Evaluation of Weld Joint: Cupro – Nickel with Aluminium 5083

Melvin Dominic, Krishnakumar, Saravanan R

Abstract: ***Cupro-Nickel and Aluminium alloy to their series, Al 5083 and 70Cu30Ni are the critical alloys in ship building mainly in piping section. Due to the reason of having a huge difference in their physical and chemical properties, obtaining a good bonding between them by welding is rather a tough job. The welding was conducted by giving waviness to the torch and allowing the molten pool of Cu-Ni to flow towards the Al 5083 and thereby joining them without melting the aluminium. The microstructure was studied by welding plain plates as well as Nickel coated plates. The microstructural study showed that there is a good bonding between the two alloys. The SEM imaging confirms the bonding of the two alloys at the welded region. The elemental composition of the weld joint was found by EDS analysis. The formation of intermetallics was confirmed by XRD analysis. Then the hardness at the weld joint was studied. The hardness value obtained from testing was promising and there with showing a good properties at the welded joint. The Ni coated welded alloys showed significant and improved results when comparing with the non-nickel plated metal plates. With the hardness value varying from the non Ni coated plates was found to be high compared to the hardness value of the Al and Cu-Ni alloy. But the further study showed that that hardness value adds much to the weld stability by the formation of good bonds between the alloys and that of the intermetallics formed. The impact tests conducted on the welded specimen shows good results with regards to the comparison with the impact strength of 70Cu30Ni and the energy absorbed by the welded specimen. The results showed that welding is possible between these alloys and the nickel coated alloys shows better results in strength and bonding than non- nickel coated alloys. This study also confirms that GTAW can be very effective in joining these dissimilar alloys.***

Keywords: ***Dissimilar alloy welding, Cupro-Nickel, Al5083, microstructure, hardness.***

I. INTRODUCTION

Aluminium being the one of the major engineering metals, its alloys mainly Al 5083 series play a major role in that of the ship building industry due to its non-corrosive nature, good workability, good strength to weight ratio and good weldability mainly in marine atmosphere .Its application in the ship building industry extends to the piping section where they exclusively serve the purpose as flanges in joining the cupro-nickel pipes mainly 7030. Cupro-Nickel having very high density, serving the purpose as a flange will increase the overall draft weight of the ship. Thus replacing the same flanges with Al 5083 alloy reduces very well the overall draft weight of the ship. Increasing the overall draft weight of the ship can affect the total weight carrying capacity of the ship as well as the buoyancy properties of the ship. Care should be taken during the welding process as it requires high precision in welding these two alloys, thus making the welding process a bit complicated due to the difference its physical and chemical properties. Here for the study, the welding has been conducted without using filler electrode to study the bonding and other properties of the welded joint.

Copper, nickel and aluminium having the same crystal structure, FCC, giving the possibility of welding the two alloys. Aluminium having a low melting point than that of cupro-nickel, where the challenge is for welding the two alloys, which can be further seen in the experiment. The use of Gas Tungsten Arc Welding (GTAW) serves the purpose as it is portable and feasible to the situation. Here the reference is to weldability. Al requires special tool and high skills to be welded due to its high thermal conductivity. The increase in the area of HAZ results in the minimum reduction of mechanical strength. The high heat input results in burns, pores and cracks in welded metal. It was observed that the pulsed current produces much more mechanical strength comparing to that of non-pulsed [1]. The dissimilar alloy welding process depicts its effects on the mechanical strength of the welded specimen. The effect of this welding process on micro structure has been studied along with the formation of intermetallic region at the weld joint [2]. For any type welding, the formation of intermetallic compounds is a crucial element. Each intermetallic compound formed brings out different changes to that of the whole weld joint, where some may improve the properties and some may degrade the properties. The intermetallic compound formed at the welded/fusion area between Cu and Al, which were identified as, Al_4Cu_9, Al_2Cu_3, and Al_2Cu. As we are using Cu and aluminium alloys, these intermetallic compounds cannot be taken as such because of the major alloying element of Al 5083 is Mg and also phases can be formed between that of Ni [3, 4]. Due to the requirement of heat for joining the two alloys, the ampere range in the welding machine is set to 180 A which can give approximately an temperature of 1400 °C where it can result in the burning of aluminium alloy during the welding process [5]. For this experiment there are chances of rapid cooling which might result in formation of cracks at the weld joint, which may cause cracks at the weld joint [6].

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The process of electro plating was conducted on that of CuNi 7030 and electroless plating [7, 8, 20, 21] was done on that of the Al 5083 alloys. Pulse electro deposition method was used for coating nickel in Al 5083 [9], which was found effective for the case and it was seen that there is good bonding or

Elements	**Ni**	**Fe**	**Mn**	**Co**	**Si**	**Cu**
Wt. %	29.98	3.80	0.722	0.05	0.014	Bal

adherence of Ni to the aluminium alloy surface. Giving the Nickel coating on the aluminium 5083 surface changes the flexural and dynamic behaviour of the alloy which include that of improved corrosion resistance, wear resistance, mechanical and physical properties and reducing the overall stress and that of the strain on the aluminium alloy [10].

