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Effect of Welding Pressure During Ultrasonic Welding Between Nickel-Plated Copper and Aluminium Sheets

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Abstract

This study investigates the effect of welding pressure on ultrasonic welding of aluminium sheet and nickel-plated copper sheet. Both specimens were 60×10×0.5 mm in size with a 10 mm overlap and the coating thickness was 8–12 µm. The experiment was performed at different welding pressures from 0.14 MPa to 0.31 MPa while maintaining constant welding energy, time and amplitude. The results showed that the highest tensile strength of 380 N was achieved at a welding pressure of 0.14 MPa, while higher pressures caused a decrease in the tensile strength, which is believed to be due to internal cracks and hardening. To achieve the strongest bond, the optimal welding pressure was determined to be 0.14 MPa.

Keywords: *ultrasonic welding, welding pressure, tensile strength, welding defects, plated copper.*

1. Introduction

Ultrasonic welding was first developed in the mid-20th century, initially as a way to improve upon the process of spot welding in the aerospace industry. Still, it was not until the 1960s that practical uses for rigid plastics emerged. The process of ultrasonic welding for thermoplastics was established. Ultrasonic welding was accidentally discovered in 1963 by Robert Soloff, founder of Sonics & Materials Inc., who managed to weld a plastic tape dispenser with an ultrasonic probe. In 1965, Soloff, with his collaborator Seymour Linsley, received a patent for this method, helping to establish a key milestone in the development of the technology. Soloff developed the first ultrasonic welding machine, and he adapted a drill press to create the first automated ultrasonic welder, which was initially used in the toy industry [1].

Ultrasonic welding is a solid-state welding process that uses high-frequency ultrasonic vibrations to join materials, primarily metals and plastics, and does not require heat, filler metal, or adhesives. It works by using the vibrations combined with the applied welding pressure on the materials. This can be used to weld dissimilar materials like aluminium and copper because it is eco-friendly, reliable, and fast, whereas the fusion welding methods are not suitable [2–4].

Ultrasonic welding equipment operates in a frequency range of 15 kHz to 70 kHz. Typically, for thinner materials, higher sound frequencies are applied, and lower frequencies are applied for thicker materials [4].

Ultrasonic waves can modify the mechanical properties of the welds (hardness and tensile strength) by modifying the dislocation density. However, to improve the above-mentioned properties, the performance of ultrasonic welding must be optimized. When welding aluminium-copper joints, the right parameter selection for the right compression, amplitude, and energy is crucial to achieve high-quality welds. The process can be divided into 4 main groups according to ISO 4063, based on which material group is welded and how. In addition, the process can be divided into two main types based on the process execution: spot welding and continuous welding, which are used for specific applications depending on the size and complexity of the part. Spot welding is simpler and can be used for small parts, while continuous welding is used for large and complex workpieces [3, 5].

Ultrasonic welding is used in many industries because of its high efficiency and versatility. It is widely used in the automotive industry to join components like electrical connectors and wire harnesses, and provides a quick and heat-free solution. In the electronics industry, it is used to join microcircuits and semiconductor components with minimal damage to the sensitive components. In the medical industry, it is used for airtight packaging and sealing for the sterility and integrity of medical products. Additionally, it is used in packaging to create blister packs and provide a tamper-resistant closure. This welding is also notable in aerospace applications to join composite structures and thermoplastic composites to enhance strength-to-weight ratios. Moreover, its ability to join dissimilar materials determines more possibilities in product design and customization across industries [6, 7].

Ultrasonic welding has many advantages over other welding methods, such as welding different materials like pure or coated aluminium and copper. For Al-Cu joints, it makes a solid-state bond, which is perfect for making lithium-ion battery packs because it will join more conductive materials with low heating. For plastics, ultrasonic welding utilizes high-frequency sound waves to melt and bond; this process is very clean and effective, with very little thermal damage [7–11].

Fig. 1. *Ultrasonic welding machine.*

2. Materials and methodology

This experiment investigates the effect of welding pressure on the ultrasonic welding of Al and Ni-coated Cu. Ultrasonic welding was used for the welding of these two dissimilar materials because it can create strong bonds without generating excessive heat, which can cause damage to certain materials.

Shakil et al. made several tests to determine the optimal ultrasonic welding parameters. They used aluminium alloy and stainless steel for the experiment and declared that a higher welding pressure requires a shorter welding time and lower energy than in the case of lower welding pressure to earn the same tensile load. Based on the literature results, we built the experiments [12].

