper weld will be evaluated for its strength with laser welding. It will be followed by microstructural analysis of joint for further study and conclusion on efficiency of welding.

II. LITERATURE REVIEW

Mohammad M. Hailat • AhsanMian et al [1]

In this paper continuous laser welding of two dissimilar materials, aluminum and copper, was investigated.

The aluminum and the copper utilized were Al3003-H14 and Cu110-H00, respectively. Two different sets of samples were laser welded; one in which a filler material, tin foil alloy (S-bond 220), was sandwiched between the aluminum and the copper and another set in which the aluminum and copper were directly welded without any filler. The foil alloy was utilized to enhance the compatibility of the two metals; aluminum and copper, reducing the brittleness of the intermetallic compound that may form and, subsequently, enhance the mechanical properties. The welding was carried out using an IPG 500 SM fiber laser. The length of the laser joint produced was 20 mm and the width was about 200 lm. The strength of the joint was evaluated by conducting the lap shear stress test. Samples in which filler foil was used exhibited a better performance in the lap shear stress test (an average of 780 N) than the samples without tin foil (an average of 650 N). The improvement in the lap shear test could be attributed to the positive effects of the filler on enhancing the compatibility of the intermetallic compound

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formed via diffusion. The fracture surface of both types of joints (with and without filler) was characterized using scanning electron microscope equipped with energy-dispersive X-ray (EDAX). To understand the failure initiation and propagation of the samples under tension, a finite element (FE) model was developed for the samples created with no filler material. The failure mechanism predicted from the FE model matches reasonably well with the experimental observations from EDAX analysis.

T.A. Mai, A.C. Spowage et al [2]

This paper presents the results of an investigation into laser welding of dissimilar metals without filler materials using a 350W pulsed Nd:YAG laser. The mixing behavior of the materials in the fusion zone, the microstructure, the presence of defects, hardness and residual stress of the joints were all investigated. oxygen-free copper and aluminium 4047 were used. Aluminium 4047 is an Al–Si alloy with low crack sensitivity due to its narrow solidification temperature range (565–575 ◦C). Two etchants were developed to reveal the microstructureof the welds. Examination of the porosity showed clear trends associated with welding speed. From the phase diagram, the maximum solid solubility of copper in aluminium is 5.65 wt.% Cu. At lower temperatures, theamount of copper that can remain in the aluminium solid solution, decreases drastically. The weldability of copper to aluminum is regarded as relatively good. The Cu–Al phase diagram shows a wide range of Cu–Al phases that may be formed. In addition, non-equilibrium cooling conditions are known to promote the formation of a cascade of metastable phases. Under optimum
processing parameters, crack-free welds of copper and Al 4047 were obtained. Attempts to weld copper with
aluminium alloy 6061, a heat-treated Al–Mg–Si–Cu alloy with high mechanical strength, were not successful due to
its poor weldability and high crack susceptibility. Solidification cracks were observed at the centre of copper–aluminium 4047 joints at welding speeds greater than 100 mm/min. However, sound welds with aluminium 4047 were obtained at lower welding speeds.
It has been shown, that controlling the melting ratio of metals is an important factor for defect-free welding of
Sound welds of three different materials combinations were produced by laser welding with a pulsed Nd:YAG
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Tadamalle, A.P. et al [3]

This paper aimed at to examine the influence of welding speed and power on weld bead geometry and performance parameters such as duty cycle, pulse overlap, energy density and bead diameter. The solidification time in this
process is very less as compared to that of conventional welding process. The mode of welding process is governed by the process parameters like laser energy, pulse duration, pulse frequency, power and welding speed.
In this contest, first experiment is conducted on austenitic
304L stainless steel sheet by varying the welding speed
from 2 mm/s to10 mm/s and second experiment is conducted varying laser power from 300 W to 3500 W. It was found from the experimental and analytical approach welding speed and laser power significantly affects on weld
bead geometry, variation in bead diameter from pulse to pulse, duty cycle and effective pulse energy.
Weld bead geometry, effective pulse energy, energy density, duty cycle, percentage of overlap and pulse off time have been analyzed. The bead width, depth of penetration decreases as the welding speed increases, depth of penetration is more sensitive to the welding speed than bead width over range of speed selected for the study. The weld bead dimensions are more sensitive to the peak power input up to 1700 W and less sensitive beyond 1700 W. Laser welding machine can't be loaded beyond 98.38 % of duty cycle. Further this work can be extended to study the effect of shielding gas, pulse duration and focal position on duty cycle, weld bead geometry and process efficiencies.