In the welding, the metallurgy and the weldability of the alloys play a major role in the formation of microstructure at the weld joint and thus deciding the tendency of the weld to crack [11, 12]. In fusion welding process, the microstructures and properties of welded joint are controlled by the melting and solidification of the weld. The diffusion process can cause variation in composition which will have great influences, mainly weldability and the performance of the welded joint. Along with phase transformations, these processes will have precipitation reactions, recrystallization and grain growth that can significantly change the microstructural and properties of the weld and , the properties such as thermal expansion constant, modulus of elasticity and Poison’s ratio play keen role of major parameters [13, 14, 15].

In a study conducted for dissimilar alloy welding process, the method was such that, using laser spot joining, where the aluminium was melted and this molten pool was used for wetting the steel surface and thus building the bend between the two metals [16]. The same principle was used for the welding of Al 5083 with Cu-Ni alloy though waviness has to be given with the torch pointing the Cu-Ni side toward the Al 5083 alloy side. For alloys with magnesium as alloying element, both GTAW and GMAW can be very effective and with increase in the bypass current, it can highly refine the weld grain and there by resulting in the increasing the micro-hardness of the weld [17,18,19]. But with reference to our application, as in ships the difficulty in transporting the GMAW equipment into the ship cabins limits us its use outside the ship and is mostly used for the process of hull erection process where continuous welding is required without break so as to obtain a single weld line

II. MATERIALS AND METHODS

A. Materials

Being significantly used for ship building, CuNi and Al 5083 becomes important due to its properties. When Cupro Nickel is used for preparing the piping sections, Al 50xx series are used for hull making in light weight ships and that for pipe flanges. Al 5083 alloy shows significantly good weight to strength ratio with an hardness value of 110 HV whereas the CuNi alloys having an hardness value of 190 HV and having very high density and being used here for piping purpose due to its non-corrosive properties, mainly its resistance to corrode in harsh environments and saline water. The role of Al 5083 is to connect between the pipe sections. If the material for the flange is used as same as that of the pipe material the overall weight is increased there by increasing the overall weight of the ship. As Al 5083 being available sufficiently at the ship building area and having very low density, Al 5083 is used for serving the purpose of the flange. Table 1 shows the elemental composition of CuNi 7030 used for piping and Table 2 shows the Aluminium 5083 for the flange. Though in real life study the flanges and pipes are round so for this study we use metal blocks of dimensions, 50x50x10mm each.

Table – 1 Chemical Composition of Cupro – Nickel

Table - 2 Chemical Composition of Al-5083

Elements	**Mg**	**Mn**	**Cu**	**Fe**	**Si**	**Al**
Wt. %	4.187	0.56	0.104	0.404	0.23	Bal

B. Gas Tungsten Arc Welding

When it comes to welding, GTAW is one at its best with knowing hoe the weld is happening. As for this, we use manual welding, where it gives the welder a good sight of the weld and thus enabling him to act in accordance to the situation. The welding was conducted at 180 ampere, the temperature of the torch tip reaching to a temperature of about 1200 °C, water cooled welding machine has been used. Table 3 shows the welding parameters that have been used. An inert atmosphere of argon was used and the gas flow rate was set at 10CFH as per the industrial welding standards. Here the entire welding process was manually done. But than in most cases, where 2% thoriated tungsten (marked red) is used, here pure tungsten electrode was used (marked green). Thorium being a part radioactive and having very high electron emission, resulting in more UV emissions and its prolonged use by a welder in the confined rooms of the ship can bring out high health hazards, thus in this experiment we use pure tungsten as a safety for the welder. As per the present industrial standards it is suggested to use pure or lanthanide tungsten electrodes. These electrodes show good electron emission making the risk of exposure very low.

Table – 3 welding parameters

Machine making	Miller Dynasty 350 USA make
Ampere range	180 A
Electrode	Pure Tungsten
Tip Angle	60 (degree)
Gas Flow	10CFH
Shielding gas	Argon
Filler Material	Nil

C. Nickel coating

The essentiality of nickel plating on the two alloys plays a major role in this experiment. Aluminium having a low melting point in comparison with that of cupro-nickel, the welding process may result in the melting and burn down of aluminium; plating makes a crucial turn around for the experiment. Having a face centred cubic crystal structure for aluminium and copper and nickel and nickel being the major alloying element of cupro-nickel, coating with nickel can be effective with bonding and that of protecting the aluminium alloy from burning away. The process of electro plating [7] was conducted on that of CuNi 7030 and electroless plating [8] was done on that of the Al 5083 alloys. Pulse electro deposition method was used for coating nickel in Al 5083 [9], which was found effective for the case and it was seen that there is good bonding or adherence of Ni to the aluminium alloy surface. Giving the Nickel coating on the aluminium 5083 surface changes the flexural and dynamic behaviour of the alloy which include that of improved corrosion resistance, wear resistance, mechanical and physical properties and reducing the overall stress and that of the strain on the aluminium alloy [10]. As we are using 30% Ni alloyed copper for piping, the bonding of the Ni coating on the surface of Cu-Ni plate will be good.