The experiment was performed by varying the welding pressure between 0.14 and 0.31 MPa in increments of 0.035 MPa, keeping the welding energy, time, and amplitude constant. The welding energy was 100 J, the welding time was 1.20 seconds, and the applied amplitude was 45 μm. Both the aluminium and nickel-coated copper samples were 60 mm long, 10 mm wide, and 0.5 mm thick, with an overlap of 10 mm, resulting in an overlap area of 100 mm². The nickel coating had an average thickness of 8-12 μm.

To perform the test, a Branson (Ultraweld L20) ultrasonic welding machine (see Fig. 1) was used to create the sample welds, and a tensile testing machine was used for the tests.

Welding pressure variation is crucial in this experiment because it affects the strength and quality of the weld.

Overall, the experiment was intended to determine the impact of welding pressure on the ultrasonic welding process of Al and Ni-coated Cu by employing a controlled setup and constant parameters.

3. Results

3.1. Effect of welding pressure on breaking force

The development of the tensile strength during ultrasonic welding of Al- and Ni-coated Cu was analyzed as a function of the welding pressure, as shown in the welding pressure-tensile strength curve (Fig. 2). The welding pressure was varied between 0.14 MPa and 0.31 MPa, and the tensile strength was measured as the average of three samples at each welding pressure level.

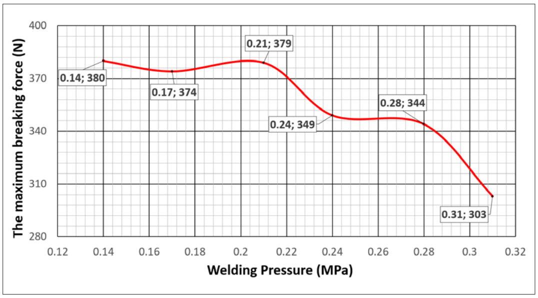

Fig. 2. *Diagram of the required breaking force and the welding pressure.*

The figure shows that the highest tensile strength was achieved at the lowest welding pressure tested, 0.14 MPa, with a tensile strength of 380 N. Although it drops slightly at 0.17 MPa to 374 N, the general trend shows a continuous decrease in tensile strength as the welding pressure increases. The lowest tensile strength is found at 0.31 MPa, where the force value is 303 N.

These results suggest that higher welding pressure negatively affects weld strength, probably due to material deformation or damage. The optimal welding pressure in terms of tensile strength in this experiment was 0.14 MPa, which resulted in the highest tensile strength of 380 N under the experimental conditions.

3.2. Effect of Welding Pressure on Fraction Location

Analysis of the fracture location showed that the welding pressure adversely affects the integrity of the joint if nothing else is modified. **Fig. 3** lshows that the aluminium sheet in the pieces welded at 0.14 MPa broke during the tensile test, indicating that the strength of the joint is higher than that of the aluminium. In the pieces welded at 0.31 MPa, shown in **Fig. 4** the weld joint broke, indicating a deterioration in the strength of the joint due to excessive welding pressure.

The figures correlate with the tensile strength measurements, confirming that when the welding pressure is at 0.14 MPa, the bond breaks in the base material, indicating a strong bond. Excessive welding pressure is not suitable for forming a proper bond, as the location of the break occurs within or very close to the bond. For strong bonds, the base material typically breaks, while in the case of incorrect parameters, the break may occur in the immediate vicinity of the weld or in the weld. This suggests that in the case of incorrect parameters, the bond forms a weak connection. In the surroundings of the welding area, the likelihood of cracks and dislocation density increases, which lowers the load-bearing capacity of the bond after welding. Therefore, 0.14 MPa is the optimal welding pressure to achieve the appropriate strength among the tested parameters.