Hang Rae Kim et al [4]

This paper presents a systematic approach to determine optimal process parameters associated with Hybrid welding using Taguchi Method. Plate of aluminium alloy (AA502-H32) of square grove is considered for welding butt joint. In order to compare weld ability of each experimental group, ultimate tensile strength (UTS) is chosen. Welding experiment is repeated three times uner same conditions. Even though process was carried out identically, result of strength test could be different due to correlation of each parameter and environmental factor. Strength data were used to compute performance characteristics of parametric combination for welding through calculation of signal to noise ratio. Through S/N ratio, a set of optimum welding parameters is ordained. Finally, using analysis of variance predominant process parameters for hybrid welding are numerically investigated. Welding parameters selected from structural welding codes of American welding society and manuals of laser and gas metal arc welding systems are Welding direction, laser power, laser focus, voltage, welding wire feed rate, root opening tolerance and traveling speed. The work was supported by Gant No. 10024116-2007-13 from Korea institute of Industrial technoliogy Evaluation and Planning.

K. Kalaiselvan, A. Elango, N. M. Nagarajan el at [5]

The present study is to reviews the influence of different parameters like laser power, welding speed, power density, beam diameter, focusing distance and type of shielding gas on the mechanical properties of dissimilar metal combinations like SS/Al, Cu/Al and Ti/Al focusing on aluminum to other materials. Discussion has been documented about the effect of different parameters on LBW. They are, Laser Power, P(KW), LBW Welding Speed, V (mm/min), LBW Power Density (W/cm2), Beam Diameter, LBW Focal Distance, f (mm), LBW Shielding Gas Flow, V (l/min). Furthermore, this paper review showed that there is a significant progress in laser welding of dissimilar materials. Most of the cited research studies are focused on understanding the parameters of various welds. There were large differences in melting point between the sheets of Ti and Al welding. There was a region within the lower melting point sheet which had melted but not mixed with the main weld pool. Compare to SS/Al and Cu/Al, Ti/Al gives sound weldment in Aluminium rich region. Future scope includes LBW technology needs to be developed for meeting industrial needs. Full understanding of the dissimilar welding process using LBW is needed to accommodate huge demand in the industries including manufacturing and the aerospace. LBW results in high quality welds. The identification of specific intermetallic phases of dissimilar sheet metals are in scope for future study.

III. MATERIAL PROPERTIES AND COMPATIBILITY

a. Material Properties

Materials used are Aluminum 6061T651**.** Each plate of aluminum is 70 mm ling x 70 mm wide x 2 mm thick.Chemical composition for each plate is as follows-Al,95.8-98.6%; Cr. 0.04-0.35; Cu 0.15-04; Si, 0.4-08; Fe, Max 0.7; Zn, 0.25 max, Mg, 0.8-1.2. Mechnical properties of same are as- Density: 2.7 g/cm^3; Melting Point: Approx 580°C; Modulus of Elasticity: 70-80 GPa; Poissons Ratio: 0.33; Electrical Resistivity: 3.7 – 4.0 x10^{-6} Ω.cm; Co-Efficient of Thermal Expansion (20-100°C): 23.5x10^{-6} m/m.°C; Thermal Conductivity: 173 W/m.K. Ultimate Tensile Strength (MPa), 260-310; 0.2%Proof Stress (MPa), 240-276 ;Brinell Hardness (500kg load, 10mm ball); Elongation 50mm dia (%), 95-97.

