Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47121

Study the Effect of Adding Pure Copper Between Steel for Spot-Welding to Improve Mechanical Properties

Leo Davoodianes, California State Polytechnic University, Pomona

I am a undergraduate student enrolled in Industrial and Manufacturing Engineering at California State Polytechnic Univesity, Pomona expecting to graduate in Spring 2026.

Dr. Moe Rabea, California State Polytechnic University, Pomona

Extensive experience in applied research and development in material and manufacturing engineering for improving properties of diverse types of material surfaces. In-depth experience of fabricating nanostructured materials for supercapacitor energy storage.

Study the Effect of Adding Pure Copper Between Steel for Spot-Welding to Improve Mechanical Properties

Abstract

Resistance spot welding (RSW) is a key manufacturing process widely taught to engineering students due to its prevalent use in industry. While students across various engineering disciplines typically learn RSW applications specific to their fields, this paper aims to provide a comprehensive understanding valuable to all students in engineering. This study focuses on the challenges of using RSW to join two pieces of 1008 Carbon Steel, incorporating pure Copper (Cu) powder between the plates to improve weld quality. From an engineering education perspective, this work emphasizes developing a deeper understanding of how material properties influence weld performance, enabling students to bridge theoretical concepts with practical applications in material science and welding technology. These materials are explored for their potential to enhance joint integrity and weld performance. By investigating these welding techniques, this work seeks to equip students with a deeper understanding of material compatibility, advanced welding processes, and optimization strategies. Specifically, the findings highlight how material science principles can be directly applied to practical engineering problems, enabling students to develop critical problem-solving skills. These insights support the development of curricula that integrate experimental methods with theoretical learning to better prepare students for industry challenges. The findings are designed to enrich educational experience, bridging theoretical knowledge with hands-on applications in both academic and research settings. This research also provides valuable insights for students preparing for industry roles, where mastery of complex welding challenges and material science is critical. As Copper is an exceptional conductor, we observed better current throughout all the weld cycles compared to our non-interlayer control specimens. Our study arrived at the conclusion that the tensile strength and joint hardness between steel plates increased due to the introduction of copper powder. The copper interlayer also resulted in better corrosion resistance at various temperatures.

Keywords: Resistance Spot Welding, Copper Interlayer, Tensile Strength, Mechanical Properties

Introduction

Resistance Spot Welding (RSW) is a process used to join metal plates by applying heat and pressure at localized points. As shown in Figure 1, two copper alloy electrodes press against the metal plates with controlled force to ensure proper electrical contact while preventing excessive deformation. A high electrical current (denoted by "A" in Figure 1) flows through the electrodes and the plates, generating localized heat at the interface due to the electrical resistance of the materials [1],[2]. This heat melts the metal surfaces, forming a molten nugget. The current is then turned off while the force is maintained, allowing the molten metal to solidify and create a strong joint at the weld spot. Once the joint cools, the electrodes are removed, leaving a durable weld. The copper alloy electrodes are essential for their excellent electrical and thermal conductivity, as well as their resistance to wear during repeated welding cycles. This efficient and fast process is widely used in industries such as automotive, aerospace, and manufacturing for creating high-strength joints with minimal material distortion. Minimal preparation is required when using RSW, and it is an easily automated process making it suitable for robotic systems. It is a joining method that requires minimal consumables (ie. no filler material required) and requires less energy compared to other methods. Important to note, RSW creates a smaller heat affected zone which translates to less adverse effects on the material properties of the base materials being used. The parameters that determine weld quality are the clamping force of the electrodes, the electric current passing through the electrodes, the length of time the force/current are applied, and the electrode contact diameter [3].

