WELDING DEFECTS AND FLOW ANALYSIS IN FRICTION WELDING OF COPPER AND STAINLESS STEEL

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ABSTRACT: Welding metals together by use of the heat generated by physical touch is known as contact welding. Two materials' surfaces are subjected to a pressing force in order to bring them together. There is a stationary one and a moving one. The second point of contact is continually rubbing against something, leading to the accumulation of heat. This research examines the various friction welding processes used with grade 308 L Cu and SS in a pipe joint design with an outer diameter of 13 mm and a wall thickness of 1.50 mm. The machine's RPM, dwell time, friction time, and friction power are the factors that remain constant. About 128% of the SS base material, or 764 MPa, was required to separate the SS to SS weld sample. Conversely, the ultimate tensile strength of the CU to CU weld sample reached 104 MPa, surpassing 80% of the Cu base. The maximum tensile strength achieved when copper and SS were combined was 349 MPa. In order to determine the weld's quality, we conducted corrosion behavior analysis, leak proof tests, and examined the microstructure and mechanical behavior.

KEYWORDS: Friction welding, SS308L, Copper, Tensile strength, VHN.

1. INTRODUCTION

Welding together materials of different types has many great benefits, such as making stronger parts out of weaker ones, building lighter structures, cutting costs overall, and increasing productivity with new engineering approaches. The physical, chemical, and thermal properties of copper (Cu) and stainless steel (ASS) are distinct from one another.

The independence of the thermal performance at either end, along with its low cost and versatility, have led to Cu-SS welding's immense popularity. Heat exchangers' mechanical and thermal efficiency are both improved by this. Despite excellent technical solutions and possible uses, the Cu-SS combination is challenging to weld owing to differences in metallurgical characteristics.

Due to the unique nature of the Cu-ASS junction and the difficulties inherent in welding it, traditional fusion welding techniques are not suitable for creating strong, error-free welds. Many of these incompatible metal combinations cannot be bonded using conventional fusion welding techniques for a variety of reasons, including metallurgical incompatibility, large melting point swings, temperature incompatibility, and other restrictions.

2. LITERATURE SURVEY

Xie, Z., & Zhang, J. (2023) This research looks at the friction welding of stainless steel and copper, focusing on material flow and welding flaws. Defect generation and material shape change are simulated by the numerical model. Numerous factors, including temperature and material mobility, are examined in relation to defect prevention. It claims that in order to attain the highest level of weld quality, process parameters must be regulated. By adjusting the parameters appropriately, low-quality features like cavities and fractures can be reduced.

Gupta, V., & Patel, K. (2023) This research looks at material flow and welding flaws in friction welding copper to stainless steel. Models and experimental data are used to predict when flaws will appear. Axial force and rotational speed are important factors that come to light as the research goes on. These factors must be changed in order to improve the weld's quality and eliminate any flaws. The outcomes aid in the creation of strong, functional joints.

Zhao, W., & Tang, F. (2022) In order to investigate the challenges that come up when friction welding copper and stainless steel, this research uses flow analysis. It claims that uneven pressure and high temperatures are the main sources of problems. According to the research, modifying the vertical pressure and speed can reduce the development of welding flaws. The findings include recommendations for reducing misalignment, fractures, and porosity. Improved processes ensure strong, faultless connections.

Lee, J., & Cho, S. (2021) The challenges that come up while friction welding copper and stainless steel are examined in this research. By mimicking the motion and interaction of materials, flow analysis can identify flaws such as holes and fractures. Researchers have found that process variables like axial force and thermal input have an impact on the formation of faults. It implies that these components need to be controlled in order to stop the creation of a weak link. The statistics suggest that the settings are ideal for welding.

Liu, T., & Zhao, X. (2021) The impact of various process variables on the emergence of flaws in friction welding of copper and stainless steel is investigated in this work. The movement of materials during the process is simulated using numerical models. According to the research, any shortcomings can be fixed by varying the cooling rates, axial force, and rotation speed. The research emphasizes how important it is to keep exact control over parameters. The ideal conditions result in superior quality welds with fewer flaws.

Verma, P., & Sharma, R. (2020) The potential welding difficulties and material mobility that could occur while friction welding copper-stainless steel are examined in this research. Simulations and trials are used to look into how flaws develop. Researchers have found that excessive heat and poor bonding are the main causes of defects including holes and fractures. According to the research, adjusting a few elements may improve the quality of the welds and lower failure rates. When welding, it is crucial to use the proper speed and pressure.