Similarly Material composition for Copper grade UNS C10100 is Cu, 99.99%; Ph,0.0003Max; Trellurium, 0.001max. Each plate of Copper is 70 mm ling x 70 mm wide x 2 mm thick.Copper specific grade selected for the purpose lower phosphorous content helps reduces oxidation of metal. Mechanical properties of selected grade isDensity (lb / cu. in.)0.32; 3Electrical Resistivity (microhm-cm (at 68 Deg F))

10.3; Melting Point (Deg F),198;Thermal Conductivity, 226 ; Mean Coeff Thermal Expansion, 9.4; Modulus of Elasticity Tension 17000.

b. Compatibility of aluminum with copper

Both Aluminum and Copper will oxidize when exposed to the atmosphere. Aluminum and copper conductors are typically plated with silver or tin. The Density of aluminum is about one third of that of copper for equal conductance the weight of the aluminum conductor material is almost halved.

Moisture is a source of hydrogen which is the cause of porosity in aluminum welds. With a rapid cooling rate free hydrogen is retained within the weld and will cause porosity. Porosity will decrease weld strength and ductility depending on the amount.The aluminum oxide film must be removed prior to welding. If it is not all removed small particles of un-melted oxide will be entrapped in the weld pool and will cause a reduction in ductility, lack of fusion, and may cause weld cracking.

Copper has a relatively high coefficient of thermal expansion, approximately 50% higher than carbon steel, but lower than aluminum. One of the problems associated with copper alloys is the fact that some of them, such as aluminum bronze, have a coefficient of expansion over 50% greater than that of copper.Some of the copper alloys are hot short. This means that they become brittle at high temperatures. This is because some of the alloying elements form oxides and other compounds at the grain boundaries, embrittling the material.There is one other problem associated with the copper alloys that contain zinc. Zinc has a relatively low boiling temperature, and under the heat of an arc will tend to vaporize and escape from the weld. For this reason the arc processes are not recommended for the alloys containing zinc.

The primary difficulties with copper are the high reflectivity to the incident laser beam and the high thermal conductivity of copper and copper alloys. Copper reflects approximately 99 percent of the incident light energy the fast infrared wavelength of the CO2 laser. This is the reason copper is commonly used for mirrors in co3 laser beams deliver system. Reflectivity id temperature dependent; when then material gets hotter, the absorption of the incident light increases. However, the high thermal conductivity of copper prevents the metal from getting hotter, thereby maintaining high reflectivity.

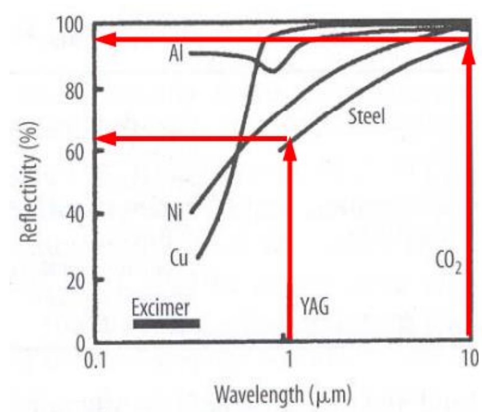


Fig.1Aluminum and Copper Reflectivity

Laser with hotter wavelength have successfully welded some copper alloys. Copper has slightly higher absorption of the incident light of Nd: YAG lasers with a wavelength of 1.06 Um. Plating copper with a thin layer of higher absorbing metal such as nickel.Has been demonstrated to improve coupling efficiency.

Generally, nickel alloys and titanium are highly weldable, with aluminum alloys and copper being case specific. The plating material and method of plating can also have a significant effect on the welding process. For example, electro-less nickel plating creates welding problems due to the inclusion of phosphor and other contaminants during the plating process. The recommended plating method is electrolytic. The thickness and type of plating is also a consideration such as coating thickness above 50 micro-inches may induce weld cracking.

