Study the Interface Properties by Adding Silicon Carbide/Silicon Nitride to Welded Aluminum for Manufacturing Education

Mr. Jorge Pena, California State Polytechnic University, Pomona

I am an undergrad enrolled in the California State Polytechnic University, Pomona, for my bachelor's in manufacturing engineering. I am a junior, and I hope to graduate in the spring of 2027.

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 stora

Study the Interface Properties by Adding Silicon Carbide/Silicon Nitride to Welded Aluminum for Manufacturing Education

Abstract

Teaching students to weld safely is a difficult task. Ensuring students understand the importance of proper welding techniques, safety precautions, and common mistakes makes for a great and educational experience. This study involved the participation of engineering students, under faculty supervision, in the testing of the interface properties of aluminum 2024 joints reinforced with silicon carbide (SiC) and silicon nitride (Si_3N_4). Utilizing gas tungsten arc welding (GTAW/TIG), SiC and Si_3N_4 particles were introduced between the welded surfaces to mix with the molten pool to attempt to improve the strength of the weld and reduce defect formation. Engineering students conducted experiments using computerized tensile testing and examined the microstructural characterization of the weld interface. Results concluded that joint strength increased, and the mechanical properties improved. This provides students with valuable experience in testing the strength of welds and materials through destructive and non-destructive testing. While also reinforcing the importance of proper welding techniques and encouraging innovative thinking in applying materials science. This knowledge and innovative thinking may carry students far into their respective careers.

1. Introduction

Heat treatable aluminum alloys such as Al 2024 are commonly used in aeronautical, automotive, and space exploration applications [1], [2]. Welding aluminum is particularly difficult because of its propensity to oxidize, and if working with alloys, it could potentially ruin its heat treatment. However, due to its prevalence, learning how to properly weld aluminum is a valuable lesson to learn for engineers who must devise the manufacturing process that includes these materials.

In several studies it has been shown that introducing silicon carbide (SiC), or silicon nitride (Si_3N_4) into an aluminum matrix, has been proven to increase the strength of the aluminum. One important aspect of increasing the strength of the aluminum is utilizing age hardening treatments to ensure cohesion within the matrix with the SiC or Si_3N_4 particles. Heat treating aluminum reinforced with SiC or Si_3N_4 seems to always produce stronger and harder composites [3]. Welding Al 2024 and introducing reinforcers must therefore be done with extra care to ensure a strong and cohesive weld, this will provide great experience to aspiring engineers and invoke conscientiousness in the design of different parts that are to be welded. Welding also requires extra care since improper welding can lead to the weaking of the welded parts due to the ruin of the heat treatment already present, as well as it being very difficult to ensure proper integration of the silicon molecules providing another barrier to the students for them to overcome.

To weld aluminum, it is necessary to use friction stir welding, or gas tungsten arc welding. Friction stir welding seems to be the best for mixing and creating a uniform distribution of SiC [4]. However, it does require machinery which is not always available to colleges. Gas tungsten arc welding (GTAW) is an accessible and popular method of welding and has been shown to maintain the strength of aluminum/SiC composites [5]. Using powder can help in introducing foreign materials into the weld. To do this, ceramic powder will be laid onto Al 2024 much like flux in submerged arc welding. Unlike submerged arc welding, GTAW utilizes gas which may push particles away from the target material. Understanding this problem and learning how to overcome this may help a student learn how important design is and may prove an effective way to increase the strength of the material.

This study is student-led and includes guidance from the professor. Research was done as part of a lab to get students more involved in the welding aspect of their majors. Students were graded depending on the quality of the weld and the results of the best weld are included in this paper. By increasing communication, students learned how to safely use the welding tools, and they discussed several ways of accomplishing reinforcement of Al 2024. This paper discusses the final decision and outcome of the experiment. This study aimed to offer students the opportunity to gain visual and hands on experience with the following procedures.

2. Experimental Procedures

2.1 Material and Welder Preparation

Flat test coupons of aluminum 2024 were prepared by using scotch bright to remove the oxides and imperfections at least 0.50 inches from the edge. The coupons and other welding materials were wiped with acetone to reduce as many contaminates as possible. Information about the Al 2024, and filler material can be found in Table 1.

The tungsten was ground to a sharp point of roughly 60 degrees, which was then balled by welding with a high cleaning percentage on waste material. A number 6, stubby gas lens cup was used with 10 cubic feet per hour of argon as the shielding gas, and 12 seconds of post flow. The electrode stick out was ¼ inch.

The ac balance was set to 80%, favoring penetration for the first pass. Frequency could not be adjusted from 60 Hz on the welder used. The current was set to 140Amps; however, a foot pedal was used to control the current and never reached this set maximum.