As the welding test cannot be conducted on that of any thickness of Ni coated, the plates were coated with 20 and 40 micron thickness on the alloy surfaces of Al 5083 and 70Cu30Ni.

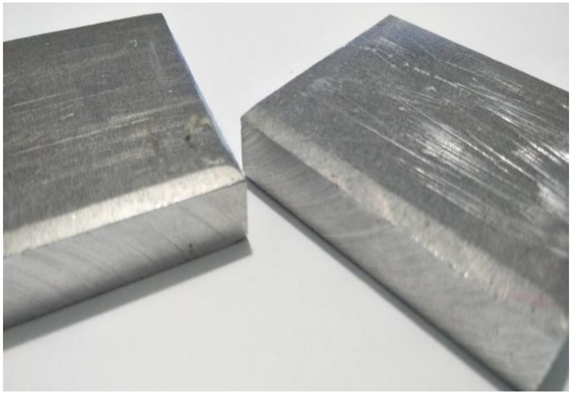


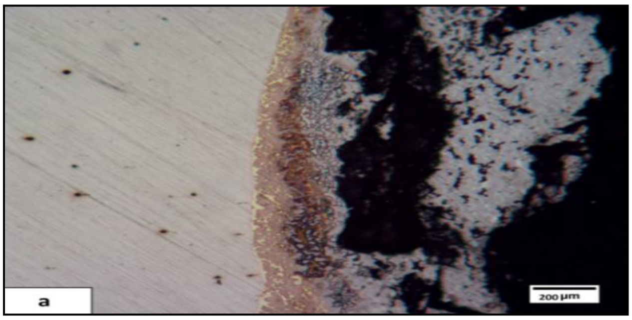
Figure 1 Ni coated Al 5083 and Cu-Ni alloys

D. Experiment

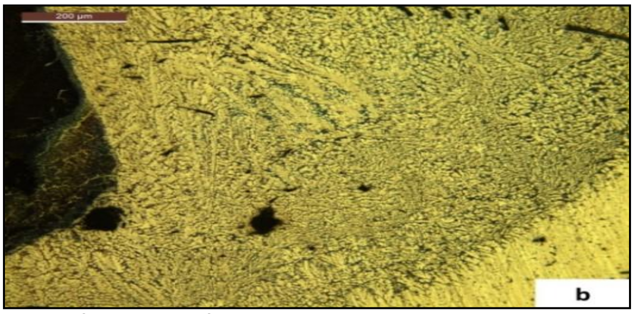
The point is to be noted is that the entire welding is done without using any filler material. This experiment is to confirm that dissimilar alloy welding between these two alloys that is 70Cu30Ni an Al 5083 is possible and to develop a methodology to weld these two alloys whose physical and chemical properties vary in a vast way. The difficulty of running the tests on pipes has led to the use of plates for the experiment. The plates of 70Cu30Ni and Al 5083 with thickness of 10 mm were acquired and were checked for their elemental composition. Confirming that the alloys were prompt to their alloying quantity, each of the plates were then machine to square pieces with dimensions 50x50 mm. Firstly the uncoated Cu-Ni and Al 5083 plates were butted on a fixture and welding was done at the butt joint with the parameters shown in Table 2.3.The welding of two different alloys with different properties are different. With the difference in their melting point play a crucial point to use the appropriate welding method and adapt to the situation. As mentioned in Table 2.3, the welding is done entirely by hand to adapt to the change. Here feeding the torch directly to the joint wasn't adaptable as the aluminium will burn off due to the temperature reaching to 1100 ℃. So the weld pool was made at the Cu-Ni side and the waviness was given towards the Al 5083 side. The molten CU-Ni alloy flowed toward the Al alloy and hence melting the Al 5083 alloy and forming the weld joint. The same procedure was followed for the 20 micron Ni coated alloys. When the welding was done on the 40 micron coated alloys, the welding was done directly on the butted joint as no visible burn of aluminium was observed. Then the 20 and 40 micron thick coated plates were welded and the specimens were taken for study. The izod experiment was done in such a way that that the Al 5083 side of the plate was on the non-clamping side for the impact test. It was done to resemble as same as that of the pipe and flange joint as in ships.