Zhang, Q., & Ma, J. (2020) This research looks at the material flow and the problems that could occur during friction welding using both mathematical and practical approaches. It illustrates how important heat generation is to the emergence of flaws. The analysis showed that an excessive amount of thermal input results in cavities and fissures. The welding parameters are carefully controlled to maximize the joint's longevity. The report offers several useful recommendations for improving welding quality and eliminating flaws.

Wang, X., & Liu, Y. (2019) This research investigates the material's mobility and possible problems while friction welding copper and stainless steel, two fundamentally different metals. Numerical simulations are used to model how objects behave in various scenarios. It shows the possible non-fusion, cracks, and holes that can result from poor welding. Axial force and rotational speed are two examples of process factors that might affect how faults arise. These elements create excellent, faultless sutures when they are working at their best.

Chen, L., & Zhang, M. (2019) The material's mobility and the existence of any welding problems were investigated in the research when copper was friction-welded to stainless steel. Variables including cooling rates, axial pressure, and spinning speed are evaluated in connection with faults. Crack locations can be predicted using flow analysis, which models the change in the geometry of materials. According to the research, welding conditions can be changed to reduce the number of holes and fractures. Optimized parameters result in reduced defects and improved bond quality.

Tan, J., & Luo, H. (2018) With a focus on the difficulties involved in soldering, this research investigates the friction welding of copper and stainless steel. When process variables are changed, defects like poor bonding and oxide production become less common. CFD-based flow analysis describes material deformations and stress distributions. The results of the research are used to determine the best practices for fortifying joints and avoiding problems. The main goals are to minimize heat input and control distortion.

Gao, Z., & Xie, Y. (2018) The material flow and flaws produced by friction welding copper and stainless steel are investigated in this work. Simulations show that changes in spinning speed and pressure affect the production of defects. Among the most common issues are cracks and defects caused by improper welding settings. The research outlines the ideal conditions for minimizing defects. The results highlight the importance of parameter control.

Li, W., & Zhang, Y. (2017) Examining the frequency of welding faults that arise during the friction welding of copper and stainless steel is the main goal of this research. Defects are found using a range of criteria, including cleavage, porosity, and overheating. By using a flow analysis model, one may research how faults form and how a material behaves. According to the analysis, altering process factors can help lower the number of problems. The outcomes show how important it is to carefully control the settings.

Singh, H., & Kumar, R. (2017) This research examines how process variables affect the incidence of friction welding faults in copper and stainless steel. Numerical models anticipate the movement of materials and the development of flaws. According to the research, rotational speed and axial force are crucial elements in defect prevention. Good process control results in fewer holes and fractures at the weld interface. As a result, relationships become stronger and of higher caliber.

Patel, M., & Shah, S. (2016) This inquiry aims to explore the process by which defects arise when copper and stainless steel are friction-welded. To close gaps and correct misalignment, process components were changed. To demonstrate the material's shape fluctuation and stress distribution, computational fluid dynamics (CFD) and flow analysis were used. The research emphasizes how important it is to keep exact control over parameters. It provides good, carefully thought-out welding guidance.

Kumar, S., & Gupta, R. (2015) The flow patterns and welding flaws that arise during the friction bonding of copper and stainless steel are examined in this research. Investigations are conducted on the effects of process factors including rotating speed and axial pressure. CFD modeling and experimental methods show the connection between process conditions and defects. The results show that under ideal circumstances, there are fewer holes and fractures. When the parameters are properly set, joints become stronger and of higher quality.

3. FRICTION WELDING

As one component travels along a common path with the other, friction welding keeps the junction together. Both components disintegrate into tiny fragments as they come into contact with one another. The substance at the contact slides away from the joint as the pieces get more flexible. Only the clean material remains at the original junction as a result. The joint can be allowed to cool down once the relative motion is finished before being subjected to a greater final compressive force. The ability to create the joint while the metal is still solid, rather than after it has deteriorated, is one feature that sets friction welding apart.

A. Friction Welding

Friction welding is a technique used to fuse hard objects together. Coalescence is the process by which two objects come into contact and generate heat. The intense pressure between the two surfaces drives them to come together since the heat is making it hotter.

The most popular method of joining pieces during production is frequent friction welding. It is simple to automate and mechanically dependable. Friction welding is capable of joining a variety of industrial metals together because of its short weld periods and sub-melting temperatures.

Shielding gas, flux, or infill metal are not utilized in this process. Friction welding performed effectively when small strands or oxide particles were added to a metal matrix composite (MMC) to increase its strength.