The material was then positioned in a butt weld position with no gap. This setup was the same for both treated and untreated welds, but in the case of treated welds, the ceramic material (which was composed of 60% SiC, and 40% Si_3N_4) was dusted over the weld area.

2.2 Welding Procedure

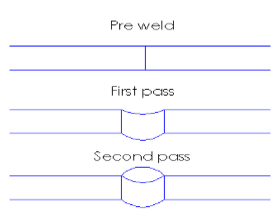

Fig. 1: building up the weld

To prevent the argon flow blowing away the ceramic powder, the pedal was pressed with the torch away from the coupons, initiating the post flow, then the torch was then brought into position. The torch angle was nearly vertical, with a slight pushing angle. The arc was initiated with a high frequency start. The weld was made as normal, dipping the filler, keeping the puddle close to flush with the top surface. A second pass was made with ac balance set to 40%, favoring cleaning, and building up the weld. The method was the same as Fig. 1. Both treated and untreated welds received the same welding process.

2.3 Testing

Some of the coupons were placed in the tensile testing machine. The coupons were clamped and then pulled at 0.50 inches per minute until failure. Results and photos shown in results. Other coupons were imaged under a microscope. Photos of grain structure are in results.

Table 1: composition of materials used

Compos-itions	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others-Each	Others-Total	Al
Base Metal Al 2024	0.50	0.50	3.8-4.9	0.30-0.9	1.2-1.8	0.10	0.25	0.15	0.05	0.15	remainder
Filler metal ER 4043	4.5-6.0	0.80	0.30	0.05	0.05	-	0.1	0.2	0.05	0.15	remainder

3. Results and discussion

3.1 Stress Strain analysis

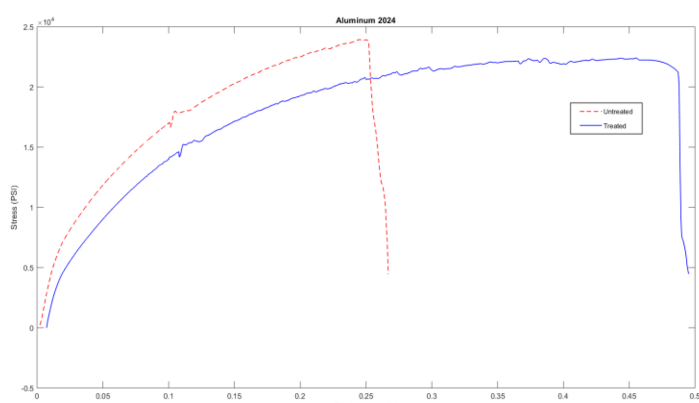

Fig. 2. stress-strain graph of both treated and untreated

As the data in fig. 2 shows, treated welds experienced nearly twice as much strain before fracturing. It should be noted however, as can be seen in figure 3, while the untreated weld fractured in the weld interface, the treated weld was not tested to its full strength, as the base metal outside of the heat affected zone fractured first. What this means is that, although the material failed first, the weld stayed strong indicating that treatment was significant.

This exercise provided students with the ability to witness firsthand a fracture caused by overloading, and the opportunity to witness their own work. This also proves to be a valuable lesson in the strength of alloys vs. composite materials. While alloys tend to be stronger than pure materials, they also tend to be a lot more elastic than composite materials. The students saw this firsthand and now understand the power of composite materials.