III. RESULTS AND DISCUSSION

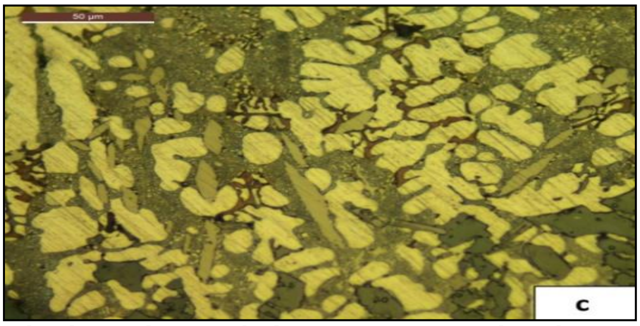
Even though the non- usage of filler material can cause major anomalies in the study, no major problems were faces in the experiment and good results were observed in that of the studies conducted. The 40 micron coated alloys showed far and better evolved results in comparison to that of the non-coated and the 20 micron coated alloys. The presence of nickel results in that of rapid cooling of the weld area.



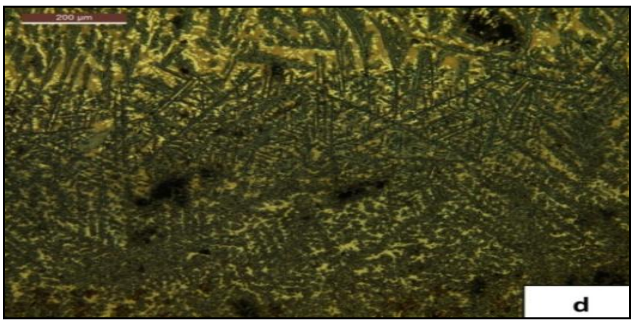
Even though there are chances of rapid cooling which might



result in formation of cracks at the weld joint, there were no



cracks observed, as per the literature survey conducted it was



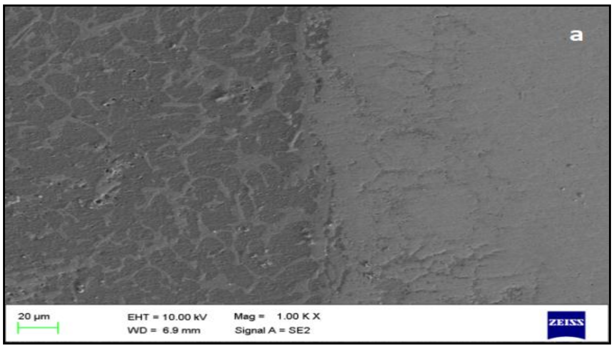
precise to the point [6].

Tests were conducted other than the mechanical strength test as the study was to determine the ability of these two alloys to make a bond between each other. The hardness, microstructure, SEM EDS XRD and mapping were conducted so as to confirm the formation of bonds between the two alloys that is, there exist a good weld between the two alloys.

A Microstructure

Figure 2 (a) Microstructure of the non-Nickel coated alloy weld joint, **(b)** Microstructure of the 20 micron thick nickel coated alloy weld joint**, (c)** Microstructure of the 40 micron thick nickel coated alloy weld joint showing the bonding between the alloys, **(d)** Microstructure of the 40 micron thick nickel coated alloy weld joint showing minimal Al burns.

When the normal plain weld conducted significantly showed clear images of bonding between the two alloys, it was observed that the aluminium got burned at the weld joint. The Figure 2 (a) shows the microstructure of the plate without Ni coating. The brown colouring shows the welded area and that of towards the left in light shades shows that of the heat affected zone. From the Figure 2 (a) towards the right side shows the aluminium that got burned during the welding process [5]. The Ni coating which was given to the material surface played a major role in that of giving better hold between that of the two alloys. Even though the 20 micron coated specimen weld showed good results, there was still significant amount of burn than can affect the weld. As observed in the microstructure for 20 micron coated weld joint Figure 2 (b), the comparison with the specimen without nickel coating, the burns are less also giving a better microstructural image and showing the evidences of bonding. Our main concern here is to obtain a welding joint with no visible burns of aluminium and that of perfect bonding between that of the AL 5083 and 70Cu30Ni alloys. When the study was conducted on that of the 40 micron coated specimen, the results was significantly good in comparison with that of the 20 micron coated specimen. The microstructure study showed that there were very less amount of burned aluminium Figure 2(d). The distribution of nickel and the binding between the alloys are clearly visible from the microstructure in in Figure .2 (c). This clearly confirms that the 40 micron coating is effective in reducing the Al burns in this dissimilar alloy welding.



