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Martensitic Stainless Steel Brazing by Using Ag-Cu-Ti as Active Filler Metal Alloys

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HIGHLIGHTS

- Martensitic stainless steel was welded by the brazing method
- The mechanical properties were evaluated by the single-shear experiment.
- Optical microscopy was used to study the microstructure of the weld joint.

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ABSTRACT

Brazing fillers for joining applications are essential to advanced material design and fabrication. Several types of brazing fillers have been developed in recent decades to join similar or different engineering materials. Important parts of automotive and aircraft components, including steel, are often joined by brazing. In this study, Similar samples of martensitic stainless steel were welded by the brazing method, using effective silver-based metal alloys. The brazing welding is done in inert gas atmosphere furnaces, by placing the samples in a special container filled with argon gas during the welding period and at a flow rate (10 to 15 minutes) inside a cylindrical furnace. Three types of metal alloys (silver, copper, and titanium) with different weight ratios of Ag, Cu, and Ti were used with a fixed welding time (10 minutes) at an appropriate temperature for each joint. A set of examinations and tests were conducted to find out the microscopic structure of the bonding site and the extent of the binder overlapping with the base material. Optical microscopy was used to study the microstructure of the weld joint. Optical and scanning electron microscopy (SEM) is used to study the joint microstructure. All joints of samples exhibited continuous bonding between the base metal and the filler metal, good wetting between the surfaces, and it was also noticed that the higher the proportion of titanium, the better the wetting between the surfaces., the greater the percentage of diffusion of the filler elements and the strength of the bonding with the base metal. The use of titanium-containing fillers in brazing is good for bonding in turbine blades of martensitic steel.

1. Introduction

Welding, brazing, soldering, riveting and adhesive bonding of material are examples of the joining material process. Brazing is a method of establishing a permanent, strong metallic bond between two (potentially dissimilar) materials. Brazing is distinguished from soft soldering by the melting of filler metal in the junction; this alloy must be capable of wetting the base metal and have a liquidus temperature over 450°C (to distinguish it from soft soldering), but below the melting point of the materials being connected. When using filler metals with melting ranges much beyond 450°C, jewelers often refer to their profession as soldering, but certain new filler metals are pushing brazing process temperatures considerably below this barrier. Brazing offers a number of benefits over other connecting methods like adhesives, fasteners, or welding, and as we'll see below, it can be a very versatile approach. [1,2]

The martensitic stainless steels discussed in this article are widely used in a range of industries. Because of their unique mix of properties, these steels may be used as structural materials in nuclear reactors, diesel, aircraft, and rocket engines, as well as stationary gas turbines. The most demanding technological operations in the fabrication of structural components are intermediate and final assembly. Various types of cutting and welding are commonly used in these techniques. Brazing is used to create precise items with thin walls and complex geometries that need a low level of accuracy. For a lengthy period of time, brazed connections can withstand high temperatures, static and dynamic mechanical stresses, and the impacts of hostile media without losing their properties. [3,4]. M St St is a martensitic heat-resistant stainless steel with high creep strength and mild corrosion resistance that is commonly used in fossil-fuel power plants for intermediate and low-pressure steam turbine blades.

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It has been studied for its mechanical characteristics, fatigue resistance, and corrosion resistance. [5,6]. The majority of these investigations, however, are restricted to conventional processing methods such furnace and vacuum brazing [7]. Induction brazing is a quicker and more effective technique than vacuum brazing because it uses a fast and regulated form of heating to aid in element dissolution, diffusion, and chemical interaction between the base and filler metals. Induction brazing has a high heating rate of up to 100 degrees Celsius per second, which is necessary to avoid liquation of the braze alloy with distinct solidus and liquidus temperatures [8].

As a result, the wetting and pouring of braze alloy into the gap are critical characteristics to consider in order to achieve a high-quality connection [9]. The height of the brazed alloy's rise in the capillary is determined by its capacity to flow into the gap, which is essential for connecting sections of honeycomb systems like heat exchangers. For instance, in my work [10].

The filler metal is put immediately between the two pieces to be brazed in the case of "sandwich" or "repair" brazing. In the case of dissimilar materials, a spacer composed of different materials is used in addition to the filler metal to act as a transition layer and reduce heat stresses during brazing. Repair brazing is frequently employed in the repair of aircraft engines and stationary gas turbine components subjected to severe environments, such as turbine and compressor blades. Due to high temperatures and pressures, as well as exposure to foreign objects, cracks, hot gas wear, corrosion, and shock damage may develop. The maintenance and repair brazing technique is used to extend the service life of these components. For example, the works present a current development of a two-stage hybrid technique, which includes the process of turbine blade repair brazing with a nickel-based filler metal Ni – 18.5Cr – 10Si wt. percent. Surface flaws in a turbine blade may be repaired using this type of brazing in both narrow and large gaps [11,12].

