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Investigation of Intermetallic Compound Formation in Dissimilar Metal Welds between Copper and Stainless Steel using Gas Tungsten Arc Welding

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ABSTRACT

Dissimilar metal joints are used in aerospace industry to combine the unique properties of different materials and to achieve ideal performance and weight savings. The aerospace industry demands for highly reliable structures with less weight and this is always a challenge for material scientists to develop various structures with less weight. This paper describes about the metal joint made between Copper and stainless steel using Gas Tungsten Arc Welding (GTAW). Copper is known for its high thermal conductivity whereas steel has high corrosive resistance and high mechanical strength. This type of dissimilar metal joints can be used in critical aerospace heat exchangers to maintain proper temperature control in spacecraft engine components. Welds are made with and without filler and the weld is analysed. The weld is analysed using EDX. This analysis shows the element composition in the formed intermetallic compound and found that the weldment has a huge amount of element oxides that make the weldment brittle and leads to crack.

1. Introduction

The aerospace and aircraft industries require welds of the highest quality and strength. Dissimilar metal joints are the area of research today due to various advantages. Since the physical and chemical properties of the two materials are distinct, joining dissimilar metals is quite challenging [1-3]. Using friction welding magnesium and aluminium can be welded [4]. Copper and Stainless steel dissimilar metal joints possess a wide range of applications in aerospace industry and joining this metal combination is not easy since the physical and chemical properties differ to a large extend [5-8]. The thermal conductivity of the metal decides the volume of metal melts during

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welding. Heat conduction happens during the phase change from molten state to solid state occurs and at the interface latent heat of fusion is released [9, 10]. The various causes of welding failures are analyzed [11, 12] Laser Beam welding and Electron beam welding are the good sources of welding technology for the dissimilar joints of Copper and Stainless steel [13]. This research focus on the study of dissimilar metal joints of Copper and Stainless steel using GTAW which can be used to weld copper and stainless steel [14]. The X- Ray studies can be made to analyze the formed intermetallic compound towards quality and strength [15, 16]. X-Ray diffraction is a useful analysis to find the crystalline structure of the weldment. The weldment should not contain any oxides which will make the grain brittle which in turn leads to crack in the weld [17-20].

The literature that is currently available reveals that not many researchers have studied Copper-SS304 dissimilar metal joints, and even then, there is insufficient data to generate high quality welds using GTAW. Despite the critical importance of achieving high quality welds there is a gap focusing on the application of GTAW towards dissimilar joints of Copper and Stainless Steel. In this investigation, GTAW is used to join copper and stainless steel 304, and the weldment is then quantitatively analyzed using X-ray diffraction and SEM-EDX. By determining the crystalline type, grain size and composition of intermetallic compound, the weld is analyzed towards quality and integrity and to analyze whether this welding technique can be useful for aerospace applications. This research seeks to bridge the gaps in the existing literature by systematically investigating the welding parameters through various analysis.

2. Welding and Characterization

2.1 Specimen Preparation

Stainless Steel 304 and pure copper plates of size 100mm X 60 mm X 6 mm have been chosen for the study of dissimilar metal joints. The plates are machined using a normal lathe to the necessary size as shown in Figure 1.

These materials should be completely free of gas or oxide films. The creation of an exterior layer of oxide and nitride and an inner layer into which oxygen and nitrogen have diffused are the outcomes of the absorption of oxygen and, to a lesser extent, nitrogen. Before welding, the specimens are cleaned using trichloro ethylene and then with Hydro Fluric acid to get rid of dirt, oxides and any other extraneous materials.