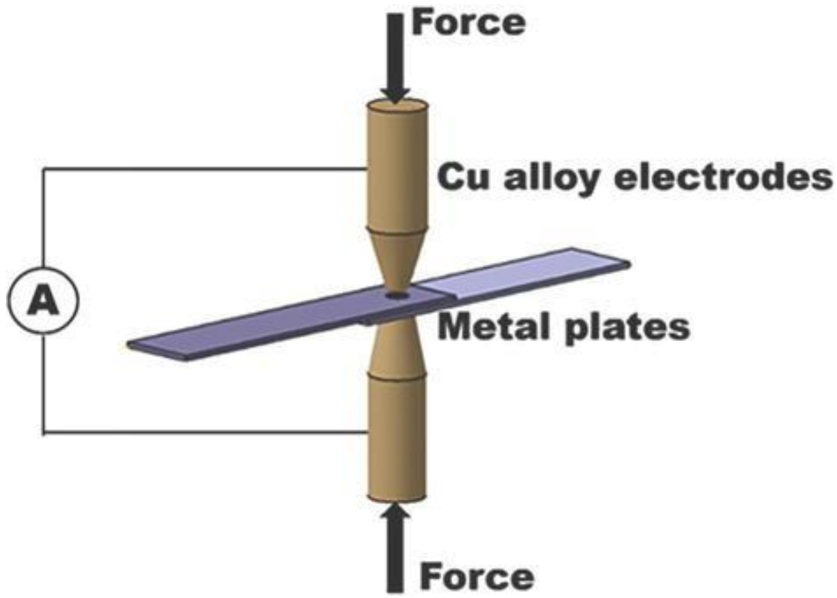

Figure 1: Diagram of RSW process [1].

Beyond its industrial significance, RSW is also widely taught in engineering curricula as a fundamental welding process. Hands-on welding experiments, such as the one conducted in this study, provide students with practical exposure to welding principles, material science, and mechanical testing. Being engaged in experimental work allows students to bridge theoretical knowledge with real-world applications, strengthening both their problem-solving and analytical skills. The insights gained from this research not only contribute to technical advancements in spot welding but also highlight the role of laboratory-based learning in engineering education.

While spot welding of similar materials such as two sheets of 1008 carbon steel is straightforward, introducing an intermediate layer can enhance or hinder the weld properties, depending on the intermediate material and application of the finished piece. This study specifically investigates copper as an interlayer due to its exceptional thermal and electrical conductivity, properties that align with our goal of improving weld uniformity and strength. There is a need to enhance the scope of RSW in terms of joining dissimilar materials. Blending different desired material properties two alloys have into one finished piece will only add to the advantages of RSW, and many studies have been done using various materials as interlayers [4].

Many materials including nickel, aluminum, titanium, copper alloys, zinc coated steel, and magnesium alloys have previously been studied regarding spot welding processes [5].

Though, pure copper itself, known for its excellent electrical and thermal conductivity, has seen limited investigation as an intermediate layer in resistance spot welding. Investigating less-studied materials like copper fosters critical thinking and problem-solving, encouraging students to explore unconventional solutions and analyze material behavior in more complex engineering scenarios. This study aims to evaluate the effect of pure copper powder as an interlayer between 1008 carbon steel sheets. By analyzing the mechanical properties of the welds, we aim to provide valuable insights into the suitability of this approach for industrial applications.

Another aspect to consider when joining metals through all welding methods, including resistance spot welding, is the corrosion of the materials being joined. Corrosion plays a critical role in the performance and durability of resistance spot-welded joints, particularly when incorporating dissimilar materials such as 1008 carbon steel and pure copper powder as an intermediate layer. The electrochemical interaction between carbon steel and copper introduces potential for galvanic corrosion due to their differing electrochemical potential. In the presence of an electrolyte, such as moisture or environmental contaminants, the steel (acting as the anode) tends to corrode more rapidly compared to the copper (the cathode). This galvanic reaction can lead to localized material degradation, especially at the welded interface, where material interactions are most concentrated.

Materials and Methods

Materials

Sheets of 1008 carbon steel, each 0.8mm in thickness, were used. The intermediate layer consisted of pure copper powder with an estimated particle size range of 40-50µm. Table 1 presents the chemical composition of the materials.

Table 1: Chemical composition of materials used.

Material	C (%)	Mn (%)	Si (%)	Fe (%)	Cu (%)
1008 Steel	0.08	0.30	0.15	99.47	-
Pure Copper Powder	-	-	-	-	99.9

Sample Creation

Two sheets of 0.8mm thick1008 carbon steel were welded together to create our control samples without an intermediate layer. Similarly, two sheets of 0.8mm thick 1008 carbon steel were welded together to create our samples with the addition of an intermediate layer of pure copper powder. For each test, three control samples were created, and three samples with intermediate layers were created. We tested three samples of each type on every test and took the average from the results to use as our data. All twenty-seven samples were welded using a water cooled 1-24-20 type ACME rocker arm Resistance Spot Welding machine as shown in Figure 2.