Filler metals are available in a variety of forms, including strips, wire, powders, and paste. Brazing foil that is flexible and has an organic binder amorphous foils, etc. The elements makeup of a braze alloy is influenced by the type of braze alloy used, which is determined by the specific engineering purpose [13-15].

2. Methods and Materials

Martensitic stainless steel (gas turbine blade) Inconel 420 was used in this study and used in this research studying the repairing of the damaged turbine blades which are made from martensitic stainless steel by using an active brazing process. microstructure properties for martensitic stainless steel brazed by effective silver-based metal alloys in inert gas atmosphere furnaces at different- concentration and temperatures at constant holding time was studied in order to find the suitable filler alloy and parameters which affected the microstructure and bonding morphology using optical microscopy of the brazed joints, since repairing the blades more cost-effective than replacement.

3. Experimental Work

The samples were prepared by cutting the root of the blade by wire cut to the cubic dimension of (10x10x5) cm and then polishing process by the polishing device. After cleaning and preparing the samples, the filler metal or mortar is placed correctly before welding between the parts to be welded and held together by clamps made for this purpose (from stainless steel metal) as shown in Figure 1 (a, b). The brazing process was carried out in an electrical furnace under a protective atmosphere (highly purity Argon gas (99.999%)) to ensure that the brazed samples are free from undesirable contaminants between the mating materials. The past filler metals were prepared by weighing a suitable amount of metal powder alloy and mixed with a drop of glycerin to form a filler metal paste that is suitable for one joint. The types of filler alloys are listed in Table 1. Lastly, the samples were investigated with a scanning electron microscope (SEM; model Quanta 2000) equipped with Oxford Instruments Energy.

Dispersive Spectroscopy (EDS) to evaluate the elements and phases present in the brazing region and interfaces. SEM was in charge of the mapping analysis (Hitachi; model SU8000).

That the design shown in Figure (1-b) and used in the welding method is not very different from other designs. It was used only to ensure an even distribution of the temperature surrounding the sample and holds the sample.

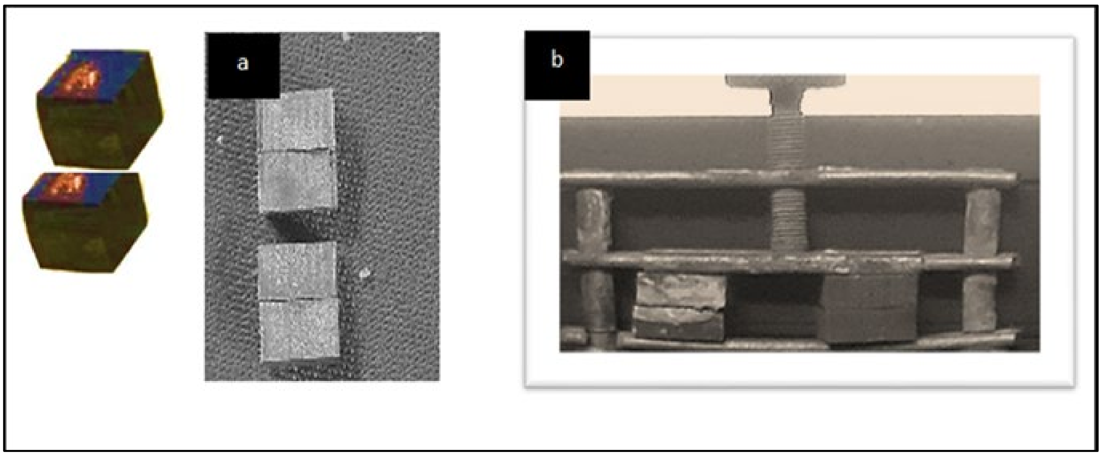

Figure 1: (a,b) samples prepared

Table 1: active filler alloy specification

Filler Type	Filler composition Wt %	Alloying content Wt%			Filler Condition	Brazing Temperature C°
		Ag	*Cu*	*Ti*		
F1	72Ag27Cu1Ti	72	27	1	baste	800
F2	71Ag26Cu3Ti	71	26	3	baste	900
F3	70Ag28Cu2Ti	70	28	2	baste	900
F4	70Ag26Cu4Ti	70	26	4	baste	950

4. Results and Discussion

4.1 The Microstructure of Bond with Filler Ag 72%wt, Cu 27%wt, Ti 1%wt

Figure 2 The material was first examined using an optical microscope. Figure 2 shows optical micrographs at 80,150,300,600X magnification. There were no notable fractures or gaps in the brazed joint, and the interface was confirmed to be continuous throughout. The whitish phase may be seen clearly all across the sample region. The breakdown of some base metal does occur owing to interdiffusion between the filler metal and the base metal in picture 1500x, as can be seen in (a, b, c). This stage is also rich in silver, copper, and very little titanium filler.