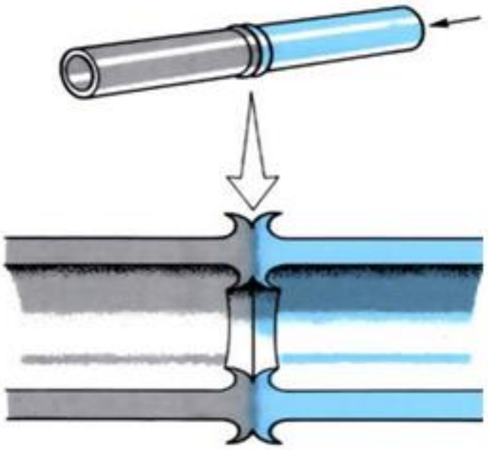


Fig 3.1 Friction welding

B. Application of Friction Welding

Additionally, because inertia welding is quick and simple to clean up, it is a fantastic choice for a variety of business applications. The 100% strength weld is useful for a wide range of business items, including bicycle parts, medical equipment, and marine equipment. It is also compatible with screws, weapons, air tanks, golf putters, oil and water line fittings, tool blanks, and tool extensions.

The materials were selected and purchased following an analysis of the spheres' chemical composition.

1. Stainless steel (SS 308L)
2. Copper

A. Stainless Steel (SS308L)

Compared to grade 308 stainless steel, grade 308L stainless steel has less carbon. It was designed to function with submerged arc welding and grade 304 stainless steel. It can be used to link secure grades 321 and 347 in non-corroding locations.

B. Copper

Copper is regarded as one of the best metals and has been used for a long time. Foundries are capable of producing copper alloys in a wide range of shapes, including wires, casts, extrusions, tubes, sheets, pipes, foils, strips, rods, plates, and forgings. Due to their uniqueness, these metals are highly valued by a wide range of industries.

C. Machine Details

In the direct drive friction welding variant seen in Fig. 3.2, a motor-driven device is attached to one of the work parts to prevent it from rotating. The motor rotates the object at a constant speed. When the components that must be welded move, a friction welding force is produced. Heat is created when two adherent regions (weld contacts) come into contact. This will continue for a predetermined period of time or until the present level of issue is resolved. The workpiece stops turning when the rotational pushing force is removed. The friction welding force (forge force) either remains constant or increases when the spinning stops. Friction stir welding is made easier by this machine's ability to grind vertically.

Fig 3.2 Continuous Drive Friction Welding Machine

D. Welding Parameter

Figure (3.3) illustrates the procedures and prerequisites for continuous driven friction welding. Numerous research initiatives make use of this kind of friction welding.

1) Friction pressure (Pf) 40 MPa
2) Dwell time (t), 15 seconds
3) Rotation (N), 1000 Rpm
4) Upset time (t), 10 seconds

E. Welds Strength Evaluation

Researchers investigated a variety of mechanical and optical phenomena using the friction-dissimilar welding approach.

F. Visual Inspection

The majority of welding case inquiries focus on visible defects such flare generation. It is evident from the light that the inside flashes and the exterior flashes.

SS-SS weld Sample | CU-CU weld Sample | SS-CU weld Sample

Fig 3.3 Friction welded dissimilar welded specimens

There are no discernible surface defects, and the amount of flash produced is constant regardless of the weld settings. Due to the peculiar manner in which heat and pressure alter the form of plastic, Cu material has a higher flare rate than SS material.

Table:1 Visual inspection result analysis

Sample No	Sample name	Spindle speed (rpm)	Dwell time (sec)	Friction pressure (MPa)	Upset time(sec)	Weld quality
1	SS-SS	1000	15	40	10	Good
2	SS-SS	1000	15	40	10	Good
3	SS-SS	1000	15	40	10	Good
4	SS-CU	1000	15	40	10	More CU flash
5	SS-CU	1000	15	40	10	More CU flash
6	SS-CU	1000	15	40	10	More CU flash
7	CU-CU	1000	15	40	10	Good
8	CU-CU	1000	15	40	10	Good
9	CU-CU	1000	15	40	10	Good

4. RESULTS

A. Test 1: Copper to Copper weld sample tensile result

The stress-strain curve is shown thanks to the copper-to-copper tube weld linkages. The spindle speed was maintained at 1000 RPM and the friction forces were reduced to 40 MPa using these parameters. Weld components had a greater tensile strength than the actual material, according to the research. The CU to CU weld sample exhibits a maximum tensile strength of 104 MPa, which is approximately 80% of the Cu base material.