IV. Current welding processes for Al-Cu and disadvantages

a. Soldering and Brazing:

When copper is brazed to aluminum and the heating process takes too long, the copper will diffuse into the aluminum at the joints. A low melting Al-Cu alloy (Al-Cu33 eutectic temperature 548°C) is thus formatted, and this could lead to erosion by perforation.

Therefore, during the brazing process, the flame should never be directly applied to the joint, because the heat should be transferred by conduction through the parts to be brazed. As soon as the filler metal begins to melt, the flame must be quickly removed.

A second issue with brazing copper to aluminum is that the aluminum has a much lower melting point than copper (Al: app. 650°C; and Cu: above 1000°C). Therefore, the flame is usually directed on the copper. Nevertheless, once the heat transferred from the copper to the aluminum reaches the melting range of aluminum, it will start to burn down very fast, while the copper is still taking the heat. The formation of the above mentioned low melting Al-Cu alloy accelerates the destruction of the aluminum components.

There are no conventional furnace designs which will cool quickly enough to halt the continual formation of the aluminum-copper eutectic. For this reason, brazing copper to aluminum in a furnace is not practiced.

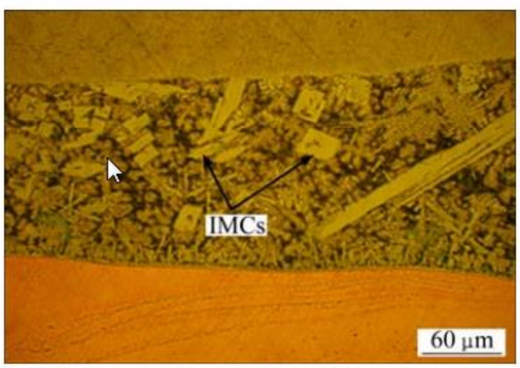


Fig.2 SEM image of brazing seam zone in Cu/Al Joined

XIA et al [8, 9] attempted to join Cu with Al using vacuum brazing with a eutectic Al−Si filler metal, but this technique cannot produce a Cu/Al joint with desired property.

Micrographs of the Cu/Al samples as shown in fig above at the brazing seam zone display four layers between Cu and Al, namely, the transition region on the Al side, the middle brazing seam region, the IMC layer and the intermediate layer of saturated solid solution on the Cu side. The morphology and distribution regularities of the brazing seam microstructure severely affect the shear strength of the Cu/Al brazing joint.

Moreover, the increased micro hardness of the joint is large due to the formation of the Al2Cu IMC particles. However, these IMC particles are hard, brittle and can easily become the stress concentration areas in the brazing process when they appear in bulk shape which may become the source of crack initiation and expansion.

b. Tungsten Inert Gas Welding

TIG welding uses non consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by inert shielding gas.

We should generally always TIG-weld aluminum with alternating current (AC). Welding with direct current (DC) will make it difficult to eliminate the aluminum oxide layer. This oxide layer can mix with the filler metal, contributing to contamination.

Disadvantages:

- The dissimilar metal welds of aluminium and Copper using TIG shows number of limitations in reliability and strength of joint
- A low solid solubility and difference in thermal physical properties of aluminium and Copper forms the brittle intermetallic compound which affects the mechanical behaviour of weld.
- The microstructures of HAZ of aluminium appears to be coarser then the base metal.
- The strength of joint is found in a range of 500 to 800 N; however it is about 1100- 1200 in the base metal for joint of 1mm Copper sheet and 0.8mm aluminium sheet
- Very brittle intermetallic compounds are formed when metals such as steel, copper, magnesium or titanium are directly arc welded to aluminium

Figure below presents the transition zone of the joint studied by Park et al. (2009). Its width is 20

to 25 µm (average micro-hardness value 82 H). X-ray microanalysis indicated the presence in this zone of a hypereutectic alloy (in atomic fractions) of 9.3% Cu and 89.8% Al. Based on the results from the study by Park et al. (2009) on the effect of the control of heat input by advanced welding process on the size of IMCs, it may be possible to significantly reduce the thickness of the IMC of the Cu-Al welded joint. In addition, the use of buttering or an AlSi12 filler between the Cu and Al could also contribute to increased dissimilar weld ductility (Weigl et al. 2011). The occurrence of the intermetallic phase cannot be avoided; however, the use of advanced technology can reduce the interface layer thickness.