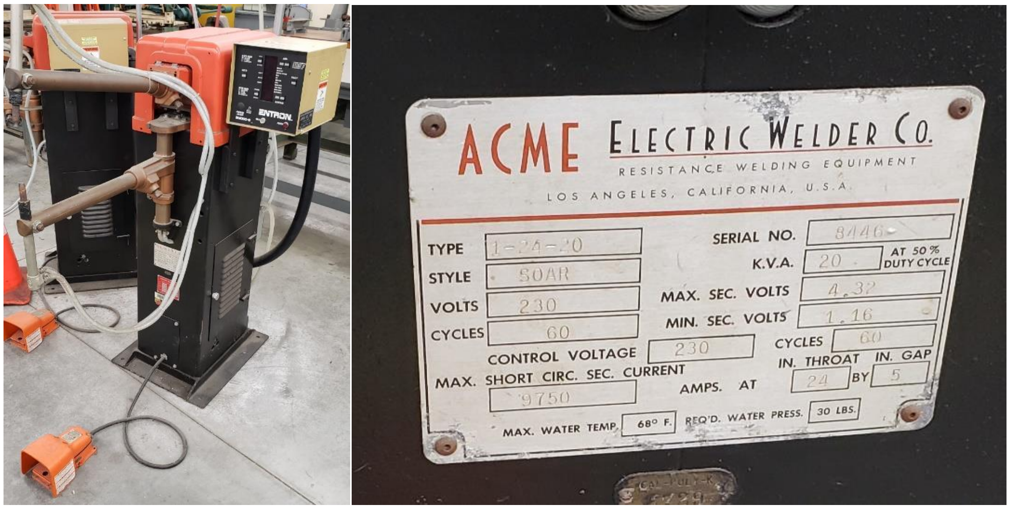

Figure 2: ACME 1-24-20 rocker arm Spot Welding Machine and data plate.

Figure 3: Entron EN1000-B welding controller set to schedule 12.

An Entron EN1000-B set to schedule number 12 was used as the welding controller, shown in Figure 3. All welds were performed using a clamping force of 2kN, current of 12kA, and time of 1.5 seconds. The separate sheets were held together with pliers during creation to ensure the safety of the welder as shown in figure 4. Examples of two finished test samples are depicted in figure 5. The welding equipment used to create our samples is common in educational labs nationwide and is simple enough to be used after basic training or under direct supervision from an instructor. This is important as the ability to recreate the samples and experiments in an educational setting further bridges the gap between theoretical and practical education. Ease of accessibility also promotes future work on this topic and allows students and instructors alike to recreate or expand on the scope of our research in the future if desired.

Figure 4: Test sample creation using pliers for safety.

Figure 5: Two examples of samples created for testing.

Tensile Shear-Strength

Tensile tests were performed on three of the samples without a copper interlayer, and three samples with the interlayer. The tensile tests were conducted to determine if the copper interlayer resulted in any increases or decreases in shear-strength compared to a standard weld joint. Each sample was placed into the machine's clamps, and they were tightened to prevent any slippage during testing. During each test the samples were pulled in tension until the welded joint failed, to which the maximum force applied to the sample was recorded. After recording the maximum shear forces on all six tests the numbers were averaged for our final data values. The tensile tests were carried out on an Instron tensile tester shown in Figure 6. Sufficient tensile testers like the Instron are common in educational labs and are simple to operate with basic training or instructor supervision. As tensile testing equipment uses large amounts of force to pull material until failure, it is important that proper operating procedures are used to ensure safety and to avoid damaging testing equipment.

Figure 6: Instron tensile tester and clamps used to secure samples.

