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Intermetallic Formation in Friction Welded Aluminum Tocopper with Nickel Interlayer

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Abstract:*In this paper, aluminum has been friction welded with copper.Aluminumhas also been friction welded with a nickel interlayer in between. Hardness tests and 3 point bend tests were conducted on the weld zone using different friction welding parameters.It was found that intermetallic phases were formed in the weld zone,but were reduced when welding was done using nickel interlayer. Electron-dispersive spectroscopy confirmed the findings.These phases made the weld brittle. Intermetallicare undesirable hard phases that are formed during welding. Scanning electron microscope (SEM) results show a pale – silver layer of aluminum on broken specimen of copper.*

Keywords: *Friction Welding, Nickel Interlayer, Bend Test, SEM-EDS*

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I. Introduction

Friction welding is a well-established solid state welding technique to weld Dissimilar metals. Earlier friction welding was being done without an Interlayer. however; It was Found by Researchers that the presence of 1 or 2 Interlayer's between the 2 metals to be welded substantially improved some mechanical properties. Mostof the literature in Joining of Aluminiumto copper pertains to electronic and electrical Applications. Copper wires arereplacing gold wires in bonded structures in microelectronics.So,it is of interest to find the umber and properties of the intermetallics formed at the Aluminium- copper interface. In a research work Conducted By C.J.HangEt al Three IMC layers were clearly found at the Cu/Al.

Interfaces by their different colors using optical microscopy.The results of micro-XRD analysis confirmed that Cu_9Al_4, and $CuAl_2$ were the main IMC products, while a third phase could have biannual[1].one of the earliest studies on aluminium copper joints was done by braunović and alexandrain 1994.they showed that high micro hardness in the weld zone resulted in brittleness. This lead to low strength and a cleavage type of fracture as seen in SEM[2].a similar finding has been reported for brazing of an aluminium and copper joint containing an Al_2Cu phase. Comparisonof processes and parameters for welding of Al 1060 with pure Cu reveal that the formation of the intermetallic compounds and their effects on the weld properties are mainly influenced by the welding speed, heat input, the thermal properties of the base metals and the filler metal as well as the dilution between the base metal and filler metal [3].Ochi et al have studied friction welding of copper with various metals like stainless steel, nickel and titanium. Good, stable joints were obtained with nickel. This could be due to the fact that copper forms an isomorphous alloy with nickel and there is absolutely no chance of intermetallic formation at any temperature [4].

This finding further corroborates our choice of nickel as an Interlayer between aluminiumand Copper. The hardness characteristics created by the Al_2Cu Intermetallic compounds result in increased brittleness in the weld metal, which can act as a stress raiser leading to the Initiation of cracks. According to another recent work by Khodiret al. A variety of Intermetallic phases form during friction stir welding ofAluminiumto Copper. Many sharp hardness peaks were observed in the weld zone and a maximum hardness of 420 Hvhas been reported [5].

However, the fractured surface was fairly ductile and did not show any effect of brittle intermetallic. Friction stir spot welding studies have been carried out on aluminium copper composite with 2 types of tools- cylindrical and triangular. Higher hardness was found when triangular tool was used and higher temperature was found under the same processing conditions using cylindrical tool [6].It has to be mentioned that intermetallic play a dual role in aluminium-copper system. It is not always that intermetallic are detrimental to the mechanical properties. While, generally it is accepted that intermetallics are brittle and they affect mechanical properties adversely, researchers have reported some positive effects of intermetallics also. They may act as reinforcements to the composite structure enhancing strength [7]. Defect free bonding and improved strength due to thin intermetallic layer in friction stir welding of of AA1050 has also been reported. [8]

II. Methodology

In this work Aluminium and copper both of commercially pure grades were used.Aluminium and copper were welded using friction welding.Aluminium was also welded using nickel as interlayer figure 1 shows the friction welding machine used in this work. Thetest reference that has been used for the chemical analysis of this specimen is ASTM1251. Tables 1 and 2 are shown below, which indicates the the chemical analysis of aluminum and copper used in this work. Thediameter of work pieces used in the work was 19 mm for both aluminum and copper.