3.2 Image Analysis

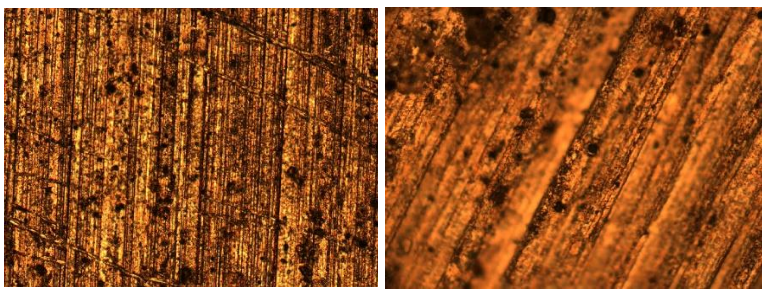

Fig. 3. base material at 20x and 50x magnification respectively

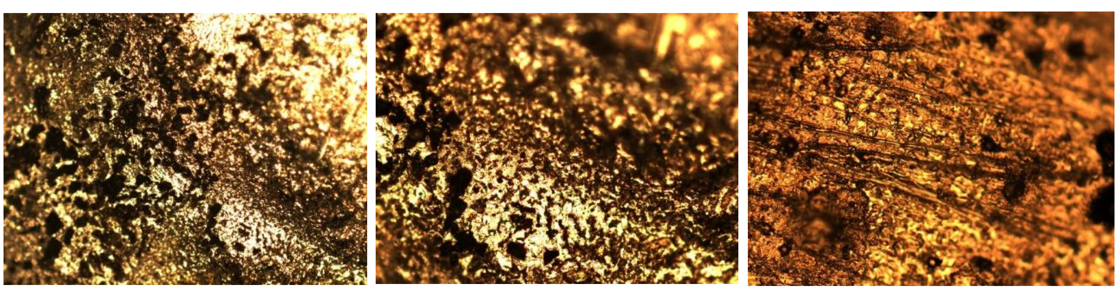

Fig. 4. untreated weld bead at 5x, 10x, and 20x magnification respectively

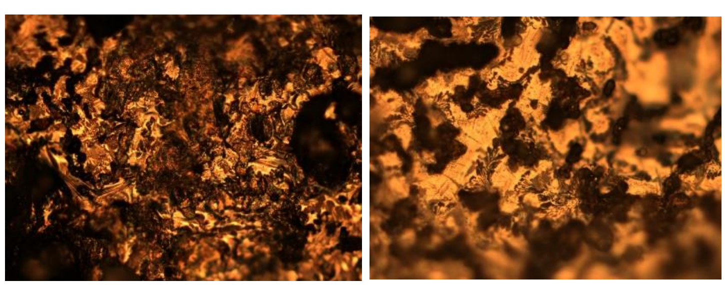

Fig. 5. treated weld bead at 20x and 50x magnification respectively

Fig. 4 shows an untreated weld under the microscope. Compared to fig. 5, fig. 4 shows a lot more straight lines like fig. 3 indicating that the weld formed linear grains much like the normal grains. Although figs. 3, and 4 might not be as significant as Fig. 5, being able to identify different microstructures and visually compare the treated to the untreated welds makes these pictures helpful in the learning process for the students.

In Fig. 5, the weld treated with the ceramic mix is shown to have relatively large grains, compared to Fig. 3, with a few tiny ones. There are also a lot of particulates at the surface. This could indicate that the weld treatment is at the surface level.

Identifying these details provides aspiring engineering students with the experience to identify the quality of the manufacturing processes that they may soon encounter when they enter the industry. While also providing a valuable opportunity for the students in identifying good welds, and identifying aspects of welds such as nucleation, and how grains form firsthand. Some students had even confused the particulates with pores. Which goes to show that even firsthand experience does not always lead to correct conclusions, but with the guidance of the professor it does help students gain understanding by seeing their mistakes and challenging their first assumptions.

4. Conclusion

This study sought to find different ways of improving the strength of a weld by introducing particulates into the weld. At the same time, students gathered great hands-on learning by participating in this study.

This study found that with the introduction of SiC, and Si_3N_4 the weld grew stronger than the base material. However, more study should be held with larger samples of Al 2024 to show if the method is more superficial than seen in the present.

Students who participated in this study gained a lot of conceptual understanding from this study based on the visual and hands-on aspects. Students learned how to adapt and overcome a barrier to introducing particulates in a weld, while also learning how to weld aluminum. Importantly, students had the opportunity to closely examine welds, learn how metal behaves when it is pushed to its limits, and how composites may look under the microscope.

References:

[1] P. Nikiel and P. Kutyła, “Microstructure and selected mechanical properties of hot-rolled AA2024/SIC composite manufactured by Powder Metallurgy,” *Composites Theory and Practice*, vol. 25, no. 2, pp. 102–112, Jun. 2025. doi:10.62753/ctp.2025.08.2.2

[2] R. K. Arya and A. Telang, “Silicon nitride as a reinforcement for aluminium metal matrix composites to enhance microstructural, mechanical and tribological behavior,” *International Journal of Engineering and Advanced Technology*, vol. 9, no. 3, pp. 3366–3374, Feb. 2020. doi:10.35940/ijeat.c6032.029320

[3] M. B. Niyaz Ahmed *et al.*, “Mechanical properties of sic nanoparticle-reinforced Al-2024 Alloy,” *Fracture and Structural Integrity*, vol. 19, no. 72, pp. 148–161, Feb. 2025. doi:10.3221/igf-esis.72.11

[4] J. P. K. *et al.*, “An experimental analysis on sliding wear characteristics of TIG-welded AL6061 reinforced with SIC,” *AIP Advances*, vol. 14, no. 6, Jun. 2024. doi:10.1063/5.0213976 [1] “ER4043,” Weld Wire, https://www.weldwire.net/weld_products/product-2/ (accessed Jan. 20, 2026).

[5] P. K. Mouria, R. M. Singari, and R. Wattal, “Microstructural and mechanical response of SIC and TIO2 particles reinforced friction stir welded AA7075 and AA2024,” *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 18, no. 3, pp. 1331–1343, Dec. 2023. doi:10.1007/s12008-023-01667-0