Vicker's Hardness Test

The Vicker's Hardness Test was conducted to evaluate the hardness of the weld joint for three groups of samples: three control samples without a copper interlayer, three samples with a copper interlayer, and three heat-treated samples with a copper interlayer. The heat-treated samples were exposed to 200°C for 15 minutes prior to testing. Each sample was tested using a load of 200 grams applied for 10 seconds. Hardness measurements were taken within the weld joint for each sample, providing an average hardness value for comparison. These tests were designed to assess whether the addition of the copper interlayer and subsequent heat treatment affected the mechanical properties of the weld joint. This was crucial in quantifying the local mechanical enhancements introduced by the interlayer, allowing us to assess its contribution to overall weld quality. Conducting the Vicker's Hardness Test required careful attention to safety protocols. The diamond indenter and testing machine were operated with proper training to avoid damage to the equipment or injury. We ensured that the samples were securely clamped during testing to prevent unexpected movements. Additionally, safety goggles were worn to protect against debris or fragments that could potentially dislodge during testing. These precautions ensured a safe and efficient testing process.

Corrosion test

To evaluate the corrosion resistance of the weld joint, two 1% hydrochloric acid (HCl) bath tests were conducted. For the first test, three control samples without a copper interlayer and three samples with a copper interlayer were immersed in the bath for 30 hours at a constant temperature of 35°C. For the second test, much like the first, three control samples without a copper interlayer and three samples with a copper interlayer were immersed in the bath for 30 hours, but at a constant temperature of 55°C. During both tests, measurements were taken every 5 hours to track the progression of corrosion. The weight loss of each sample was recorded using a Sartorius 2003 MP1 scale, depicted in Figure 7. The results provided a precise comparison between the control and interlayer samples. This method allowed for the quantitative assessment of material degradation over time. The test highlighted the potential influence of the copper interlayer on corrosion behavior, particularly in an acidic environment. We anticipated that the copper interlayer would reduce material degradation, and the results strongly aligned with this hypothesis, particularly in the higher temperature environment. These results were used to determine whether the addition of copper enhanced or diminished the corrosion resistance of the weld joint. Although the solution was diluted, handling hydrochloric acid should only be done in a properly ventilated area, preferably by an instructor. Personal protective equipment (PPE), including chemical-resistant gloves, safety goggles, and lab coats, should always be used to minimize exposure to the acid. Any spills should be neutralized immediately using a sodium bicarbonate solution, and all waste should be disposed of in compliance with hazardous materials regulations.

Figure 7: Sartorius 2003 MP1 scale used to measure weight loss due to corrosion.

Results and Discussion

Tensile Test Results

The tensile tests showed an improvement in peak tensile load when the copper interlayer was introduced. Control samples without the interlayer achieved an average peak load of 278.8 MPa, while samples with the copper interlayer achieved a higher average peak load of 291 MPa. The 4% increase in tensile strength confirmed our hypothesis about the copper interlayer's role in improving heat distribution during welding. Interestingly, this enhancement was achieved without introducing significant defects, a common concern with dissimilar material interfaces. Previous studies have found that pre-metallurgical bonding between a copper interlayer and steel base material reduces the number of defects, such as pores or cracks, which would also reduce the displacements in the lattice structure of the material in the weld joint [6]. These findings, paired with our results during testing, indicate that the copper interlayer enhanced the weld joint's load-bearing capacity, supporting its suitability for use in structural applications.

Vicker's Hardness Test Results

The Vicker's Hardness Test revealed subtle differences in hardness values across the samples. Non-interlayer samples had an average hardness of 85 HV, while samples with the copper interlayer showed a slightly increased average hardness of 85.5 HV. Previous studies have observed that introducing alloying interlayers may lower the martensitic transformation temperature, resulting in a harder weld joint after solidification. Other studies have supported this, noticing an improved hardness at the fusion zone due to martensite formation and better grain refinement compared to the base material. Heat-treated samples with the interlayer exhibited the highest average hardness of 90.2 HV, demonstrating the further effectiveness of heat treatment in refining the weld joint's microstructure and relieving residual stresses. Similarly, heat treatment has been shown to enhance weld integrity and corrosion resistance in studies on NiTi claddings with copper interlayers [7]. This improvement in hardness also suggests an increase in the weld joint's resistance to deformation and wear under mechanical loading.

Corrosion Test Results

The corrosion tests, conducted in a 1% HCl solution at 35°C and 55°C, demonstrated the significant impact of the copper interlayer on the weld joint's corrosion resistance. At 35°C, non-interlayer samples showed a steady increase in weight loss, reaching 87 $(g/cm^2)*10^{-5}$ after 30 hours. In contrast, copper interlayer samples exhibited considerably lower weight loss, reaching only 41 $(g/cm^2)*10^{-5}$ after the same period. Similar improvements in corrosion resistance have been observed in dissimilar joints with interlayer materials, as reported in studies on titanium–stainless steel welds using electromagnetic welding [8].