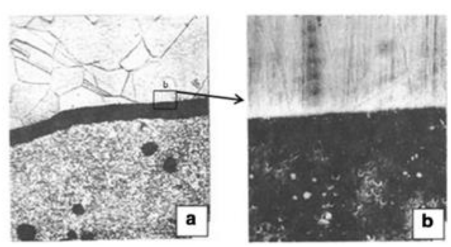


Fig.3 Microstructure of Cu and Al fusion dissimilar weld (a) Fusion butt weld (b) High magnification zone

c. Gas Metal Arc Welding

Aluminum is an active metal which reacts with oxygen in the air to produce a hard, thin film of aluminum oxide on the surface. The melting point of aluminum oxide is approximately 3600ºF (1982ºC) which is almost three times the melting point of pure aluminum (1220ºF (660ºC)). In addition, this aluminum oxide film absorbs moisture from the air, particularly as it becomes thicker. Moisture is a source of hydrogen, which causes porosity in aluminum welds. Hydrogen may also come from oil, paint, and dirt in the weld area. It also comes from the oxide and foreign materials on the electrode or filler wire, as well as from the base metal. Hydrogen will enter the weld pool and is soluble in molten aluminum. As the aluminum solidifies, it will retain much less hydrogen. The hydrogen is rejected during solidification. With a rapid cooling rate, free hydrogen is retained within the weld and will cause porosity. Porosity will decrease weld strength and ductility, depending on the amount.

Hot cracking or solidification cracking is a primary cause for aluminum cracks.As we are all aware aluminum is much weaker than steel and has a much lower weld solidification temperature. These cracks typically occur due to thermal expansion and contraction. The resulting stresses may tear the weld apart.

d. Friction Stir welding

The material is heated by friction between the rotating shoulder and the work piece surface and simultaneously stirred by the profiled pin leaving a solid phase bond between the two pieces to be joined. Special preparations of the weld seam and filler wires are not required.

Disadvantage;

- A longer friction time caused the excess formation of an intermetallic layer. However, some of the welds showed poor strength depending on some accumulation of alloying elements at the interface, which are the result of a temperature rise and the existence of intermetallic layers such as FeAl

- Although tensile strength for copper and aluminium joints were generally acceptable when compared with those of the base metals, some of the welds showed poor strength as a result of the accumulation of alloying elements at the interface. This was the result of temperature Mechanical and Metallurgical Properties of Friction Welded Aluminium Joints rise and the existence of a grey layer. This grey layer formed due to heat dissipation in friction welding and was found to contain a considerable amount of intermetallic compounds

- The presence of contaminants at the interface of the metals reduces the joint quality. No significant effect was observed on welding properties with respect to the surface finish operations.

Fig. shows EDS analysis points defined on the SEM microstructure in interface region. Table 5 illustrates the EDS analysis results taken from the points 1, 2, 3, 4 and 5, respectively represented by SEM. The EDS results confirm that Cu-Al joints contain some intermetallic compounds. Formation of these brittle intermetallic compounds degrades the strength of the joints.

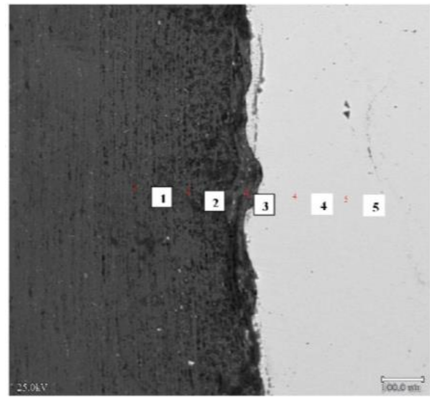


Fig.4 SEM Microstructure of interface region in the friction welded Cu-Al joint

V. ADVANTAGES OF LASER WELDING COPPER AND ALUMINUM

Laser welding is a fusion process performed under inert cover gas, where filler material is most times not added. Like electron beam welding, Laser welding is a high energy density beam process, where energy is targeted directly on the workpiece. Laser differs from both GTAW and EB (electron beam) welding in that it does not require that the workpiece complete an electrical circuit. And since electron beam welding must be performed inside a vacuum chamber, laser welding can almost always offer a cost advantage over EB in both tooling and production pricing. Below are some specific advantages of laser welding copper and aluminum joint.