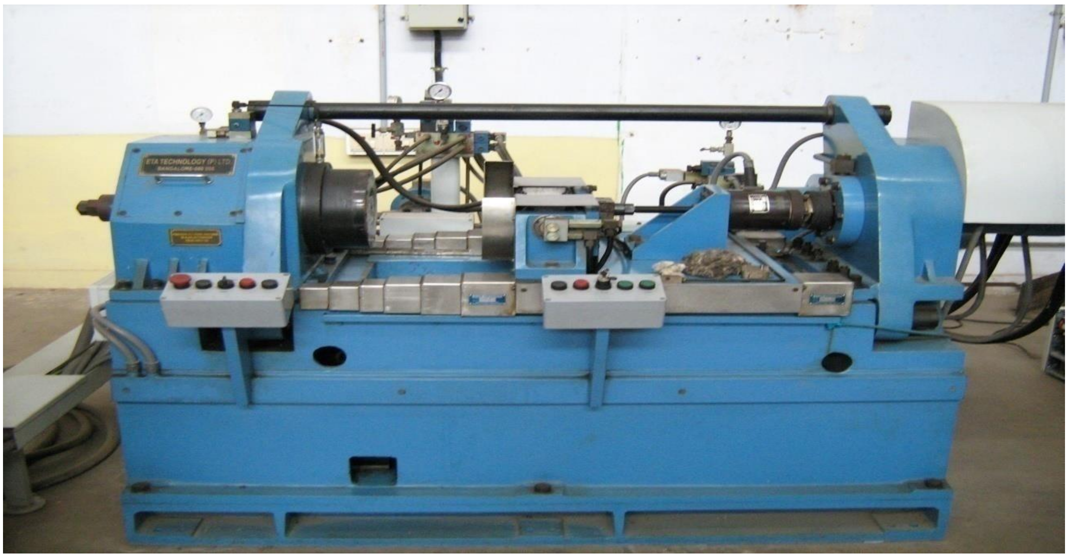

Fig.1: Friction Welding Machine

Table 1: Chemical Composition of Aluminium Specimen

Elements	Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
%	97.961	0.596	0.424	0.092	0.094	0.567	0.033	0.009	0.021

Friction welding was performed on the dissimilar metals, copper and aluminium to enable Mechanical bonding. An ETA welding machine was used to weld the work pieces. The work piece was turned to a Diameter of 19mm and an average length of 75mm. A total of 18 Pieces Were Prepared since It was planned to perform the experiment using an L9 Array. Theprocess parameter such as friction-pressure, upset-pressure, Burn-off length, Speed combination As shown in Table 3 with Three levels. The table 4 presents the optimal parameters.

Table 3: Parameters and Levels

Parameters	Level 1	Level 2	Level 3
Friction Pressure (Tons)	2	2.5	3
Upset Pressure (Tons)	4	5	6
Burn Off Length (mm)	1	2	3
Speed (rpm)	500	750	1000

Table 4: Optimum Parameters

S.No	Fp(Tonnes)	Up(Tonnes)	BOL(mm)	Speed (rpm)
1.	2	4	1	500
2.	2	5	2	750
3.	2	6	3	1000
4.	2.5	4	2	1000

5.	2.5	5	3	500
6.	2.5	6	1	750
7.	3	4	3	750
8.	3	5	2	1000
9.	3	6	1	500

2.1 Bend Test

Bend tests were carried out as per astm-e190-92 standard. Each of these sections was subjected to guided three point bend test. The dimensions of the specimen and schematic of bend test are shown in figures 2 and 3 respectively. 8 aluminum-copper specimens corresponding to friction welding conditions shown in table 4 was tested.