A typical diffusion brazing joint, as shown in Figure 3, consists of four zones: (I) an isothermally solidified zone, (II) a thermally solidified zone, (III) a bonding affected zone, and (IIII) a base metal zone, respectively.

During the holding brazing time, isothermal solidification formed the isothermally solidified zone. When the thermally solidified zone was cooled, the leftover liquid was immediately solidified. The liquid-solid transition reaction layer between the filler and the base metal forms farther distant from the joint centreline. Dissolution and inter-diffusion cause these reactions. As a result, the bonding line and diffusion affected zone (DAZ) are formed, denoted by (III). The SEM reveals isothermal solidification in large areas, which is linked to the Ag-solid solution phase. Thermally solidified zones resulting from partly isothermal solidification show in black patches, while diffusion-affected zones are not visible.

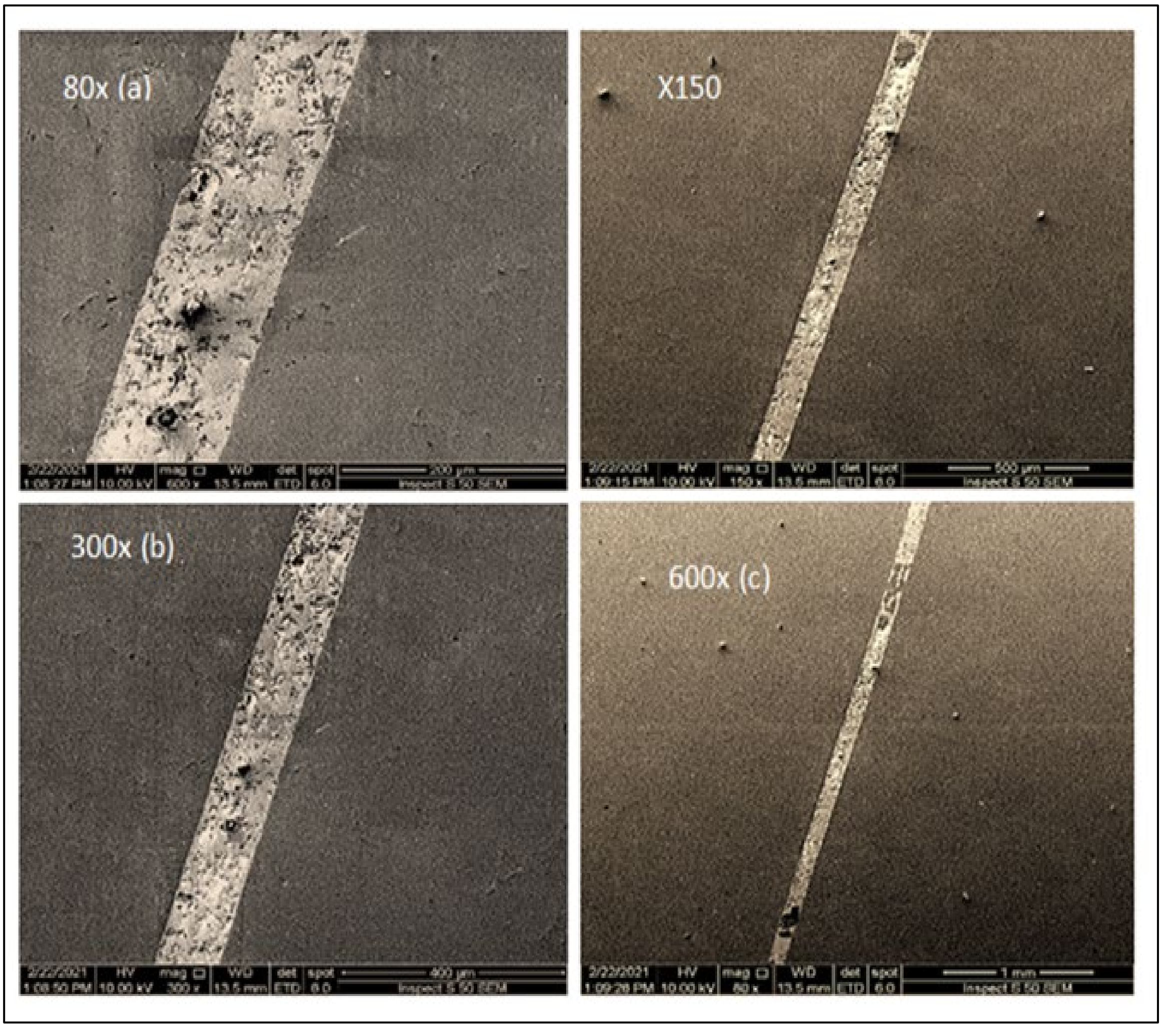

Figure 2: Microstructure of bond with filler(Ag72%wt+Cu27%wt+Ti1%wt)

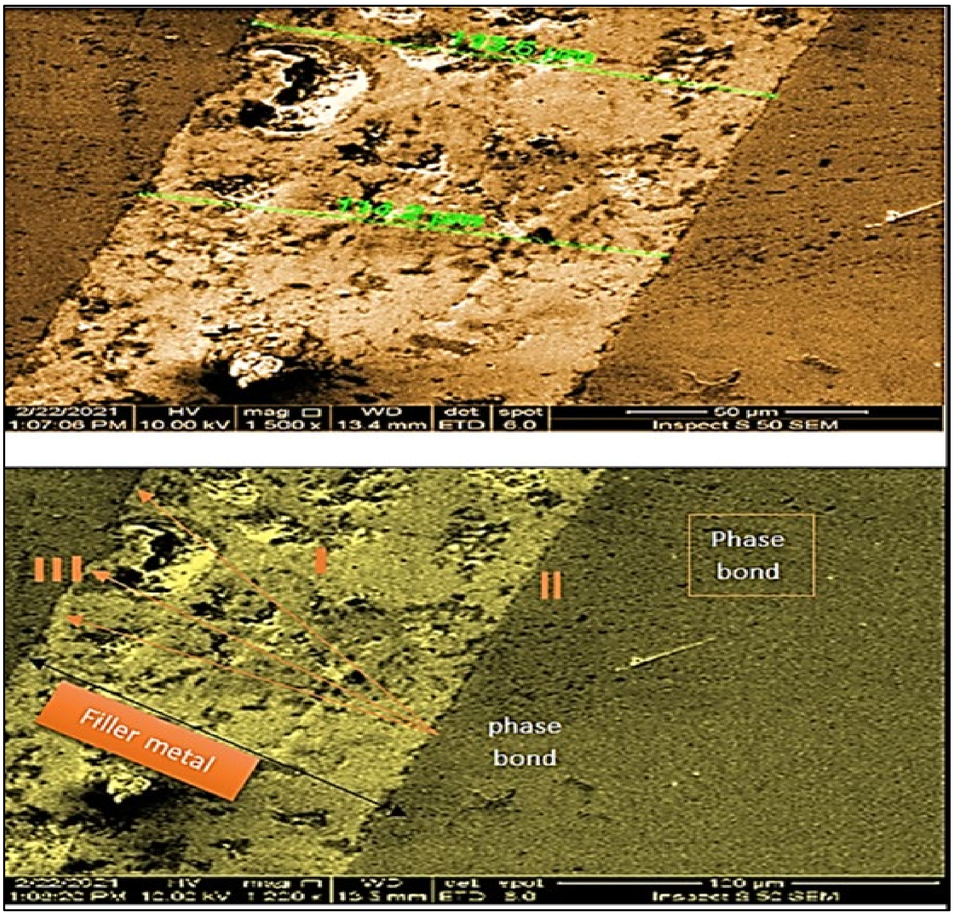

Figure 3: Phase Bond with Filler (Ag72%wt+Cu27%wt+Ti1%wt)

4.2 Microstructure of Bond with Filler (Ag70%wt+Cu28%wt+Ti2%wt)

Figure 4 (a, b, c, & e) shows that the joint has a solid metallurgical bond and a continuous connection, suggesting acceptable wettability. Fills the joint clearance or gap and eliminates possible voids at the interface between the two components by spreading via capillary action. The capillary force is caused by contact between the base metal and the filler metal; a considerable overlap and spread of silver and copper fill with the base metal, as well as a distinct spread of titanium, can be seen in picture 1500x.