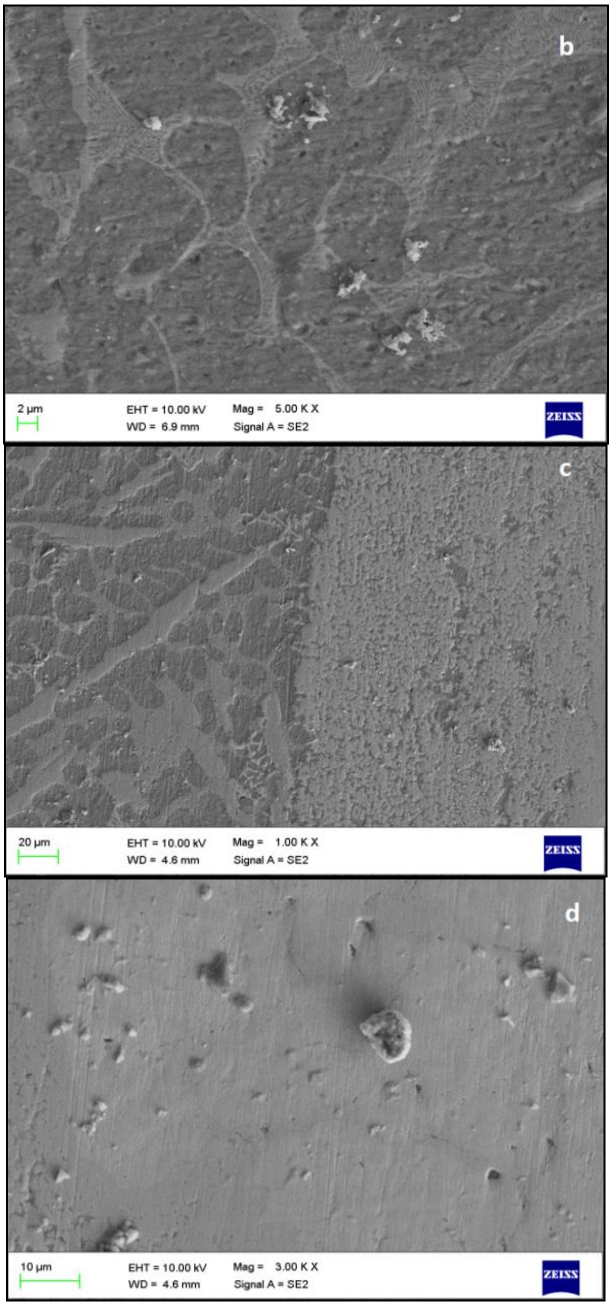
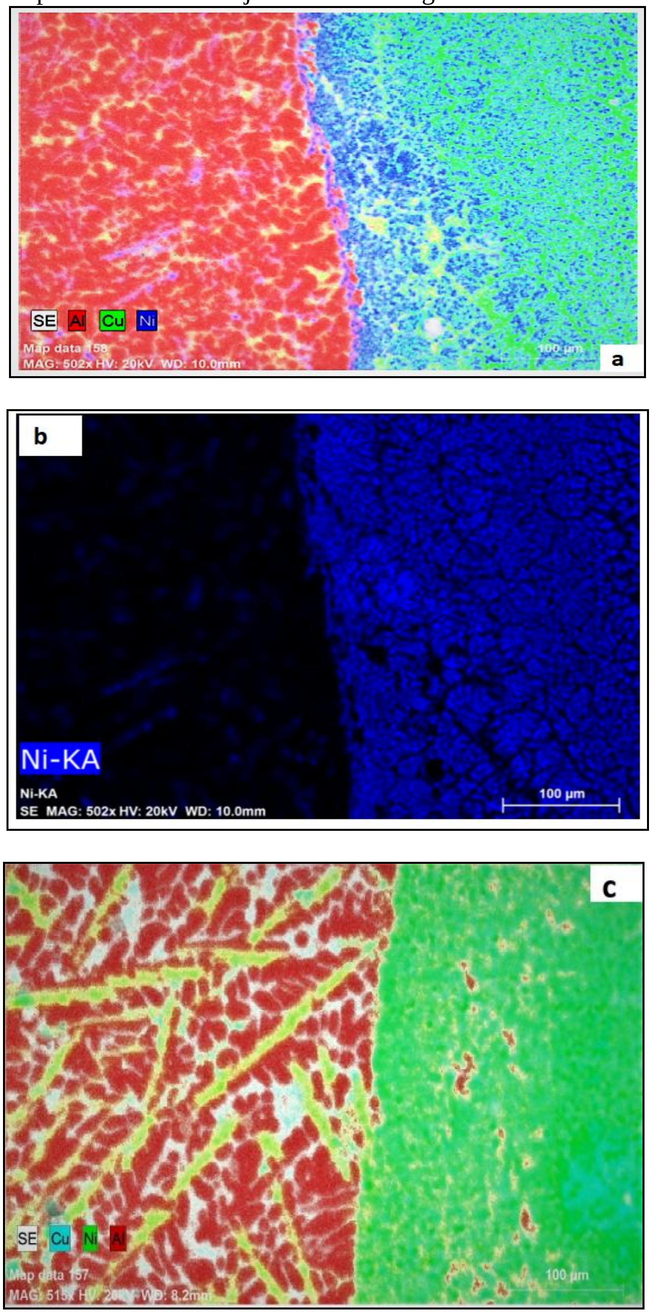


Figure 3 (a) SEM image of 20 micron nickel coated specimen weld joint, **(b)** SEM image of Ni at the weld joint of 20 micron nickel coated specimen weld joint, **(c)** SEM image of 40 micron nickel coated specimen weld joint, **(d)** SEM image of Ni at the weld joint of 40 micron nickel coated weld joint.