At the elevated temperature of 55°C, the weight loss increased for both sample groups, as expected due to the accelerated corrosion rate. Non-interlayer samples reached 121 $(g/cm^2)*10^{-5}$ after 30 hours, whereas copper interlayer samples showed improved resistance, with a weight loss of 62 $(g/cm^2)*10^{-5}$. These results highlight the copper interlayer's effectiveness in mitigating the weld joint's susceptibility to corrosion, likely due to copper's electrochemical stability and its role in reducing galvanic interaction between the steel components. This substantial reduction in corrosion aligns well with our expectations, reinforcing the potential of copper interlayers for use in environments where resistance to chemical degradation is paramount. However, we did note some localized corrosion at the interface, which warrants further investigation.

The results of the first corrosion tests are summarized in Table 2 and Figure 8, showing the weight loss over time for both non-interlayer and copper interlayer samples at 35°C. In Table

3 and Figure 9, the results of the second corrosion test at 55°C are summarized. The graphs clearly illustrate the superior corrosion resistance of samples with the copper interlayer, even under more aggressive conditions.

Table 2: Weight loss of Non-Interlayer and Copper Interlayer samples at 35°C.

	1% HCl bath at 35°C	
Time (hr)	Non-Interlayer Weight Loss ($(g/cm^2)*10^{-5}$)	Interlayer Weight Loss ($(g/cm^2)*10^{-5}$)
0	0	0
5	63	31
10	60	29
15	69	31
20	74	35
25	79	38
30	87	41