Figure 4 (a, b, c, & e) shows the bond phase with filler (Ag70%wt+Cu28%wt+Ti2%wt). It's difficult to see the diffusion-affected zone. The binary phase of alpha+ beta is still present, and when the temperature reaches 880 C, it tends to completely transition to the beta phase. The phase transformation was not followed by chemical changes. The bonding phases of titanium and silver joined Ag-solid, and a little amount of Ag and Cu could have a substantial influence on joint strengthening.

Figure 5 also shows that when temperature brazing rises, the diffusion-affected zone becomes more active. There is virtually an interaction layer between the base metal and the filler metal when the holding duration is barely 10 minutes. When the amount of Ti in the base metal and filler metal was raised, a diffusion-affected zone developed, which was claimed to improve the base metal and filler metal joining strength.

And there is a wide spread of silver over the surface of the base metal, indicating a full fusion of silver and copper, which is clear to spread but not entirely smelting. Titanium cannot melt at this temperature, although it does play a part in diffusion.

4.3 Microstructure of Bond with Filler (Ag71%wt + Cu26%wt + Ti3%wt)

exhibits the microstructure of a specimen brazed at 900 C for 10 minutes with Ag-Cu-Ti filler. When the Ti content was increased from 1% to 3% w and the temperature was raised, the interfacial microstructure changed dramatically.

Figure 6 (a, b, c, & e) bond phase with filler (Ag71%wt+Cu26%wt+Ti3%wt). shows the situation. Ti possesses a body-centered cubic crystal structure in the beta phase, which was produced at a high temperature of 900 C. The metals have melted into a liquid phase at high temperatures, facilitating the diffusion process, which has been shown to extend the bonding phase to 200 µm thickness. Diffusion is the driving force behind the liquid solidification method's brazing junction. Isothermal solidification increased the surface of the filler in response to high temperature, as seen in Figure 7 The Ti-solid phase can be found in the thermal solidification zone. Temperatures of 950°C melt most of the solid phase, although a eutectic phase is still produced The EDS analysis revealed that the cu-weight ratio rose, forming more bonding material (see figure 6 (a, b, c, & e)). The high oxygen weight ratio indicated that oxygen interacted with Ag, resulting in silver oxide spots (see figure 6 (a, b, c, & e)).

The sample is degassing from argon gas at 500 C, and the microstructure was imaged at 950 C for Ag70 percent W+Cu26 percent +Ti4 percent W. When we compare sample three in Figure 3, the process of bonding and spreading of the filling is much more with the surface of the base metal, and we notice the existence of a percentage of oxygen as a result of the increase in temperature Furthermore, the images indicated that metals molten at high temperatures like to mix. Despite the scorching heat.