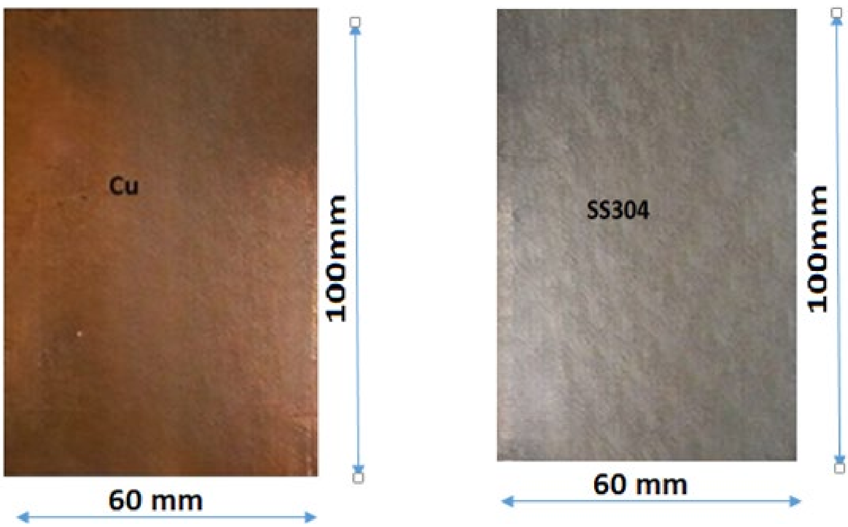

Fig. 1. Specimen for welding

2.2 GTAW of Copper and Stainless Steel 304

Gas Tungsten Arc Welding (GTAW) which is also known as Tungsten Inert Gas (TIG) welding is a popular welding process used for joining wide range of materials including space materials. In this research GTAW is used for joining copper and stainless steel. This joining of dissimilar materials together can be challenging due to the difference in physical and chemical properties of both metals.

TIG welding has been tested for welding copper and stainless steel 304. Every experiment involves adjusting the current value to determine the melting point of both stainless steel and copper. Following a series of trails it was discovered that the stainless steel had melted at a current value of 130 Ampere. The heat produced at this current level is enough to melt both metals. Since tungsten has a far higher melting point than copper and stainless steel, it is used to melt metals. Another weld is performed with a filler material of SS304 rod. The GTAW welding machine used for this research is shown in Figure 2.

Fig. 2. TIG welding machine

The TIG-welded coupons without filler material are shown in Figures 3 and with SS 304 filler is shown in Figure 4. During visual inspection the weld made without filler material was found to be without cracks but over a period of time cracks were formed towards the length of the weld.

Fig. 3. Copper and SS304 Joint without filler

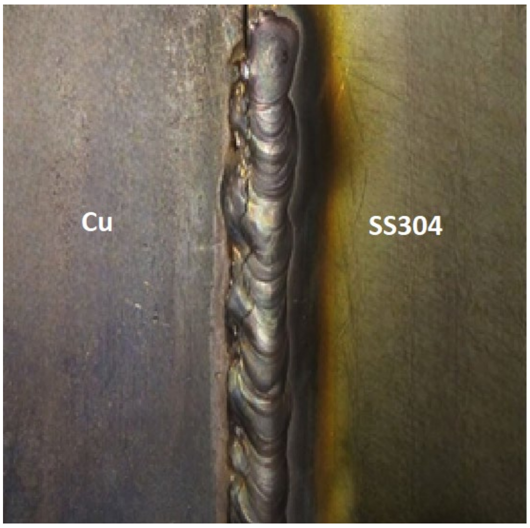

Fig. 4. Copper and SS304 Joint with filler

2.3 X-Ray Diffraction

A potent analytical technique for figuring out the atomic and molecular structure of crystalline materials is X-ray diffraction (XRD). Samples are taken from weldment without filler. In order to create a diffraction pattern on a detector, X-rays are directed towards a sample. XRD provides details on a material's phase composition, lattice characteristics, and crystal structure by examining the diffraction pattern [21]. A monochromatic X-ray source, often with a set wavelength, is pointed at a crystalline sample in X-ray reflectometry (XRD). The characteristic Kα line of weldment is around 1.54 Å (angstroms), which is the wavelength at which the source usually produces X-rays.

Bragg's Law is a formula for figuring out the interplanar spacing, or d-spacing, in a crystal lattice that was developed in 1912 by Sir William Henry Bragg and his son Lawrence. The equation is as follows: $n\lambda = 2d \sin(\theta)$, where μ is the X-ray wavelength, d is the interplanar spacing, and θ is the diffraction angle.

2.4 SEM-EDX

An effective technique for analysing the weldment to find the impurities and oxides is Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDX). Samples are taken from weldment without filler. SEM offers detailed surface morphology of the microstructure of the weld, displaying characteristics such as inclusions, defects, and grain boundaries [22, 23]. Elemental analysis is made possible by EDX, which helps to determine the composition of the base metal, the heat-affected zone, and the weld metal, among other areas within the weld. In order to evaluate the quality of the weld, find contaminants, and guarantee structural integrity, this information is essential. In order to gather understanding of the microstructural and compositional aspects of weldments which is a crucial component for assessing their mechanical properties and performance SEM-EDX is frequently used in welding research.