- Precise control of the laser beam offers users several benefits over TIG, MIG and spot welding
- Weld strength: The laser weld is narrow with an excellent depth-to-width ratio and higher strength.
- Heat affected zone: The heat affected zone is limited, and due to rapid cooling, the surrounding material is not annealed.
- Metals: Lasers successfully weld carbon steel, high strength steel, stainless steel, titanium, aluminium, and precious metals as well as dissimilar materials.
- Deformation: Parts have minimal deformity or shrink.
- No weld Defects, welds are super finished with no weld protrusions
- LBW Can weld material below 2 mm

VI. Selection of Laser welding Parameters

For continuous wave lasers below are the parameters-

- Laser power.
- Welding speed (seam and stitch welds).
- Position of the focal plane of the beam with respect to the surface of the work piece.
- Beam size and shape on the work piece.
- Power density (power/beam size).
- Wavelength of the laser beam.
- Beam divergence (focal length of the focusing lens).
- Intensity distribution of the beam.

In This study Nd:YAG diode pumped laser (Maximum power, 4.4kW) is used specifically for copper and aluminum. We have selected laser power, welding speed and position of focal plane of the beam with respect to the surface of work piece as main parameters based on capability of laser welding machine.

Output of the experiment is measured in the terms of weld penetration, tensile strength of the joint to evaluate the laser welding experiments.

VII. Experimental design

In this study Nd:YAG diode pumped laser (Maximum power, 4.4kW) is used. The experiment was designed based on a three level Full factorial design Laser power (1.2 - 1.43 kW), welding speed (30 - 70 cm/min) and focal point position (-2.5 - 0 mm) being the laser independent input variables. Table 1 shows laser input variables and experimental design levels used. RSM was applied to the experimental data using statistical software, Minitab-16. We have considered full factorial design of experiments to generate regression equation for further study and conclusion from experiment.

	Aluminum		Copper	
	Min	Max	Min	Max
Power (Kw)	2	3	3	4
Speed (mm/min)	540	660	720	900

Table 1: Laser parameters and variables

The two inputs (factors) that are considered important to the operation are Power (X_1), Speed (X_2),. We want to ascertain the relative importance of each of these factors on Yield ultimate tensile strength (Y).power, Speed and Position can all be varied continuously along their respective scales, from a low to a high setting. Yield is observed to vary smoothly when progressive changes are made to the inputs. This leads us to believe that the ultimate response surface for Y will be smooth.

We want to try various combinations of these settings so as to establish the best way to run the polisher. There are eight different ways of combining high and low settings of Speed, Feed, and Depth. These eight are shown at the corners of the following diagram.

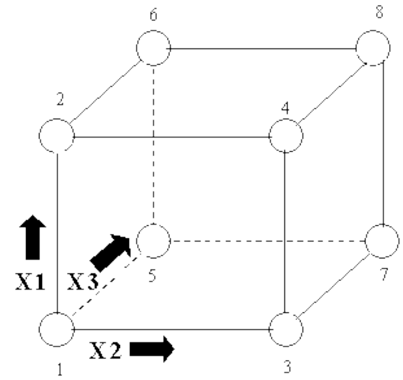


Figure 5 2^3 Two-level, Full Factorial Design; Factors X1, X2, X3. (The arrows show the direction of increase of the factors.)

Note that if we have *k* factors, each run at two levels, there will be 2^k different combinations of the levels. In the present case, $k = 4$ and $3^3 = 32$.