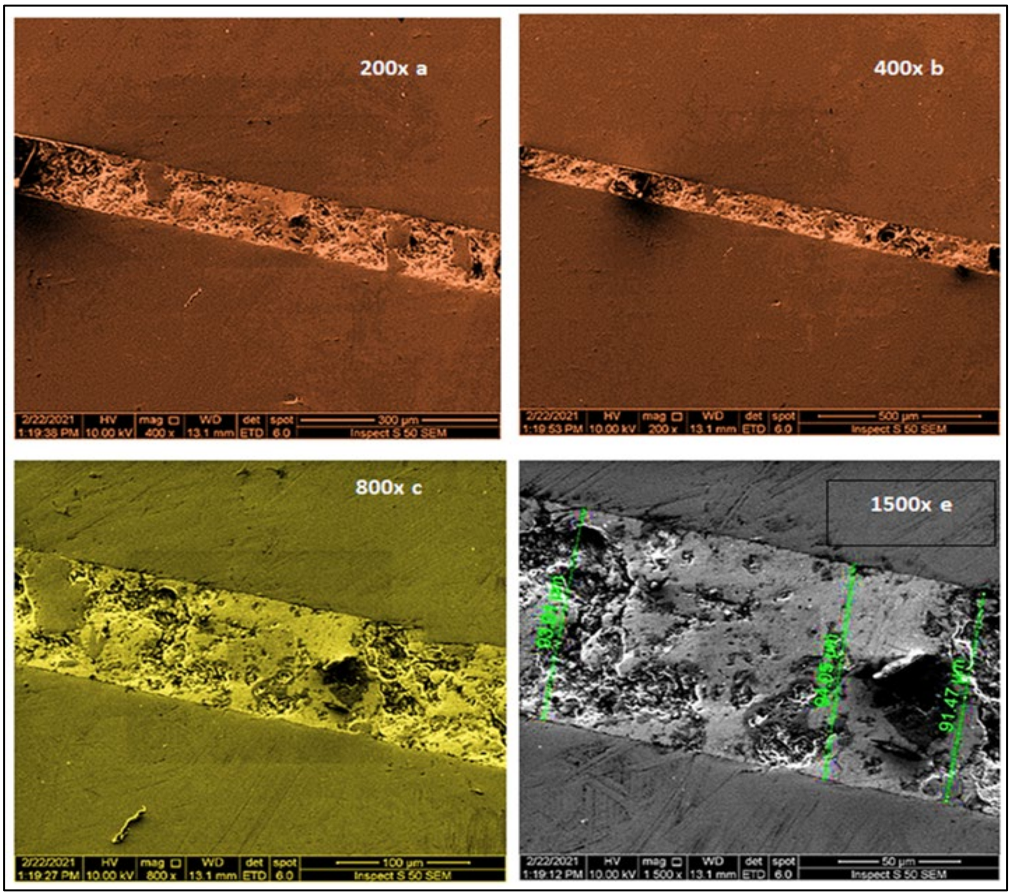

Figure 4: Microstructure of Bond with Filler (Ag70%wt+Cu 28%wt+Ti2%wt)

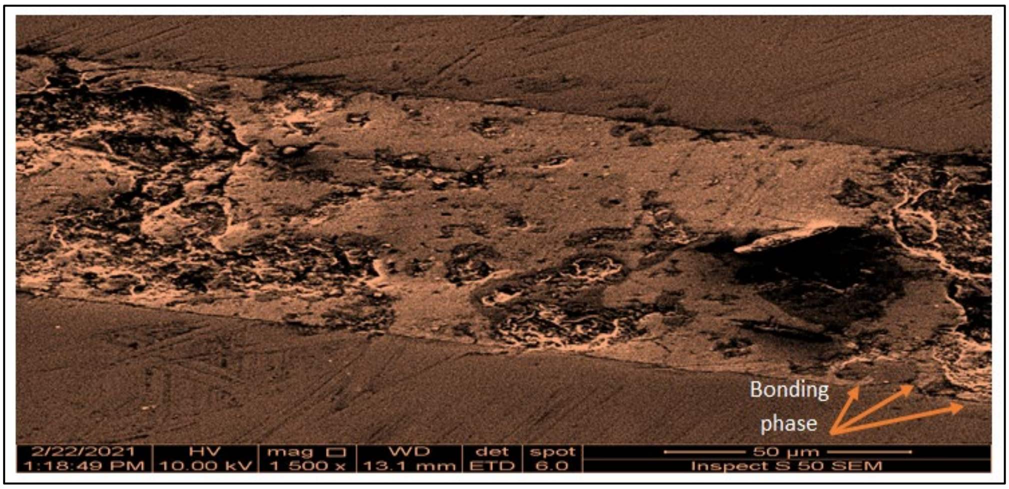

Figure 5: Bond Phase with Filler (Ag70%wt+Cu28%wt+Ti2%wt)