3. Results and DIscussion

3.1 X-Ray Diffraction Analysis

The X-ray diffraction pattern received for the weldment sample has to be matched with the standard JCPDS reference data and it was found that the data closely matches with JCPDS cards 70-3039 which in turn shows the data for copper and 87-0721 which shows the data for Iron and not with any other metals. Therefore, it is clear that the weldment is an alloy with copper and iron as the major elements. Among the two, Copper values with JCPDS card no 70-3039 collection code 053247 match more precisely. This shows that copper content is higher in the weldment than iron. The coupled 2$\boldsymbol{\theta}$ reference peaks from JCPDS cards are shown in Figure 5. The X-ray diffraction pattern of the weldment is shown in Figure 6. The calculated Miller indices for the high-intensity peaks from the reference data are shown in Table 1. From reference, it is found that the lattice structure is cubic. For a cubic lattice, the lattice constant values are equal, i.e., a=b=c.

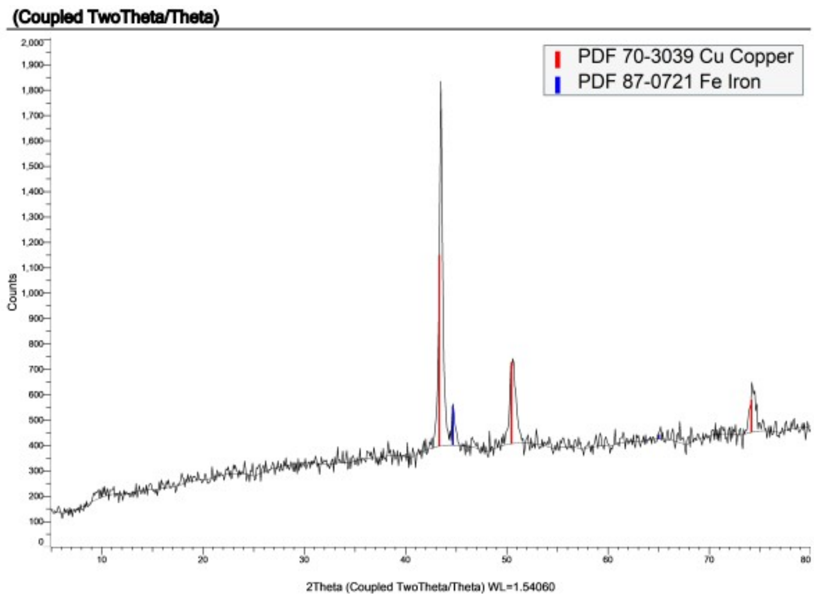

Fig. 5. Coupled 2$\boldsymbol{\theta}$ reference peaks from JCPDS cards

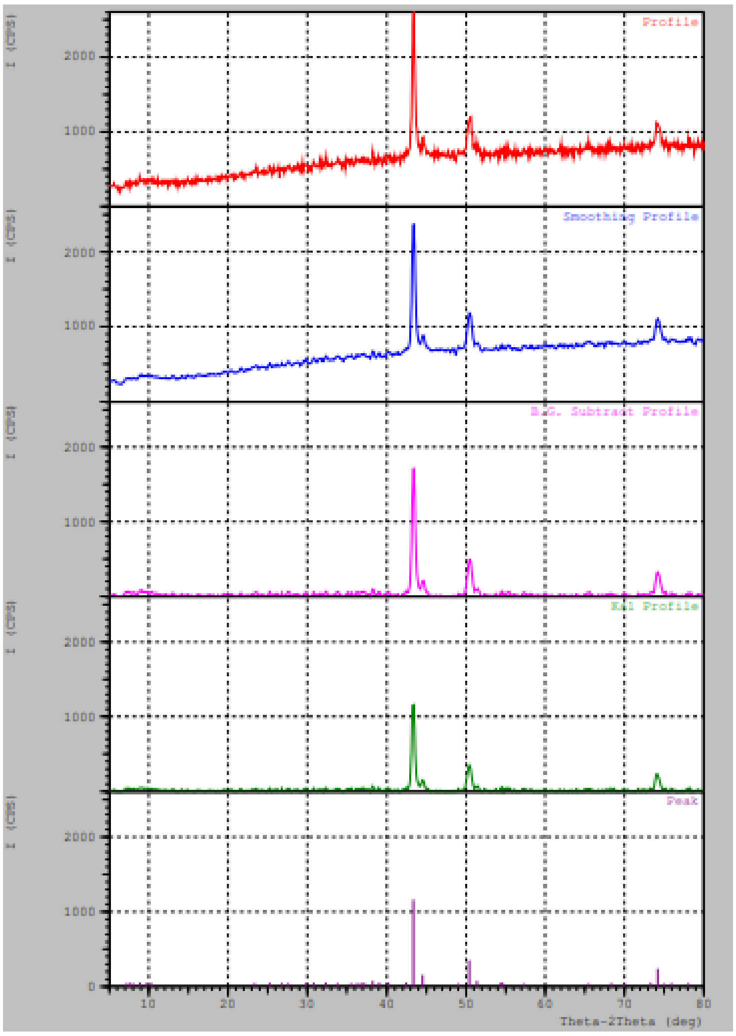

Fig. 6. X-ray Diffraction pattern for the Weldment

Table 1
Miller Indices of GTAW weldment

2Theta	d	Miller Indices (h l k)
43.3421	2.08597	1 1 1
50.4148	1.80866	2 0 0
74.1844	1.27724	2 2 0

For a cubic lattice structure, the lattice constant value can be found using the equation given below:

$$\frac{1}{d^2} = \frac{h^2 + k^2 + l^2}{a^2}$$

To find the lattice constant, Miller indices (111) and its corresponding d value of 2.08006 are chosen, which yields a = 3.60276. This value of lattice constant 'a' for the weldment is compared with the reference data where the value is recorded as a = 3.61300 which is almost the same as that of the weldment. Therefore, in the weldment, the crystalline structure of copper and stainless steel does not vary and copper will maintain its FCC structure and the iron present in the weldment also maintains its FCC structure.