Standard order: he numbering of the corners of the box in the last figure refers to a standard way of writing down the settings of an experiment called `standard order'.

Replication: Running the entire design more than once makes for easier data analysis because, for each run (i.e., `corner of the design box') we obtain an average value of the response as well as some idea about the dispersion (variability, consistency) of the response at that setting.

Here's the design matrix again with the rows randomized. Below is the experiments setup with the 3K factorial design.

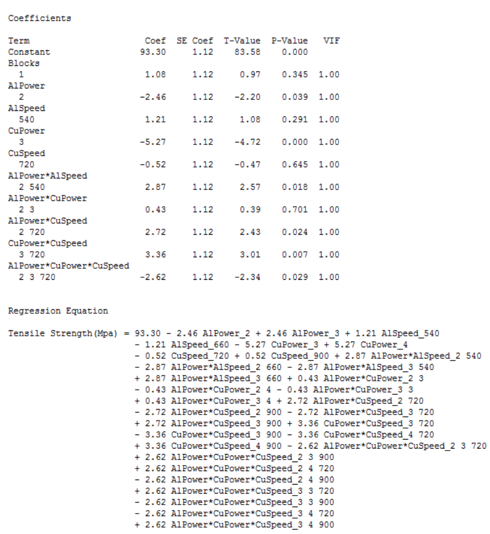
The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a lower S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the lowest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) will be performed for each response individually to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted.

AlSpeed	CuPower	CuSpeed	Tensile Strength(Mpa)
540	4	720	110
660	3	720	101
660	4	720	85
540	4	900	93
660	4	900	95
540	3	720	98
540	3	900	84
540	4	900	108
540	4	720	96
660	4	900	116.5

540	3	900	85
540	3	720	92
660	3	900	90
660	4	720	88
660	3	900	82.2
660	3	720	86.4
540	3	720	85.1
660	3	900	81.5
540	3	900	83.6
660	4	900	114
540	4	900	110.3
540	3	900	86.5
540	3	720	90
660	4	720	94
660	4	720	98
660	3	900	88.8
540	4	720	95.5

Table 2: DOE- designed Experiments

VIII. RESULTS



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Coefficients

Term                        Coef  SE Coef  T-Value  P-Value   VIF
Constant                   93.30     1.12    83.58    0.000
Blocks
  1                         1.08     1.12     0.97    0.345  1.00
AlPower
  2                        -2.46     1.12    -2.20    0.039  1.00
AlSpeed
  540                       1.21     1.12     1.08    0.291  1.00
CuPower
  3                        -5.27     1.12    -4.72    0.000  1.00
CuSpeed
  720                      -0.52     1.12    -0.47    0.645  1.00
AlPower*AlSpeed
  2 540                     2.87     1.12     2.57    0.018  1.00
AlPower*CuPower
  2 3                       0.43     1.12     0.39    0.701  1.00
AlPower*CuSpeed
  2 720                     2.72     1.12     2.43    0.024  1.00
CuPower*CuSpeed
  3 720                     3.36     1.12     3.01    0.007  1.00
AlPower*CuPower*CuSpeed
  2 3 720                  -2.62     1.12    -2.34    0.029  1.00