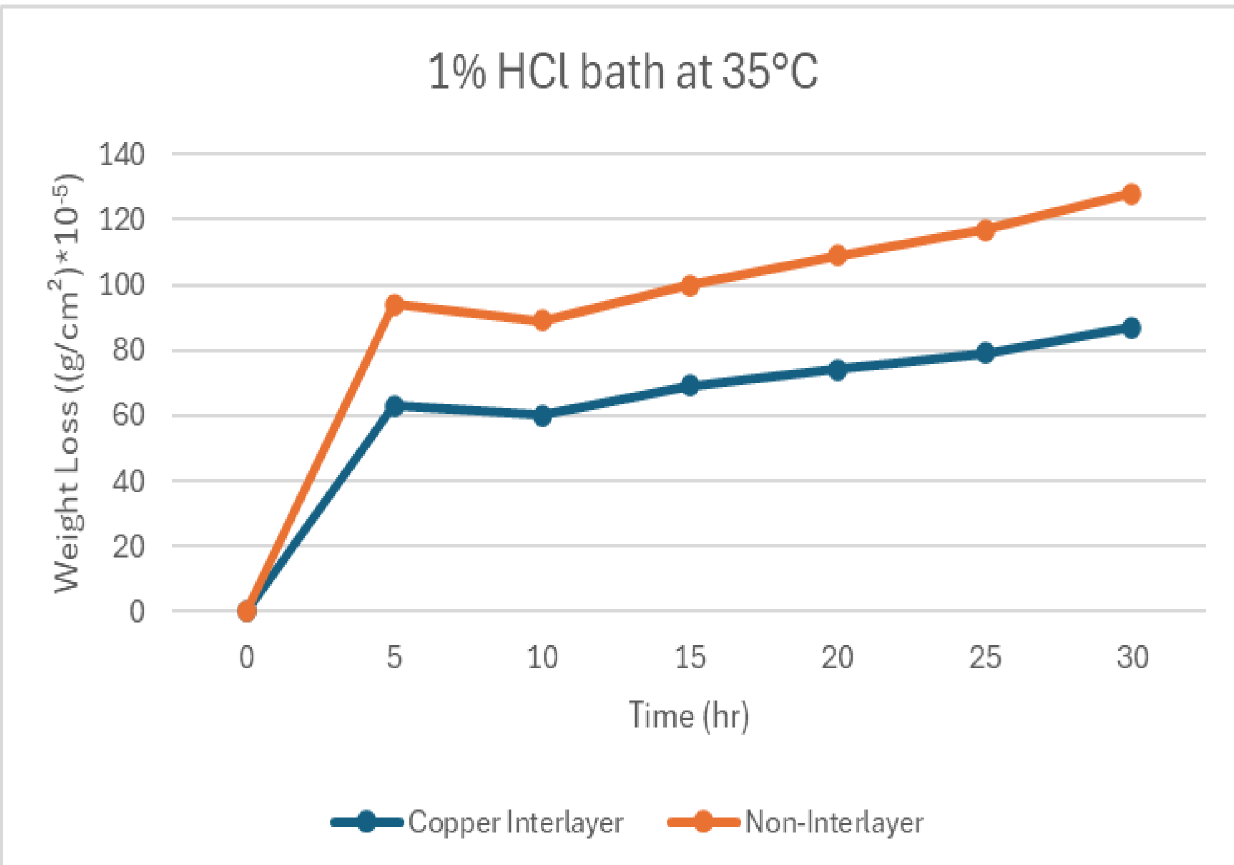

Figure 8: Graph of weight loss vs. temperature at 35°C.

Table 3: Weight loss of Non-Interlayer and Copper Interlayer samples at 55°C.

	1% HCl bath at 55°C	
Time (hr)	Non-Interlayer Weight Loss ((g/cm^2)*10^{-5})	Interlayer Weight Loss ((g/cm^2)*10^{-5})
0	0	0
5	71	34
10	79	31
15	82	35
20	89	39
25	109	44
30	121	62

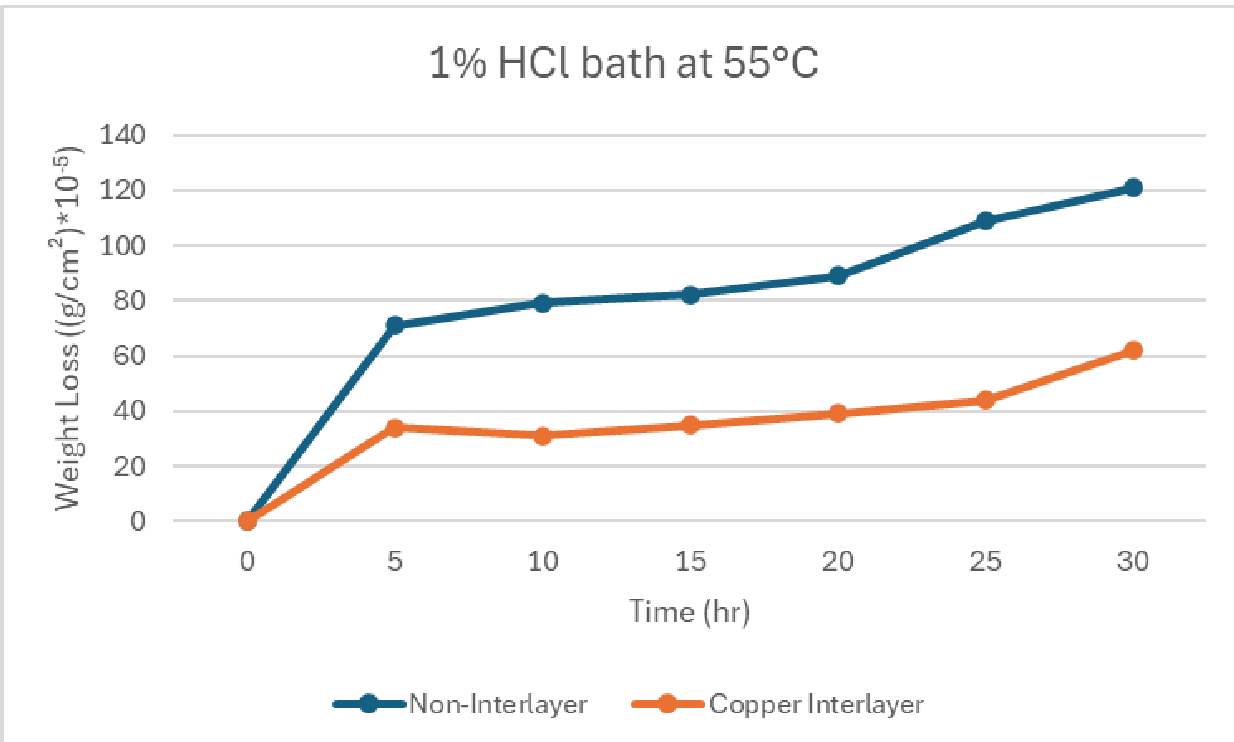

Figure 9: Graph of weight loss vs. temperature at 55°C.