3.2 SEM-EDX Analysis

GTAW weldments are exposed to SEM-EDX analysis. The combination of Scanning Electron Microscope (SEM) along with Energy Dispersive X-ray Analysis (EDX) gives the exact essential creation of the weld which assists us with confirming the presence of alloying components and distinguish the possible impurities in the weldments at the joining point. The intermetallic combination is explored towards quality and strength of the weld. Figure 7 shows the range of various components found in the intermetallic compound of Copper and Stainless steel joint made with GTAW. Table 2 shows the component and its weight percentage in the GTAW weldment.

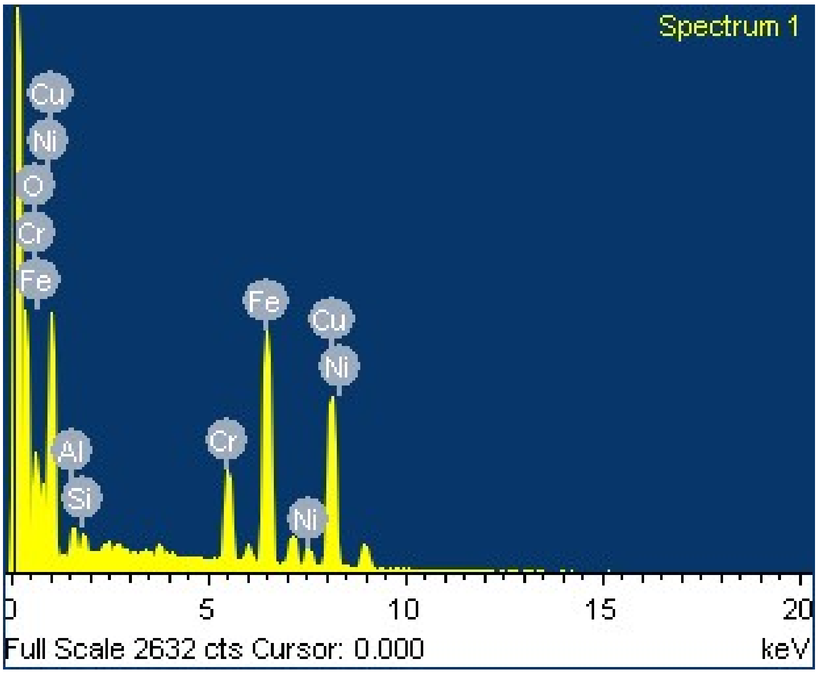

Fig. 7. EDX spectrum showing elements in the intermetallic compound of GTAW specimen

Table 2
Elements and Weight fraction in the intermetallic compound of GTAW specimen

Elements	Weight%
Silicon dioxide and Aluminium Oxide	15.16
Chromium	7.89
Iron	30.10
Nickel	3.61
Copper	43.24

The EDX spectrum of GTAW shows the presence of oxygen together with silicon and aluminum as Silicon dioxide and aluminum oxide which is around 15.16 percentage. In GTAW weldment the immense presence of aluminum oxide and silicon dioxide which are brittle in nature makes the weldment exceptionally weak and prompts to crack development. Similarly, the intermetallic compound shows the presence of copper the weak phase is significantly more than the iron which is a major reason for the crack and weak weld. Figure 8 and Figure 9 shows the surface morphology of the GTAW weldment at a magnification of 1000x and 2000x with a 20kV acceleration voltage. These images shows that due to the presence of aluminium and silica oxides in the intermetallic compound the grains in the weldment are more brittle in nature which is the reason for the weak nature of weldment and leads to cracks.