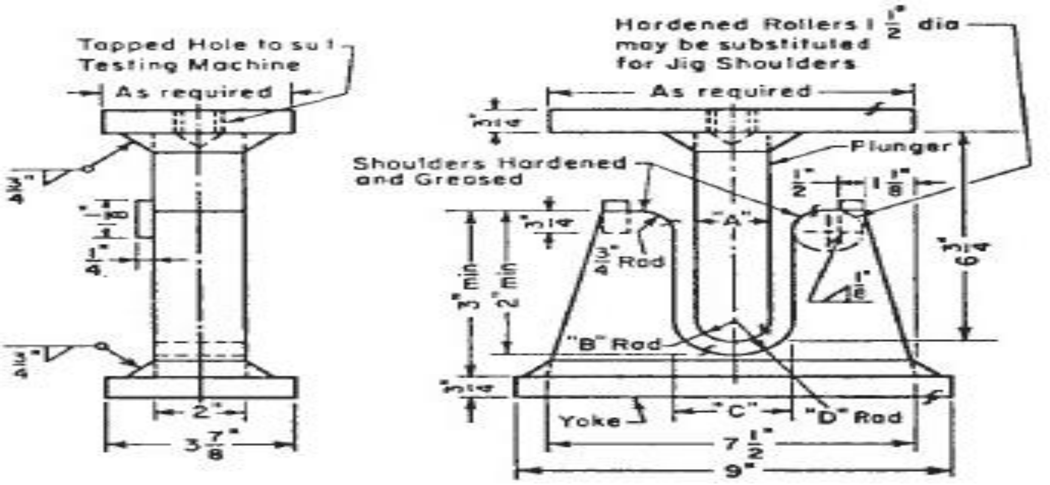

Fig.2: Point Bend Test Jig Dimensions

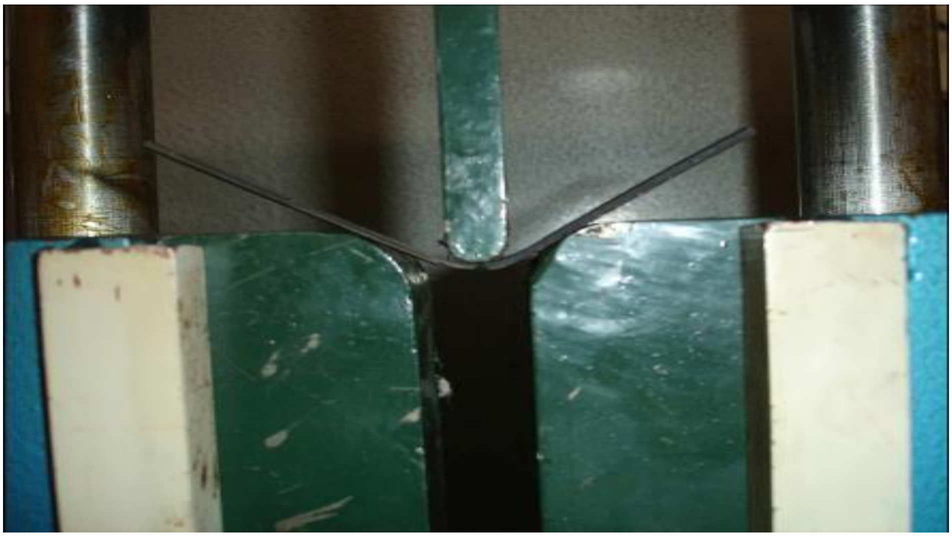

Fig.3: Bend Test Experimental Set-Up

2.2 SEM-EDS Studies

SEM was taken both for aluminum friction welded to copper and with nickel interlayer. Purpose of SEM was to analyze the fracture and also to see if the fractured surface was in any way modified withthe addition of nickel interlayer. Sem-edax studies were also done in order to study the diffusion on aluminum into copper and vice versa. Again SEM-EDAXas repeated with nickel interlayer in order to see if diffusion of metals into each other was reduced in the presence of nickel interlayer. Literature has shown that presence of interlayer does affect mutual diffusion of elements.

III. Results& Discussions

3.1 Hardness Test Results With and Without Interlayer

Hardness was first taken without interlayer. The table 5 shows the hardness values for different parameters.

Table 5:hardness values of different parameters

Sample	F.P	U.P	B.O.L	RPM	Copper HAZ	Aluminium HAZ	Weld Zone
1	2.0	4	1	500	95.367	86.967	101.234
2	2.0	5	2	750	93.934	78.334	102.967
3	2.0	6	3	1000	91.167	83.267	78.034
4	2.5	4	2	1000	89.634	98.634	125.600
5	2.5	5	3	500	93.500	87.167	76.034
6	2.5	6	1	750	92.900	91.900	79.334
7	3.0	4	3	750	93.367	87.667	102.634
8	3.0	5	1	1000	90.434	101.900	75.367
9	3.0	6	2	500	88.734	94.600	86.100

Generally, it is seen that hardness in the weld zone is higher than hardness in the heat affected zone of aluminum as well as copper. This could be due to recrystallization of grains in the weld zone.The actual value of hardness at the interface depends upon the combination of all friction welding parameters.Hardness values on both the HAZ sides are lower by around 5-10 hv.this could possibly be due to the presence of the nickel interlayer which inhibits formation of brittle intermetallic in the HAZ region. Further proof of reduction in intermetallic formation is obtained from results of bend test.