Formation of phase plays a major role in fields of alloy formation like in casting or as in the case of welding. The intermetallic formed confirms the binding and that od the strength of that of the alloy. The Figures 3.3 (a)shows the SEM image of the weld joint whose specimens are 20 micron coated, from which a clear bond that has been formed could be observed and as in Figure 3.3 (b) it is clearly seen the Ni particle that is present in the welded area. Now comparing the 20 micron coated alloy weld, it could be seen that as in Figure 3.3 (c) that the bond formed is rather sufficiently strong and covering a good area with 40 micron coated specimen.

Nickel here at the weld joint was properly scatted all along the weld joint and thus enhancing the bond at the wel area as in Figure 3.3 (d). This formation of intermetallic was then confirmed using XRD analysis and further EDS analysis giving the percentage of the elements that are present at the weld area.

When it comes to the study in the elemental mapping, the diffusion of each of the element was clearly visible and thereby showing promising results for the weld joint. Here more importance was given to study the infusion of nickel into the weld joint there by giving more stability at the weld. Studying the Figure 3.4 (a) the mapping of the welded area with 20 micron coating, exposing the weld area and the fusion of the two alloys and the formation of bonds. The Figure 3.4 (b) shows the mapping of nickel in the weld area. There was proper infusion in the weld area seen in blue lines towards the darker region, which in comparison to that of 40 micron coated specimen is very low. Here the Ni particles are suspended in the weld joint as small fragments.



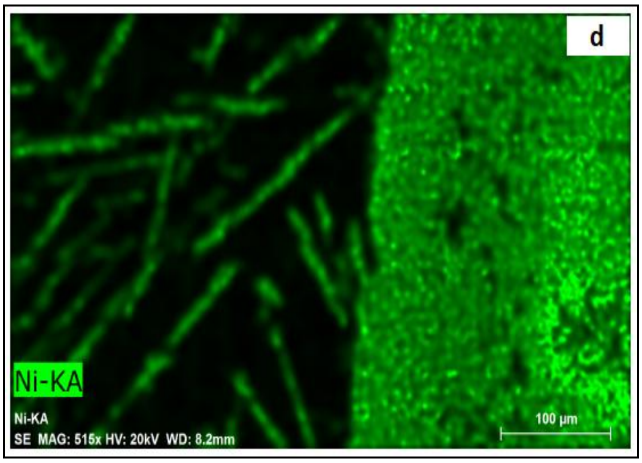
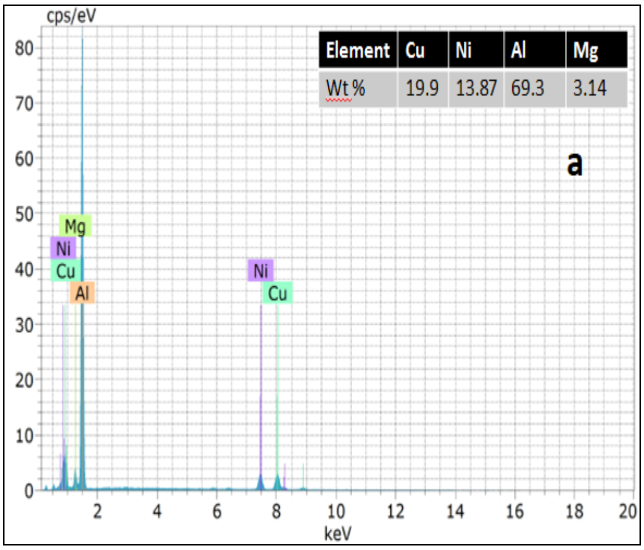


Figure 4 (a) Elemental mapping done of 20 micron thick Ni coated welded specimen,**(b)** Elemental mapping of Ni in 20 micron thick Ni coated welded specimen,**(c)** Elemental mapping done of 40 micron thick Ni coated welded specimen,**(d)** Elemental mapping of Ni in 40 micron thick Ni coated welded specimen.