Educational Impact and Industry 4.0 Integration in Welding Experimentation

In engineering education, hands-on experimentation is crucial for reinforcing theoretical knowledge. This study provided students with direct experience in material selection, welding parameter adjustments, mechanical testing, and data interpretation. These practical experiences are essential for developing engineering competencies, including better understanding in heat transfer, electrical conductivity, and weld defects. Hands-on experimentation allows students to better understand how material properties affect weld quality which is an insight difficult to gain through theory alone.

Hands-on learning enhances knowledge retention and problem-solving skills by allowing students to apply theoretical concepts in real-world welding scenarios. Unlike classroom-only instruction, physical experimentation reinforces comprehension through direct material manipulation and real-time observations. Future studies could introduce structured assessments, such as pre- and post-experiment quizzes, to quantitatively measure students' learning progress and problem-solving improvements.

Another potential expansion of this research would be to compare students who participate in welding experiments versus those who only receive theoretical instruction. A proposed study could divide students into two groups. One conducts hands-on welding and the other learning only through lectures. Knowledge retention, practical application skills, and confidence in using welding equipment could be measured using surveys, quizzes, or performance-based evaluations. This would provide more insight into how hands-on experience enhances engineering education and whether digital learning tools can supplement or replace certain aspects of physical experimentation.

With the rise of Industry 4.0, integrating digital tools such as Finite Element Analysis (FEA) simulations into welding education enhances student understanding by visualizing heat transfer, material deformation, and weld formation before physical experimentation. These tools help optimize welding parameters, predict defects, and strengthen problem-solving skills ensuring that students enter the workforce with in-demand, practical experience.

Additionally, Augmented Reality (AR) and Virtual Reality (VR) welding training tools are gaining traction in engineering education. These technologies enable students to practice welding techniques in a controlled virtual environment, reducing material waste and enhancing safety. Combining digital simulations with physical experimentation could offer a more comprehensive learning experience, equipping students with a well-rounded skill set aligned with modern manufacturing demands.

Conclusions

This study investigated the effect of introducing a pure copper powder interlayer between 1008 carbon steel sheets in resistance spot welding (RSW) and evaluated its impact on mechanical properties and corrosion resistance. The findings revealed several key conclusions:

The introduction of a copper interlayer increased the tensile strength of the weld joint, with peak loads improving 4% from 278.8 MPa for the control samples to 291 MPa for the interlayer samples. The Vicker's Hardness Test also showed a slight improvement in hardness from 85 HV in control samples to 85.5 HV in interlayer samples. Heat treatment further enhanced the hardness to 90.2 HV, highlighting the benefits of thermal processing in reducing residual stresses and refining microstructure.

Corrosion tests in a 1% HCl solution demonstrated that the copper interlayer significantly reduced material degradation. Weight loss in interlayer samples was consistently lower than in control samples across all time intervals, with the greatest improvements observed at higher temperatures. This enhanced resistance is attributed to copper's electrochemical stability and its ability to minimize galvanic interaction at the weld joint.

Beyond its technical significance, this study highlights the educational value of hands-on experimentation in engineering curricula. Direct engagement in welding, mechanical testing, and data analysis strengthens students' problem-solving abilities and bridges the gap between theory and application. Observing weld behavior firsthand reinforces key material science principles and enhances students' ability to analyze and optimize manufacturing processes—critical skills for industrial applications.

These results underline the potential of using a copper interlayer to enhance weld joint performance in environments requiring both mechanical strength and corrosion resistance. While the copper interlayer demonstrated promising results, the potential for galvanic corrosion at the copper-steel interface warrants further investigation as other studies on interlayers like Zn, Cu, and brass highlight their ability to mitigate interface corrosion, aligning with our findings [9]. This approach can be particularly beneficial for applications in automotive, aerospace, and industrial equipment where material reliability is critical.