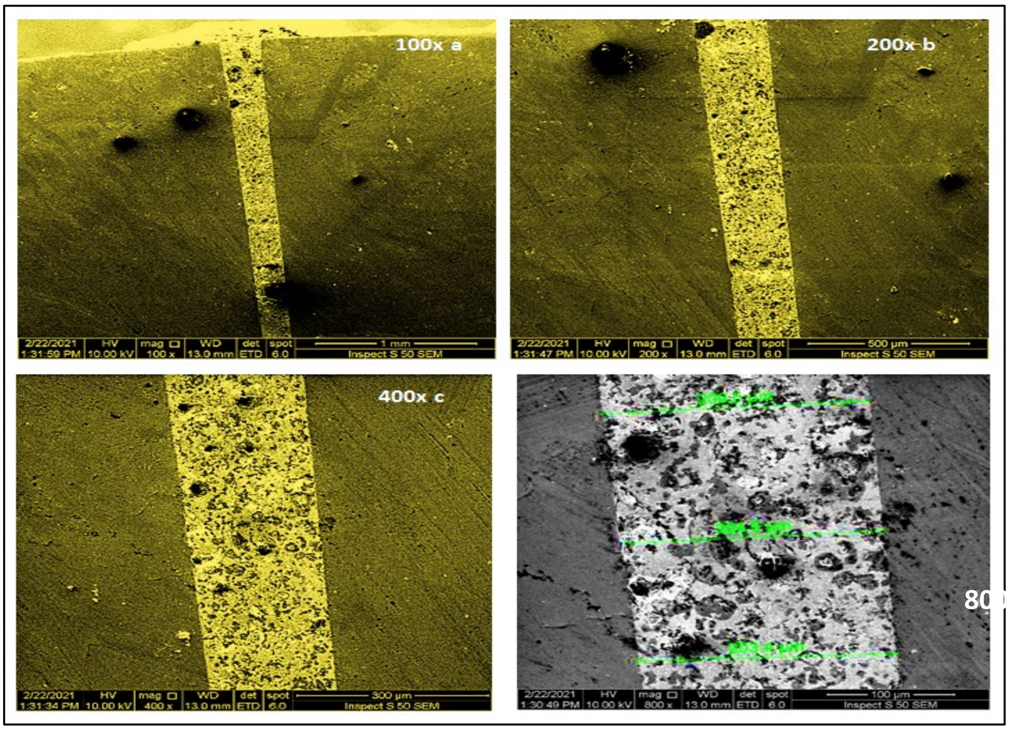

Figure 6: Microstructure of Bond with Filler (Ag17%wt+Cu26%wt+Ti3%wt)

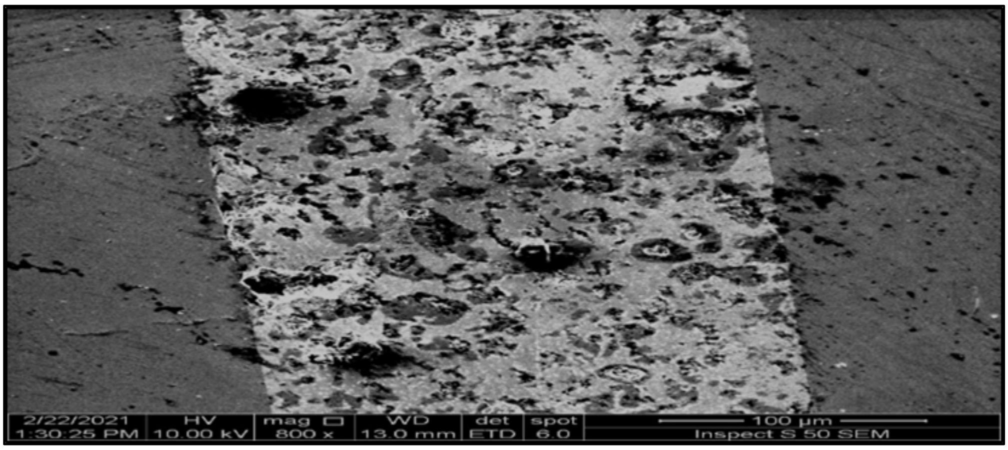

Figure 7: bond phase with filler (Ag71%wt+Cu26%+Ti3%wt)

4.4 The Microstructure of Bond Phase With Filler Ag70%wt+Cu26%wt+Ti4%wt

Figure 8 (a, b, c, & e) shows the situation, At 950˚C, the SEM revealed that there are no ternary compounds for Ag70% W+Cu26% +Ti4% W, but there is a solid solution with Ti (gamma-phase and beta-phase) phase shifts. The phase's regions do not appear as defined separated areas along the sample; instead, they appear as islands. The joint was roughly 180 µm thick. According to EDS analysis, Ag atoms dispersed and the weight ratio of oxygen rose slightly, as shown in Figure 8 (a, b, c &e) The absence of typical flaws such as micro voids and porosity can easily be observed in the interfaces. The physical contact was great, and the metallurgical bonding was outstanding At least two continuous reaction layers may be detected along the filler and base metal contacts It's worth noting that the braze metal has some dark spots. These findings suggest that there was interdiffusion between the filler metal and the base metals and that the reaction phases produced during the brazing process resulted in copper depletion in the molten filler metal. The microstructure of the brazed joint altered substantially at a higher brazing temperature, as seen in Figure 9. In this example, the silver in the brazed joint had nearly vanished.