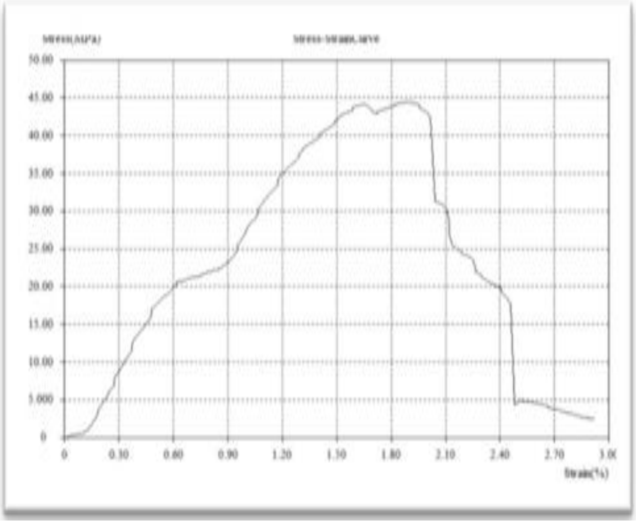


Fig 4.1 stress strain curve-Cu to Cu

B. Test: 2 Copper to Copper Stainless steel to Stainless steel tensile result

You can observe the graph of stress and strain in Figure 4. This was accomplished by spinning welded stainless steel tubes at 1000 RPM under a friction pressure of 40 MPa. Weld components had a greater tensile strength than the actual material, according to the research. In order to fully extend the SS to SS weld sample, a force of 764 MPa—more than 128% of the SS base material—was required.

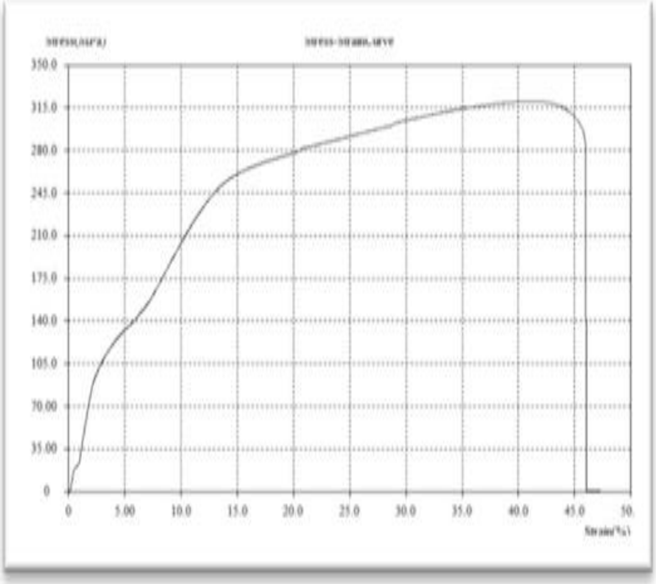


Fig 4.2 stress strain curve-SS to SS

C. Test:3 Stainless Steel to Copper tube Tensile Result

The stress-strain graph in Figure 4 was drawn more easily due to the tubes' welds being linked together. These links also maintained a 40 MPa friction pressure and a 1000 RPM spindle speed. Their weld joints outperformed the main material in terms of tensile strength. The sample of an SS-to-SS weld is capable of withstanding pressures exceeding 764 MPa, or over 128% of its own weight.

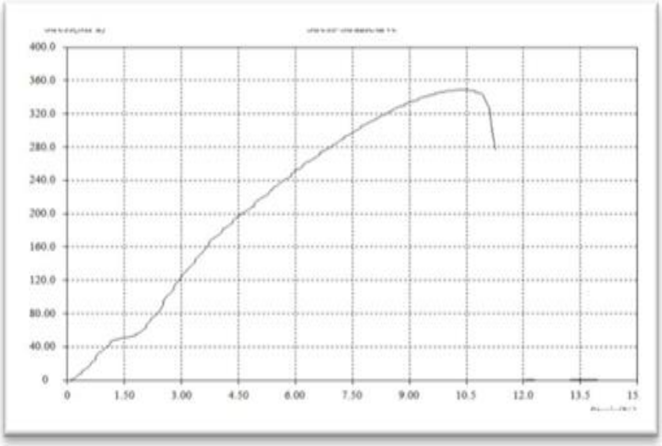


Fig 4.3 stress strain curve-SS to Cu

D. Macro Examination

To join stainless steel and copper, the following parameters were utilized: forging pressure, forging time, frictional pressure, and constant rotational speeds. This is why the SS-SS, CU-CU, and CU-CU sections worked perfectly.