The case is not the same when it comes to the comparison of 40 micron coated specimen, as the Figure 3.4 (c) shows the bonding of the two alloys giving better results than that of the 20 micron coated alloys. The clear image of nickel being infused into the Al 5083 alloy thus confirming that Ni binds the two alloys together. Ni being an FCC as same as aluminium their bonding with each other is easy. There by giving the weld its uniqueness. Here the elemental mapping of nickel from the weld area analysis simply shows the clear images of Ni in the weld area and that of the presence of nickel in the Al 5083 alloy. The comparison of Figure 3.4(b) to Figure 3.4 (d) clearly depicts the Mapping of Ni in the weld. The 40 micron coated specimen weld show better results than that of the 20 micron coated welded specimen. This clearly depicts that (a) the nickel being the best element that can bind these two alloys together to impart strength and that of joining these two alloys, (b) even without using filler material, the weld shows extraordinary bonding between the two alloys. Figure 3.4 (d) depicts clearly the above statement that there can exist a very good bonding between the two alloys by using GTAW that too without the use of a filler material.

The aluminium, nickel and copper concentration at the weld joint was found out using the EDS analysis. The EDS spectrum was taken at the cross sectional surface of the welded area. It is clearly inferable that an intermetallic phase is formed between Ni–Al, Cu-Al, Al-Mg, and Mg-Ni. The EDS result affirms by the atomic percentage that was observed in the observation. Figure 3.5 (a) and Figure 3.5 (b) shows that of the elemental analysis that was conducted at the welded area. It was observed that for 20 micron coating the percentage of nickel at the weld joint was at 13.87% and that of 13.75% of nickel in 40 micron coated specimen. It can be seen that the variation in the thickness of coating didn't affect the percentage elemental composition at the weld joint much. But still 40 micron coated specimen weld showed better result in that of reducing the aluminium burn to a great extent.



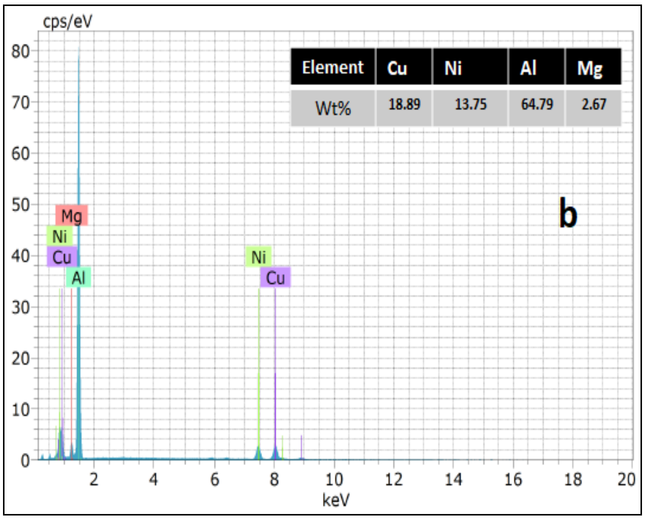
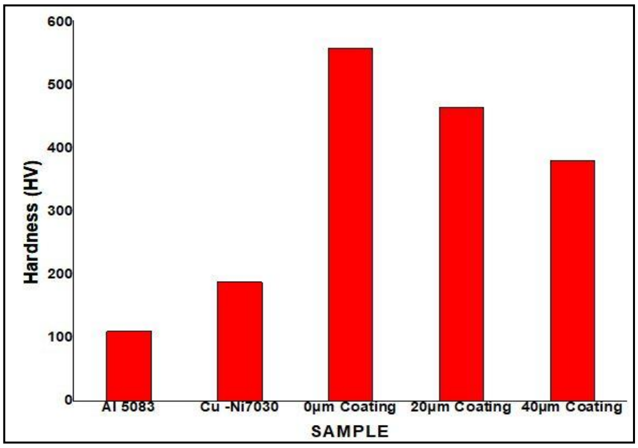


Figure 5 (a) EDS analysis of 20 micron thick nickel coated specimen weld joint, **(b)** EDS analysis of 40 micron thick nickel coated specimen weld joint.

The formation of intermetallic compounds plays a vital role in the strengthening the weld. Having the same crystal structure, it is easier for the base elements and that of the alloying elements of both Al 5083 and 70Cu30Ni to share a good bonding and the tendency to form intermetallic. The XRD test conducted showed and confirmed the formation of intermetallic compounds such as AlNi forming AL3Ni2(14-0648, 65-4197), AlMg forming Al3Mg2 (73-1148, 65-7561, 65-6848), CuNi (65-7246, 09-0205), MgNi forming Mg2Ni (65-4318, 65-3630, 65-2227), MgCu forming Mg2Cu4 (65-3621, 29-0648), AlCu forming Al2Cu3 (40-0903, 03-0877, 01-1128) at the weld joint there by confirming the bonding between the two alloys as the graph shown in Figure 3.6 on black marking which shows that of the 20 micron coated specimen and Figure 3.6 on red marking showing the 40 micron coated specimen XRD. The formation of intermetallic such as AL3Ni2, Al2Cu3, and Mg2Cu4 at the weld joint confirms that there exist a good bonding between that of the two alloys. The intermetallic that was seen during the literature study was also observed and obtained in this experiment.