3.2 bend test results with and without interlayer

The table shown below gives the results of bend test done on Aluminium-copper without interlayer. It is seen that the bend angle is very small and almost < 1 degree for most of the parameters chosen.This clearly indicates the presence of intermetallic phases.Further information about intermetallic phases was also obtained from EDSstudies, which are presented in figures 4 and 5. 3 point bend test on SS347H(18cr 10ni 1cb) and T22 (2¼Cr Mo) welded with T91 (9Cr1Mo v) have been performed by Arunkumar et al [9]. Bend angle of the order of 180 degrees were obtained in both cases, where welding was performed using GTAW. In stainless steel welding, possibility of intermetallic formation is less and hence such large bend angles have been reported. But in the case of Aluminium-copper dissimilar welds, Ananthapadmanabanhas reported bend angles of the order of ½ to 1 degrees [10]. Similar values of bend angles have been obtained in this work also as seen in table 3. Bend tests on Aluminium with pure copper (OHFC) performed by Bhamji et al [11] yielded bend angles ranging from 20 degrees to 80 degrees depending on the parameters used. In this case, better choice of pure material and judicious combinations of friction welding parameters must have reduced the presence of intermetallics to a large extent and hence the higher values of bend angle.

Table 6: Bend Angle values with and without bend Test

S.No.	Bend angle (with interlayer)	Bend Angle (without interlayer)
1	1	9
2	< 1	11
3	< 1	12
4	1	14
5	2	14
6	1	16
7	<2	16
8	<1	15

There is considerable improvement in the bend angle for all parameters chosen. This could be due to the presence of the nickel interlayer, which prevents diffusion and hence plays a part in the improved ductilityvalues due to reduction in intermetallic formation. Further information about reduction of intermetallic formation can be seen by viewing the EDS data.

3.3 Fractography Study

Figures 4 and 5 shows the SEM micrographs of al-cu weld under various operating conditions.

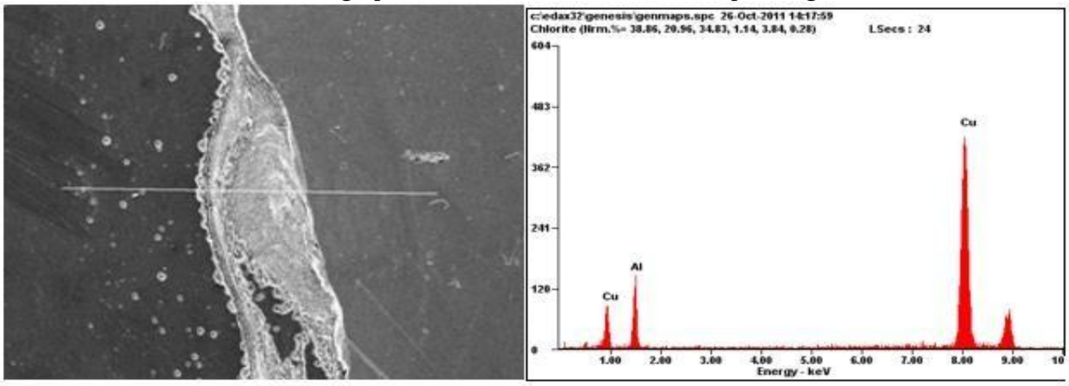

Fig.4: SEM Micrograph and SEM-EDS of Al-Cu Weld under the conditions of Friction Pressure-64mpa, upset Pressure-64mpa, burn off Length-2mm