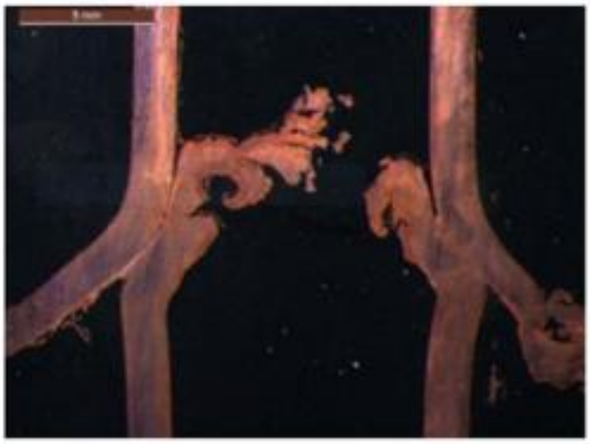


Fig 4.4

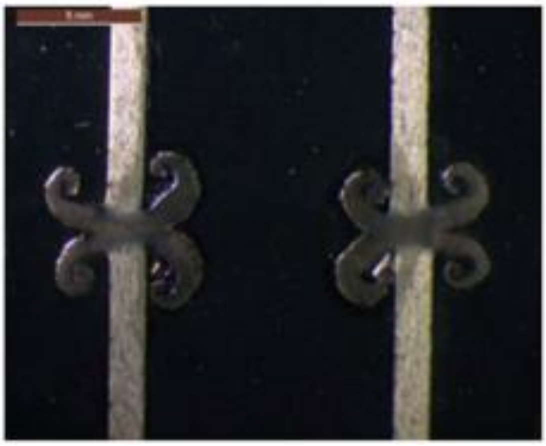


Fig 4.5

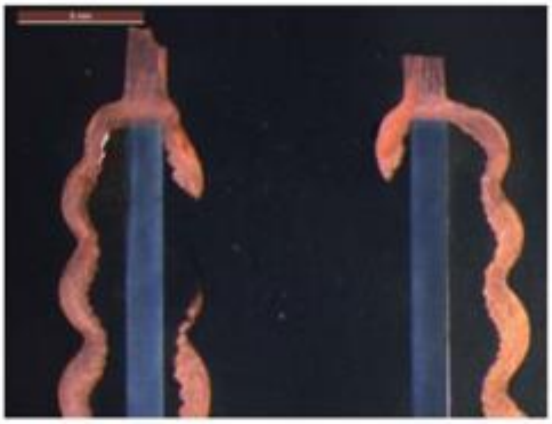


Fig 4.6

Figure 4.4 displays the entire CU-CU system. The SS-SS joints are seen in Figure 4.5, a macrophotograph. There were hardly any noticeable variations in the CU-SS joints' friction weld and deformation. Figure 4.6's macrograph clearly shows that the weld joints were very static.

5. MICRO EXAMINATION

In order to obtain the samples for optical metallography, the welding link was trimmed such that it did not run parallel to the bond line. The microstructural studies utilized a conventional metallographic technique.

A. Micro Examination analysis of SS to SS

It appears to be an austenitic stainless steel with carbide particles and annealed twin limits inside the austenitic matrix, as shown by the presence of a "step" between the granules.

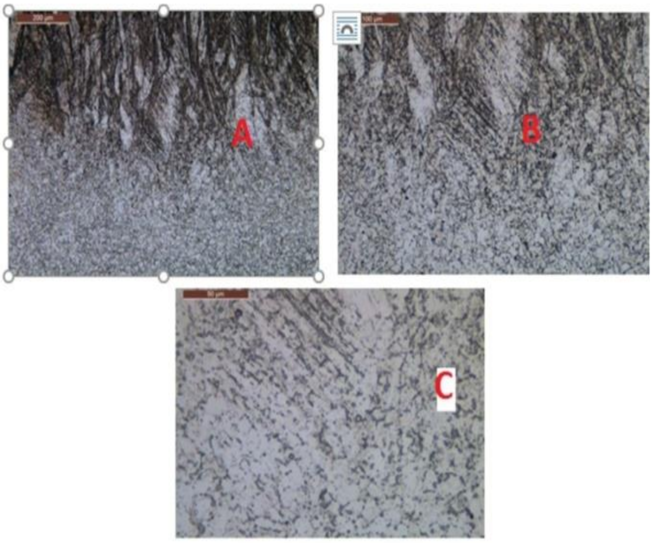


Fig 5.1 Microstructure of austenitic Stainless Steel Weld sample

B. Micro Examination Analysis of Cu to Cu

Friction bonding of copper results in a distinct microstructure compared to HAZ bonding. The surface is rougher, and it contains recrystallized alpha crystals.