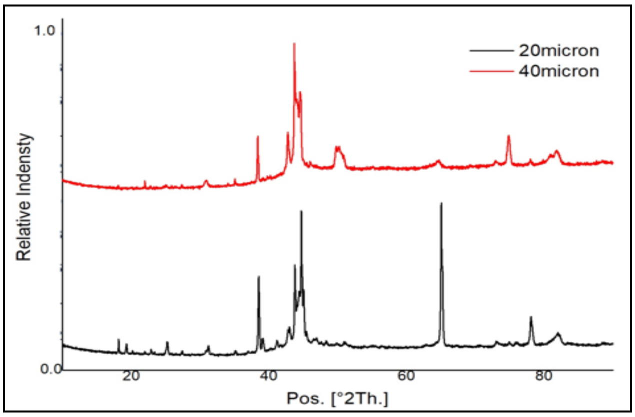


Figure 6 XRD analysis of 20 micron (marked black) and 40 micron (marked red) thick nickel coated specimen weld joint

B. Vickers Hardness Test

Figure 7 Graph comparing the hardness values in HV of Al 5083, 70Cu30Ni, weld joint without Ni coating, weld joint with 20 and 40 micron thick coating of Ni at weld joint.

The micro-hardness study played a major role in this experiment. During the initial value study, it was observed that the hardness value reaching to a peak of 560.35 HV Figure 3.7, which in comparison to the hardness value of the Cu-Ni and Al 5083 is nearing to a value that is 3 times more than the base alloy values. This is due to the mixing of the two alloys at the weld joint. Though this rapid spike in hardness can also result in that of the alloy joint, that is the weld joint to be brittle and hence the chances of the weld joint to develop crack in stressful environment. When the hardness value dropped down to an average of 466.8 HV in the 20 micron thick Ni coated alloy, which shows that the 20 micron coating given has reduced the brittleness of the weld joint . When it came to the hardness value of 40 micron thick coated specimen, it was seen that the hardness value was to an average of 382 HV Figure 3.7 which in comparison to that of the non Ni coated alloy is less. Here it shows that there is proper bonding between that of the alloys and that of the brittleness that was doubted at the weld joint was reduced. Hence the 40 micron thick Ni coating given to the alloys showed better results.

C. Izod Impact Test

On impact the specimen was found to break above the welded joint also showing that the weld joint possessing the same strength as that of the base material that is 70Cu30Ni.

The welded specimens showed exceptional strength in comparing with the base materials. With comparison to the data obtained from the reference papers the values of Al 5083 and 70Cu30Ni impact test values were obtained. The values were found to be 110 J for Al 5083 and for 70Cu30Ni 135 J. It was observed that the energy absorbed values obtained after calculations were very close to that of the 70Cu30Ni plate and showing that the weld joint possesses more impact resistance than the base material.

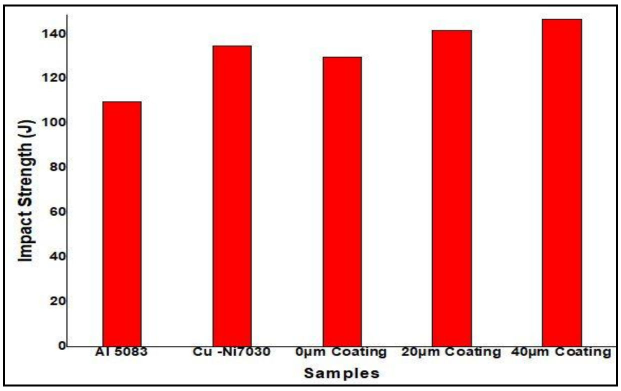


Figure 8 Bar chart showing impact test values of, Al 5083, 70Cu30Ni, weld joint with 20 and 40 micron thick coating

IV. CONCLUSION

From the experiments and the studies conducted, the following observations have been found out from this dissimilar alloy welding;

1. Dissimilar alloy welding is possible by GTAW for joining Al 5083 and CuNi 7030.
2. Even without using a filler material a good bonding between the alloys or metals can be achieved using GTAW.
3. The specimen with 40 micron coating that was welded showed better results in microstructure and improved bonding than the plain welded and that of the 20 micron coated specimen.
4. The hardness value showed to plain weld and that of the 40 micron coated alloy shows that the chances of the weld area to be brittle are reduced.
5. The formation of the intermetallic further depicts and confirms the proper bonding between the alloys.
6. The impact test conducted compares the energy absorbed with the base materials and that of the weld, which confirms good weld impact strength.

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