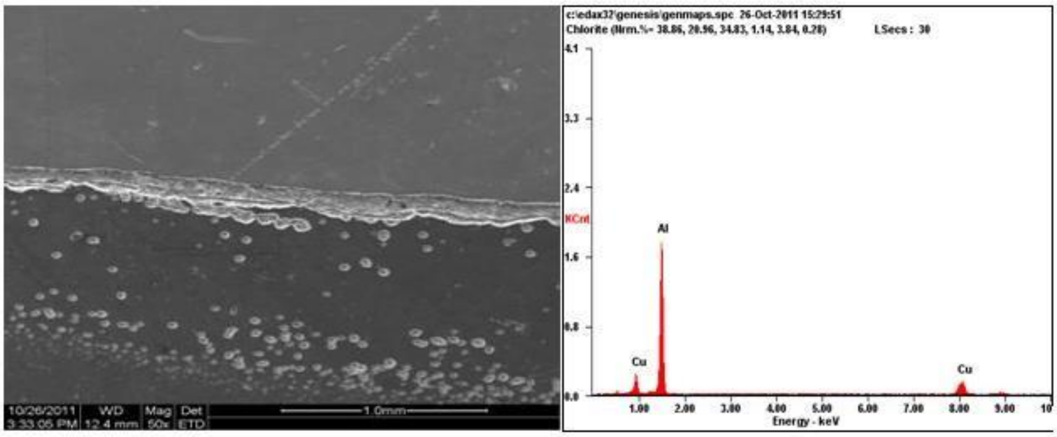

Fig.5: SEM Micrograph and SEM-EDS of Al-Cu Weld under the Conditions Friction Pressure-32mpa, Upset Pressure-96mpa, Burn off Length-3mm

SEM photographs of Aluminum- copper show the interface. SEM-EDAX has been taken for two different friction welding conditions. For both the conditions presence of intermetallic are seen. It is seen that ductility is poor of the order of 0.5 - 1.0% and hence there is a possibility of brittle intermetallic formation. Also the presence of grey layer at the interface containing both aluminum and Copper Can Be Seen in Figures 4 and5. Similar type of SEM-EDAX has been observed by Sahin[12]. These observations indicate the presence of intermetallic phases.

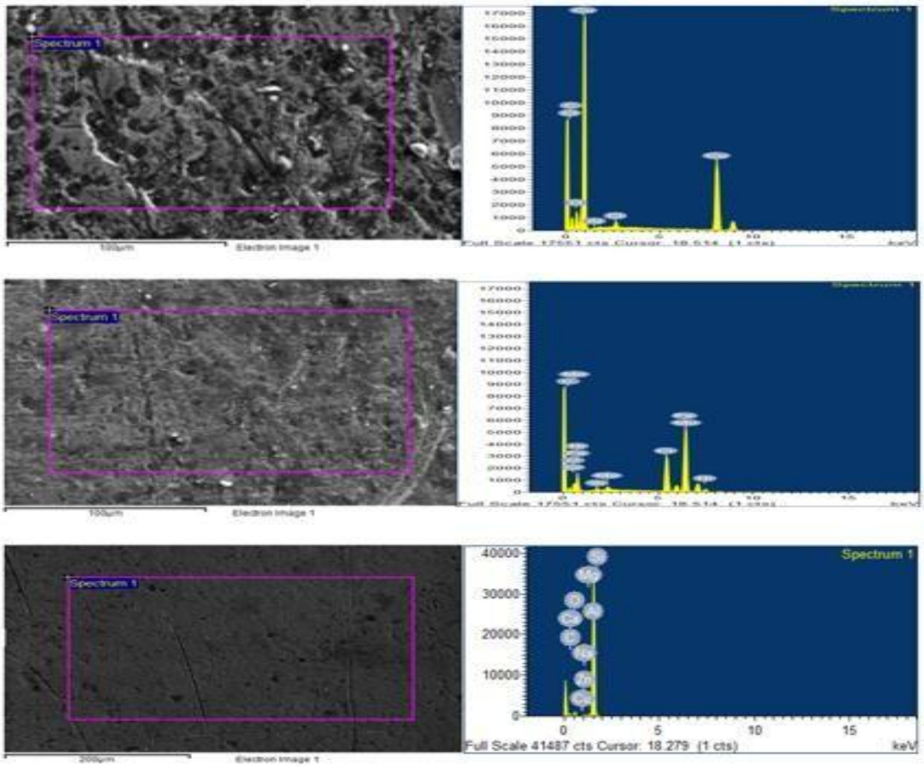

Fig.6:sem-edax on the copper and aluminumsides of the weld

Figures 6 show SEM and EDAX for copper and aluminumsides of the weld. Here the presence of aluminumis very marginal. It can be concluded that the nickel interlayer was effective inreducing the diffusion of aluminumto the copper side. Again, it can be seen that the presence of copper in the aluminumside is very marginal, which confirms that nickel played a crucial part in minimizing diffusion of copper to the aluminumside.

IV. Conclusions

Aluminumwelded with copper exhibited intermetallic compounds. These compounds are substantially reduced by using a nickel layer. This conclusion is substantiated with the help of hardness and bends test results. Bend tests also show higher bend angles when nickel interlayer is used. EDS results also show reduction in diffusion when nickel interlayer is used. This reduction in diffusion of copper into aluminumplays a major part in reducing aluminum-copper intermetallic at the weld layer.

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