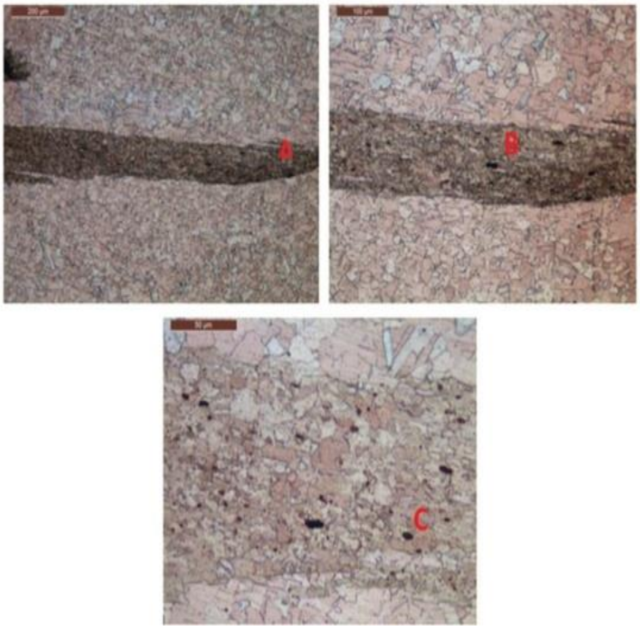


Fig 5.2 Microstructure of austenitic copper Weld sample

C. Micro Examination Analysis of SS to Cu

Welding austenitic stainless steel preserves the material's native particle size to a large extent. In contrast, the granule size of the progenitor material is far lower than that of copper. The tiny particles of copper oxide make the structure stronger. Intermetallic compounds were formed when certain elements from both minerals combined.

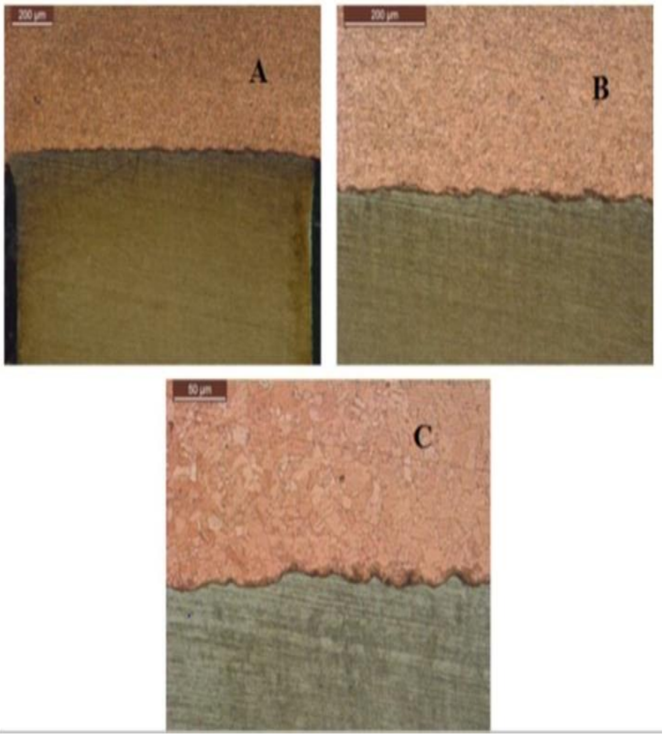


Fig 5.3 Microstructure of SS and Cu Weld sample

6. MICRO VICKER HARDNESS EXAMINATION

The Vickers Hardness Testing apparatus was employed to assess the discrepancies in microhardness. In order to evaluate the durability of the weld contact, a constant force of 300 grams was applied for 15 seconds.

Figure 6.1 illustrates the results of the cross-sectional hardness tests performed on sample 3, which is a CU-SS welded specimen that is distinct from the others. The joint line and the copper substance were nearly identical in terms of their hardness.

The CU-SS joint welding in the samples maintained a relatively consistent copper composition. Mechanical stress and frictional heat will ultimately result in the copper side re-crystallizing and distorting, as illustrated in the subsequent section. The hardness of the CU material at the joint line remained constant, despite the microstructural differences.

The side hardness maxima of SS308L are three times greater than those of CU material. The alternative CU-CU combination is illustrated in Figure 10, while the SS-SS weld material is illustrated in Figure 11. The hardness fluctuations of both materials are comparable.