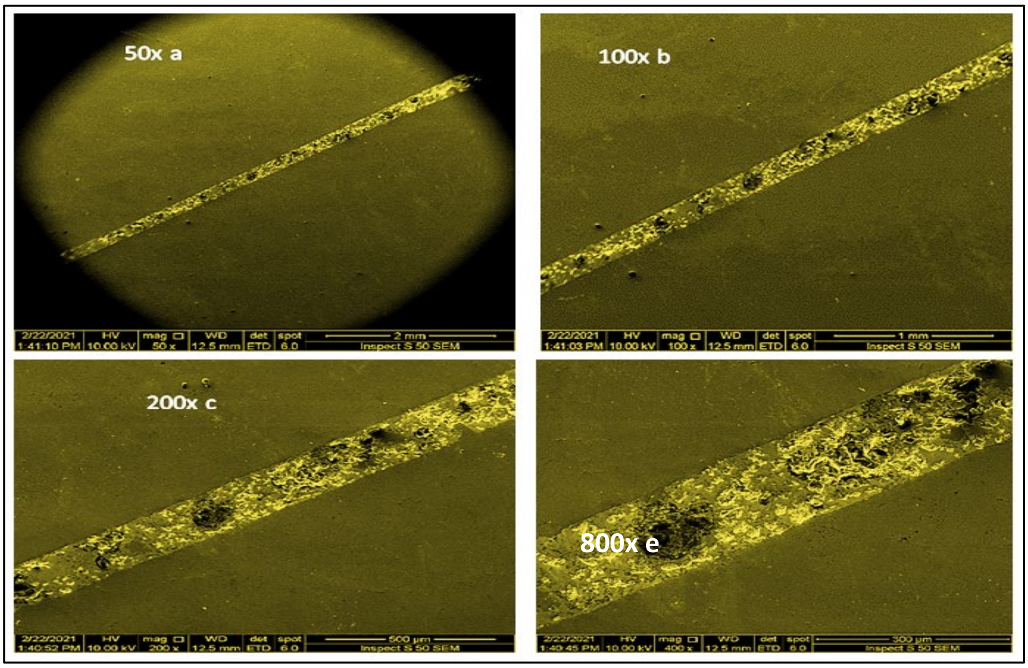

Figure 8: microstructure of bond with filler(Ag70%wt+Cu26%wt+Ti4%wt)

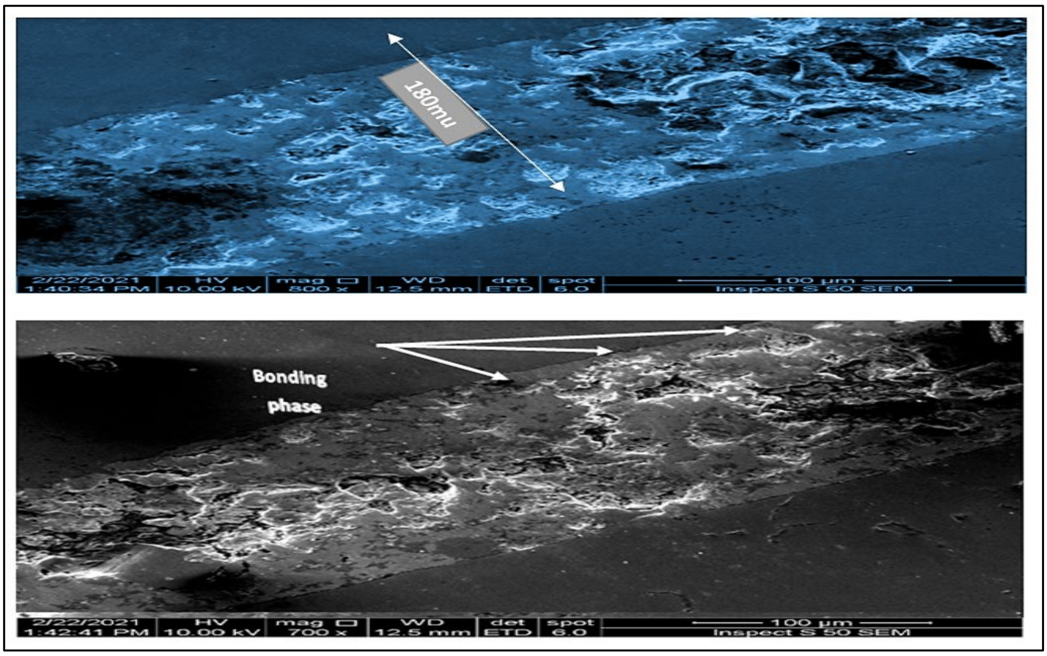

Figure 9: Bond Phase with Filler (Ag70%wt+Cu26%wt+Ti4%wt)

5. Conclusion and Recommendations

When brazing was performed on martensitic stainless steel using effective filler alloys of Ag, Cu, and Ti in different proportions and different temperatures, we concluded that the sample bonded by Ag70 Wt + Cu 26 Wt +Ti 4 Wt at 950 ºC exhibited an excellent metallurgical bond and continuous connection.

The diffusion of certain elements from Martensitic stainless steel and molten filler alloys (Ag-Cu-Ti) during the brazing process impacted the formation of reaction layers that crossed the centerline of the brazing region, as well as the bonding strength of the brazing joints.

We suggest that different ratios be used in terms of increasing the percentage of titanium in the filler material and different temperatures.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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