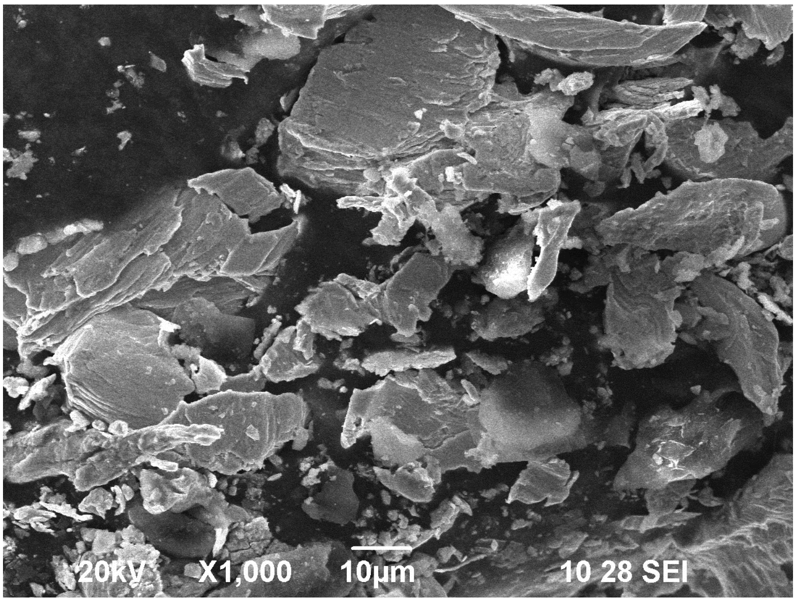

Fig. 8. SEM image of GTAW weldment at 1000x magnification

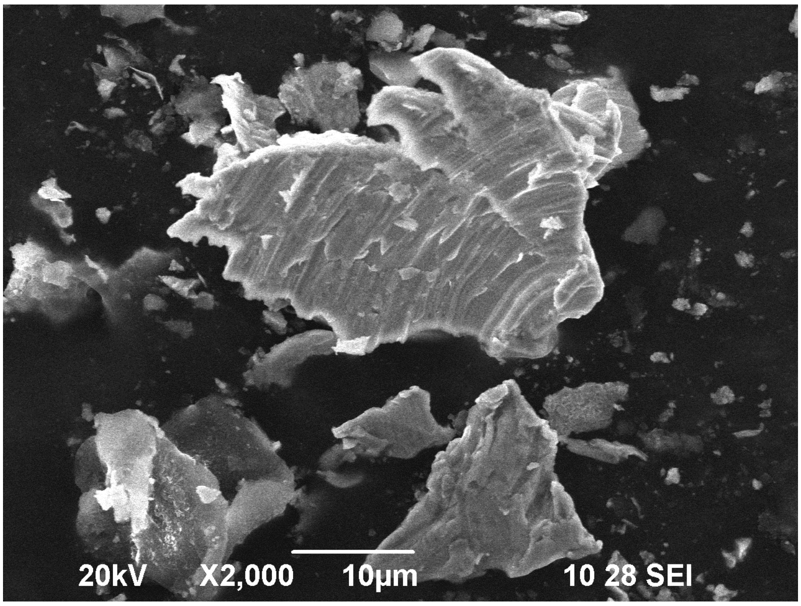

Fig. 9. SEM image of GTAW weldment at 2000x magnification

4. Conclusion

In the case of GTAW of Copper and Stainless Steel 304, it was found that a crack had developed toward the length of the weld in both the specimens welded with and without filler. Further analysis has been done to find the cause of the cracks that developed in the weldment using XRD and SEM-EDX. The results of the XRD analysis reveals that the weldment has more copper content than iron and the formed weldment is weak. The weldment grains are found to be FCC structure as that of the base metals. But SEM-EDX analysis shows the presence of 15.6% of Silicon dioxide and Aluminium Oxide. Due to the presence of these oxides the weldment grains are more brittle in nature which leads to the crack propagation over a period of time. The morphology of the weldment also prove that the grains are brittle in nature which is not a desirable quality for high precision and high quality welds.

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