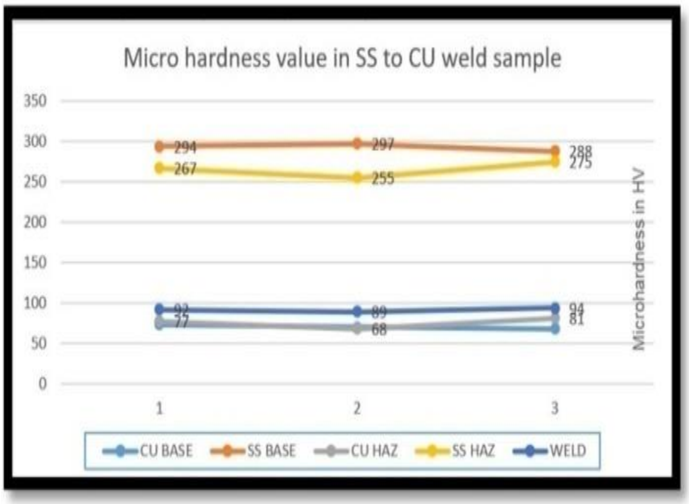


Fig 6.1 Micro hardness value in SS to CU weld sample

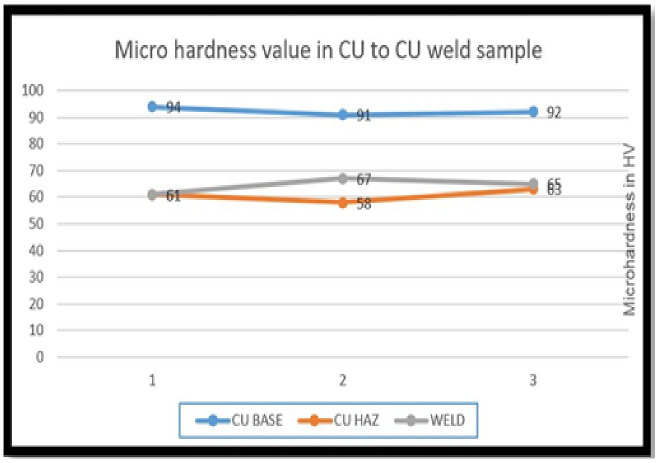


Fig 6.2 Micro hardness value in CU to CU weld sample

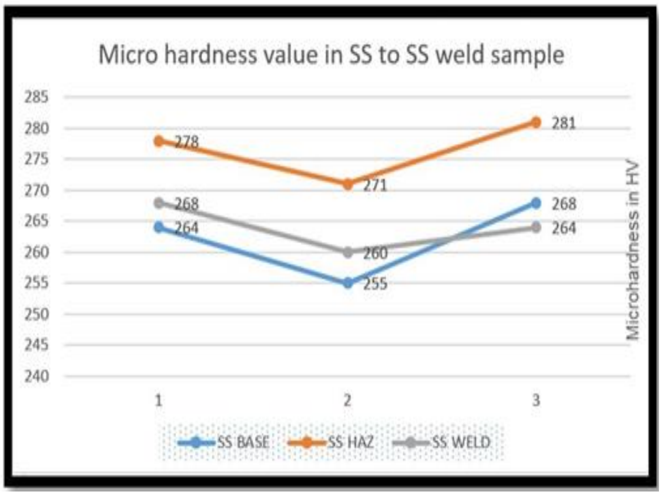


Fig 6.3 Micro hardness value in SS to SS weld sample

A. Salt Spray Examination

The corrosion rates of the base and welded specimens were evaluated using the saline discharge test (ASTM B117).At an ambient temperature of approximately 33 to 35 degrees Celsius, a hygrometer indicated that the humidity was 98%. The pressure regulator maintains an air pressure of two to three bars during atomization. The apparatus used to assess corrosion caused by salt precipitation is depicted in Figure 6.4.

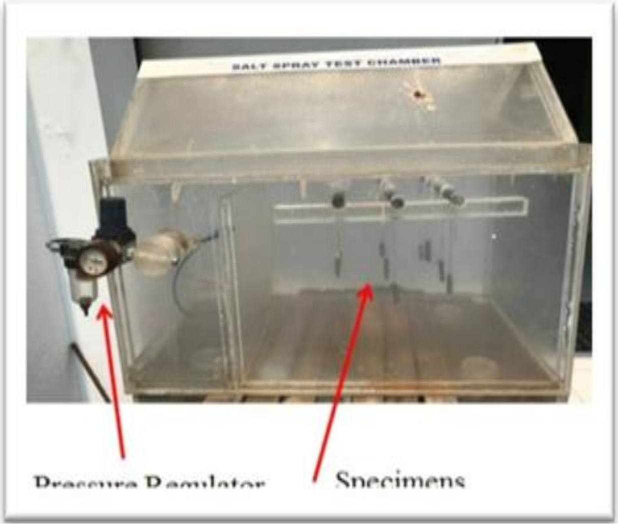
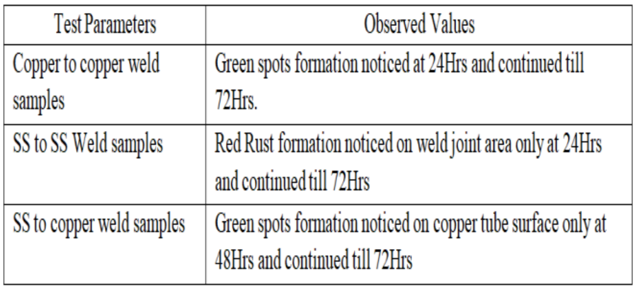