In conclusion, incorporating a pure copper interlayer when resistance spot welding 1008 carbon steel offers a feasible method to improve weld joint properties, bridging theoretical material science with practical engineering applications. This approach not only enhances weld performance but also provides valuable insights for engineering students and instructors by illustrating how material selection and process optimization can solve real-world manufacturing challenges. It serves as an educational tool to deepen understanding of metallurgical principles while fostering innovation in practical applications.

Future Work

Future research could explore the use of coatings, alternative interlayer materials, or optimized welding parameters to further enhance performance and durability. Additionally, studies on the long-term behavior of such joints in varied environmental conditions would provide deeper insights into their practical viability.

Future research could also directly compare hands-on welding with theoretical instruction to measure knowledge retention, problem-solving skills, and real-world application. Using pre- and post-experiment assessments, surveys, or structured evaluations would provide insights into the effectiveness of experiential learning in welding education.

Furthermore, as manufacturing continues to evolve under Industry 4.0, integrating digital tools into welding education could enhance the learning experience. Future research could explore the use of Finite Element Analysis (FEA) simulations, CAD-based thermal modeling, or Augmented Reality (AR) training programs to complement physical experimentation. By combining real-world hands-on welding with digital simulations, students could gain a more comprehensive understanding of heat transfer, material deformation, and weld integrity, better preparing them for careers in advanced manufacturing and engineering.

Acknowledgements

The authors would like to greatly thank Andrew Gustillo, a technician of Industrial and Manufacturing Engineering at California State Polytechnic University Pomona for his help and efforts throughout the research process, and additionally for his help with corrosion measurements.

References

[1] T. Das, "Resistance Spot Welding: Principles and Its Applications," *IntechOpen*, 2022. doi: 10.5772/intechopen.103174.

[2] Y. W. Ren and W. C. Shing, "Current measurement of resistance spot welding using DSP," *Journal of Science and Engineering*, vol. 14, no. 1, p. 33, 2011.

[3] N. Charde, "Effect of spot welding variables on nugget size and bond strength of 304 austenitic stainless steel," *Australasian Welding Journal*, vol. 57, no. 3, 2012.

[4] T. Das and J. Paul, "Interlayers in Resistance Spot-Welded Lap Joints: A Critical Review," *Metallography, Microstructure, and Analysis*, vol. 10, no. 1, pp. 3–24, 2021. Available: https://doi-org.proxy.library.cpp.edu/10.1007/s13632-021-00714-0.

[5] A. Arumugam and N. Charde, "A mechanical study of spot weld growth in mild steel, 302 austenitic stainless steel, and both materials joined," *Journal of Materials Science and Engineering*, vol. 3, 2011. ISSN: 1934-8959.

[6] K. Szwajka, J. Zielińska-Szwajka, M. Szewczyk, M. T. Mezher, and T. Trzepieciński, "Analysis of the microstructure and mechanical performance of resistance spot-welding of Ti6Al4V to DP600 steel using Copper/Gold cold-sprayed interlayers," *Materials*, vol. 17, no. 13, p. 3251, 2024. doi: 10.3390/ma17133251.

[7] Z. P. Shi, Z. B. Wang, F. G. Chen, et al., "Cavitation Erosion and Corrosion Behavior of NiTi Cladding with Cu and Nb Interlayers," *Journal of Materials Engineering and Performance*, vol. 29, pp. 3840–3851, 2020. doi: 10.1007/s11665-020-04901-y.

[8] R. Chebolu, M. Kakarla, R. Nallu, et al., "Effect of interlayer materials on microstructure, hardness and corrosion resistance of an electromagnetic welded titanium–stainless steel interface," *Acta Mechanica*, vol. 235, pp. 3687–3697, 2024. Available: https://doi-org.proxy.library.cpp.edu/10.1007/s00707-024-03908-z.

[9] A. Shakoori, T. Saeid, and A. Ebrahimpour, "On the effect of Zn, Cu, and brass interlayers in friction stir welded St37 and AZ31 dissimilar joints," *Welding in the World*, vol. 68, pp. 2891–2910, 2024. Available: https://doi-org.proxy.library.cpp.edu/10.1007/s40194-024-01819-0.