Regression Equation

Tensile Strength(Mpa) = 93.30 - 2.46 AlPower_2 + 2.46 AlPower_3 + 1.21 AlSpeed_540
                        - 1.21 AlSpeed_660 - 5.27 CuPower_3 + 5.27 CuPower_4
                        - 0.52 CuSpeed_720 + 0.52 CuSpeed_900 + 2.87 AlPower*AlSpeed_2 540
                        - 2.87 AlPower*AlSpeed_2 660 - 2.87 AlPower*AlSpeed_3 540
                        + 2.87 AlPower*AlSpeed_3 660 + 0.43 AlPower*CuPower_2 3
                        - 0.43 AlPower*CuPower_2 4 - 0.43 AlPower*CuPower_3 3
                        + 0.43 AlPower*CuPower_3 4 + 2.72 AlPower*CuSpeed_2 720
                        - 2.72 AlPower*CuSpeed_2 900 - 2.72 AlPower*CuSpeed_3 720
                        + 2.72 AlPower*CuSpeed_3 900 + 3.36 CuPower*CuSpeed_3 720
                        - 3.36 CuPower*CuSpeed_3 900 - 3.36 CuPower*CuSpeed_4 720
                        + 3.36 CuPower*CuSpeed_4 900 - 2.62 AlPower*CuPower*CuSpeed_2 3 720
                        + 2.62 AlPower*CuPower*CuSpeed_2 3 900
                        + 2.62 AlPower*CuPower*CuSpeed_2 4 720
                        - 2.62 AlPower*CuPower*CuSpeed_2 4 900
                        + 2.62 AlPower*CuPower*CuSpeed_3 3 720
                        - 2.62 AlPower*CuPower*CuSpeed_3 3 900
                        - 2.62 AlPower*CuPower*CuSpeed_3 4 720
                        + 2.62 AlPower*CuPower*CuSpeed_3 4 900
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Fig.8.1: Regression Analysis using MINITAB

Interactions between parameters are identified and parameters with higher P values are neglected and Factorial design is analyzed again with reduced parameters.

- Regression Analysis Shows CuPower is significant factor contributing to strength of joint
- T-value shows: Size of difference relative to variation in data
- Cu Power and CuSpeed also emerged as Significant parameter
- Regression equation identified for further analysis

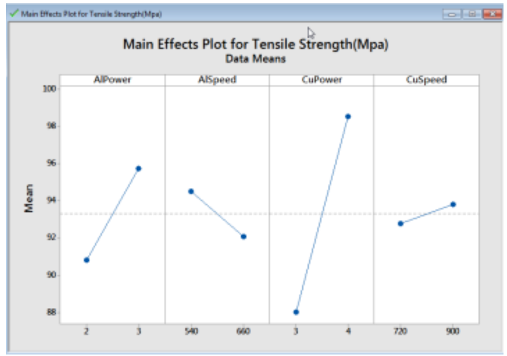

Fig.8.2: Main Effect interaction

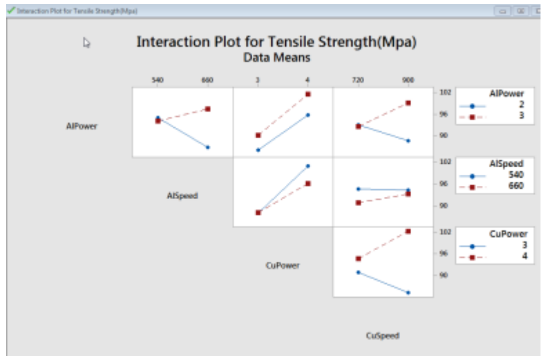

Fig.8.3: Interaction effect plots

- Normal Probability plot shows, Data is normal and can be used for further analysis
- Main Effect plot shows, Cu Power has significant effect on tensile strength

IX. CONCLUSION

- In this review of Optimizing Laser welding parameters for Copper and Aluminium joint, detailed Initial study has been completed for current issues with welding aluminium and copper by TIG, MIG, Brazing and Friction stir welding process.
- Regression equation is identified for further optimisation of process parameters
- Silicon percentage contentin Aluminum plays Major role in welding Copper and Aluminum
- Static and Dynamic laser welding parameters are identified which affects the weld quality.
- Output parameters as tensile strength of joint is identified for this study
- CuPower and Cuspeed is identified as significant parameter for achieving higher tensile strength
- Optimized parameter are:

	Al	Cu
Speed (mm/Min)	660	900
Power (Kw)	3	4

X. FURTHER SCOPE

- Conduct Microstructural analysis to understand intermetallic formation and reason for reduced tensile strength of joint
- Understand Effect of Filler material on Conductivity of material
- Efforts needs to be made to achieve higher Tensile strength for Aluminium and copper joint by laser welding
- Conclusion and results

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