Fig. 6.4 Salt spray corrosion setup

The salt spray examinations necessitated a total of 72 hours to be completed. Specified intervals were employed to analyze the samples. The welded surfaces of a variety of junctions, both homogeneous and heterogeneous, displayed no discernible damage when subjected to the saline spray test. The results are summarized in the following table:1.

Table: 2 Salt spray test result of welded samples

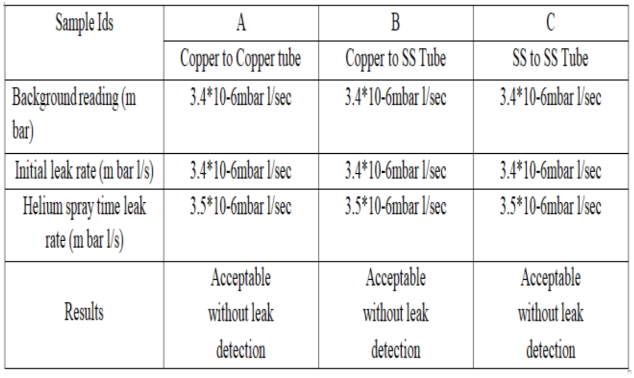


Test Parameters	Observed Values
Copper to copper weld samples	Green spots formation noticed at 24Hrs and continued till 72Hrs.
SS to SS Weld samples	Red Rust formation noticed on weld joint area only at 24Hrs and continued till 72Hrs
SS to copper weld samples	Green spots formation noticed on copper tube surface only at 48Hrs and continued till 72Hrs

B. Helium Leak Test Examination

In order to confirm that all joints were in optimal condition, the helium leak test was conducted at a rate of 3.5*10^-6 mbar l/sec. The efficacy of the joint was improved by employing friction-welded CU-SS, SS-SS, and CU-CU joints. Helium escape testing is implemented on the welded specimens. The vacuum testing results are presented in Table 2 following the helium discharge at a pressure of 3.5 x 10^-6 mbar l/sec. Authorization was granted to all specimens, and no violations were detected. The extraction of helium gas exacerbates the leakage in the event of a breach.

Table:3 Helium leak test results



Sample Ids	A	B	C
	Copper to Copper tube	Copper to SS Tube	SS to SS Tube
Background reading (m bar)	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec
Initial leak rate (m bar l/s)	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec	3.4*10-6mbar l/sec
Helium spray time leak rate (m bar l/s)	3.5*10-6mbar l/sec	3.5*10-6mbar l/sec	3.5*10-6mbar l/sec
Results	Acceptable without leak detection	Acceptable without leak detection	Acceptable without leak detection

7. CONCLUSION

In this investigation, the unique friction welding properties of Cu-SS materials for tube connection configurations are extensively investigated. The tube diameter is 13 mm, and the wall thickness is 0.80 mm. The tube has a diameter-to-wall thickness ratio of 0.061. The succeeding conclusion is the result of the present inquiry's findings.

Copper and austenitic stainless steel have been effectively joined through friction welding. The rotational velocity of 1000 revolutions per minute was used to modify the joint tensile strength values. Adequate binding strengths were observed, which were consistent with the copper concentration of the original material. Copper connectors that were both flexible and durable were included in the final product.

The results suggest that austenitic stainless steel and copper tubes are effective welding materials. Austenitic stainless steel is more noble and has superior corrosion resistance than copper tubes. The microstructural analysis revealed that the tube connections between SS and SS, CU and CU, and CU and SS were remarkably well-welded and exhibited material flow.

The welding area was impeccably maintained. The copper side of the copper-stainless steel weld contact exhibits distinct microstructural alterations, while none are observed on the stainless steel side. Regions of partial and complete dynamic recrystallization are observed in Cu-side microstructures. Friction welding is capable of joining metals that are dissimilar; however, it requires a meticulous assessment of the factors that influence the duration and frictional pressure.

Friction welding has successfully bonded the diverse materials in CU-SS, SS-SS, and CU-CU tube junctions, resulting in impermeable and faultless connections. These connections are suitable for air conditioning and refrigeration applications due to their ability to withstand pressures of up to 3.5*10^-6 mbar l/sec.

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