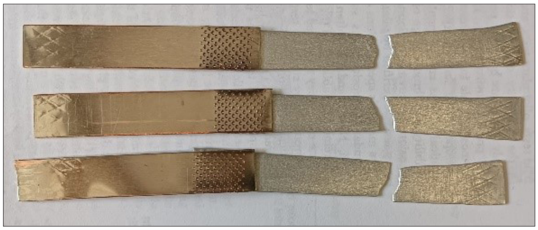

Fig. 3. *Samples welded at lower pressure.*

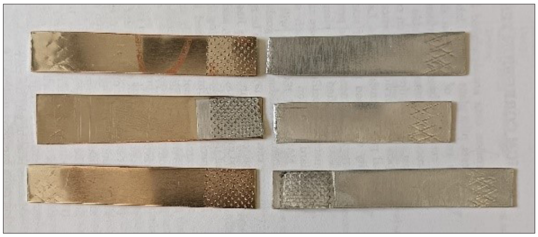

Fig. 4. *Samples welded at higher pressure.*

4. Conclusion

In this study, the welding pressure is investigated while keeping other factors constant. The results show that the highest tensile strength, 380 N, is achieved at a pressure of 0.14 MPa. At higher welding pressures, the tensile strength decreases, and the minimum value of the tensile strength is 303 N, which is achieved at the highest welding pressure of 0.31 MPa. After this, the weld has a much lower probability of forming a strong joint. This suggests that in our case, increasing the welding pressure degrades the weld quality above a certain point, so the correct parameter selection is very important during welding. Incorrect parameters can easily lead to cracks or internal damage in the weld. Analysis of the fracture location suggests that higher welding pressure reduces the load-bearing capacity of the specimen.

Future implementations based on this study could focus on process optimization of ultrasonic welding by studying other parameters such as welding energy, time, and amplitude. Further studies could include varying material thickness, joint size, and the effect of varying ultrasonic frequencies. In addition, investigating the effects of different types of coatings and surface treatments could provide valuable information for joint testing and material compatibility in ultrasonic welding.

References

[1] Woo J.: *A short History of the development of Ultrasound in Obstetrics and Gynecology*. http://www.ob-ultrasound.net/curie.html (letöltve: 2025. április 1.)

[2] Fujii H. T., Goto Y., Sato Y. S., Kokawa H.: *Microstructure and lap shear strength of the weld interface in ultrasonic welding of Al alloy to stainless steel.* Scripta Materialia, 116. (2016) 135–138. https://doi.org/10.1016/j.scriptamat.2016.02.004

[3] Tang M., Zhang P., Yu Z., Shi H., Li S., Wu D., Tian, Y.: *Study on ultrasound welding process of aluminum/copper dissimilar metals.* Physics of Metals and Metallography, 121/14. (2020) 1400–1410. https://doi.org/10.1134/S0031918X20140173

[4] de Leon M., Shin H. S.: *Review of the advancements in aluminum and copper ultrasonic welding in electric vehicles and superconductor applications.* Journal of Materials Processing Technology, 307. (2022) 117691. https://doi.org/10.1016/j.jmatprotec.2022.117691

[5] Yin P., Xu C., Pan Q., Zhang W., Jiang X.: *Effect of different ultrasonic power on the properties of RHA steel welded joints.* Materials, 15/3. (2022) 768. https://doi.org/10.3390/ma15030768

[6] Abbas Z., Zhao L., Deng J., Wang S., Hong W.: *Advances in ultrasonic welding of lightweight alloys: A review*. High Temperature Materials and Processes, 42/1. (2023) 20220298. https://doi.org/10.1515/htmp-2022-0298

[7] Bhudolia S. K., Gohel G., Leong K. F., Islam A.: *Advances in ultrasonic welding of thermoplastic composites: a review*. Materials, 13/6. (2020) 1284. https://doi.org/10.1515/htmp-2022-0298

[8] Das S., Satpathy M. P., Routara B. C., Nanda B. K., Sahoo S. K.: *Ultrasonic metal welding of Al/Cu joints with Ni coating: parametric effects on joint performance and microstructural modifications.* International Journal of Materials Research, 115/11–12. (2024) 1105-1115. https://doi.org/10.1515/ijmr-2024-0068

[9] Li J., Zillner J., Balle, F.: *In-depth evaluation of ultrasonically welded Al/Cu joint: Plastic deformation, microstructural evolution, and correlation with mechanical properties*. Materials, 16/8. (2023) 3033. https://doi.org/10.3390/ma16083033

[10] Bose S., Chelladurai H. M., Kanaiyaram P.: *An experimental investigation on feasibility of submerged ultrasonic spot welding of thermoplastics.* Proceedings of the Institution of Mechanical Engineers, Part L. Journal of Materials: Design and Applications, 238/10. (2024) 2043–2057. https://doi.org/10.1177/14644207241239475

[11] Görick D., Welsch J., Gerardo C. D., Kupke M., Cretu E., Rohling R.: *Inline Monitoring of contınous Ultrasonic Welding Processes of Thermoplastic Composites via a custom polyCMUT based Ultrasound Array.* In: 20th World Conference on Non-Destructive Testing (WCNDT) 29(6). 2024. NDT. net. https://doi.org/10.58286/29933

[12] Shakil M., Tariq N. H., Ahmad M., Choudhary M. A., Akhter J. I., Babu S. S.: *Effect of ultrasonic welding parameters on microstructure and mechanical properties of dissimilar joints.* Materials & Design, 55. (2014) 263–273. https://doi.org/10.1016/j.matdes.2013.09.074