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Research Article

Mechanical Characterization of Friction-Stir-Welded Aluminum AA7010 Alloy with TiC Nanofiber

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The effects of introducing TiC nanofibers (TiCnf) to the weld pool of Grade AA7010 were investigated in this study. The joints were made on a vertical machining centre with a lap joint arrangement. ASTM standards were followed while testing the strength of tensile and yield and percent of elongation, and hardness strength. According to the data, welds formed with TiCnf at around 1.0 wt % had a maximum tensile strength of 452 MPa. It was discovered that utilizing many nanofibers also enhance microhardness. Because of the nanofiber, the HAZ and TMT grains were polished and distortion-free, resulting in improved mechanical properties.

1. Introduction

Friction stir welding (FSW) is an essential joining process that uses frictional heat and high pressure to solidify materials. Due to their lightweight and high strength, aluminium-based alloys are often welded with brass, copper [1], and other aluminium alloys to make high-performance materials with combined properties for specific uses [2]. So far, much more research has been done to improve the quality of welds and the life of tools, both of which directly affect the overall process economy [3]. It is still hard to make significant welds at least 85% as strong as the metal they are attached to. So, experts are still working on improving weld settings to improve the quality of the welds. Many studies have been done to improve process parameters, such as the speed of the tool's rotation, traverse speed, the time it stays in one place, and plunge depth. Several new ways to finish joining processes have also been thought of [4]. Others work on changing the shape and weaving rate of the tool underwater, while others work on changing the shape and weaving rate of the tool. But there are still problems with the welds' quality and material getting into the weld zone. The strength of the weld bead is less than the minimum requirement of at least 85% of the strength of the source metal [5]. So, scientists started to look into what would happen if nanophases were added to the weld pool during the welding process. When these nanophases come together, they make nanocomposites that strengthen the weld nugget and stop cracks from spreading [6]. Because of this, people often get good results when they weld. Unique fillers like graphene nanoplatelets, graphene oxides, carbon nanotubes (CNTs), and other MoS4 are often used to improve the quality of welds. However, adding these fillers raises the cost and lowers the overall economy of the process [7]. But the cost of these fillers made the process less economical again, which led to the search for new fillers that were less expensive. Titanium carbide is a low-cost filler that works well and is often used to reinforce metal and polymer matrix composites [8]. Also, TiC works well with aluminium-based alloys, which could be used to process aluminium-based metals [9, 10].

Anil Kumar et al. [11] looked at the mechanical properties and shapes of friction-stir-welded joints made of GRADE AA7010 that had TiC nanoparticles added. Using the state of the butt process before FSW, the edges of each plate were given a rectangular groove along the edge. Four fractional volumes of 0, 5, 8, and 13% TiCNP were put into grooves that were 0 to 0.5 mm wide, and FSW was used to shape metal with metal matrix nanocomposite (MMNC) in the stirred zone or weld nugget zone (WNZ). Compared to FSW samples made without TiCNP, the WNZ achieved grain refinement with TiC by adding different volumes (5, 8, or 13%) of TiCNP after the second pass of FSW. This improved the mechanical properties. In the WNZ, samples with 13 vol % part TiCNP had a higher hardness of 150 HV [12].

Sun and his colleagues [13] looked at what happened when pure copper metal was mixed with TiC particles. During the friction stir welding process, 5 m-sized TiC particles were injected into joints made of pure Cu. The author says that the Vickers hardness of Cu joints with TiC particles dispersed in them is 110 HV, much higher than the hardness of the stir zone without TiC particles, which is only 70 HV. Al-Mg and A316L alloys were welded better by Fallahi et al. [14] using TiC nanopowder. With the intermetallic joints, this work looked at getting two ideal cross speeds of 16 and 20 mm/min while keeping the rotational speed at 250 rpm. With six passes at a cross-sectional speed of 16 mm/min, the FSW achieved a high level of joint strength. The ultimate tensile strength (UTS) of the AA5083 base metal (BM) was increased to 94% and elongation decreased by 3%. There was a 250% increase in Vickers hardness in the stir zone. Mehdi et al. [15] looked into the mechanical performance and characterization of multipass FSWed AA6082-T6 with TiC-strengthened nanoparticles. With multipass FSPed-TiC and AA6082-T6, the mechanical properties were made by keeping the spinning speed at 1350 rpm, the welding speed at 65 mm/min, and the tilt angle at 2°. All TiC nanoparticles were broken up and spread out evenly in the fifth pass. This made AA6082, with a tensile strength of 215.54 MPa in the base metal and 24.91% strain. Along the stirred zone, the Vickers hardness values go from 89 to 133 HV from the first to the fifth pass. Tabasi et al. [16] looked at the role of TiC nanoparticles in FSWed Al-Mg alloys that differed from each other. The strengthened nanoparticle of titanium carbide was put into the stir zone to make a metal matrix composite. Researchers say that using titanium carbide nanoparticles to help support FSW takes into account the fact that a stirred microstructure is possible with the spinning mechanism.

Studies have shown that adding TiC to the weld bead will likely make a weld with a refined microstructure better at carrying loads. Also, research on TiC-based reinforcement in the weld pool has not been as extensive as on fillers such as nanosilica, TiO_2, and B_4C. But there are not many studies that use GRADE AA7010 weld joints. Also, TiC nanoparticles have been used in research instead of whiskers, nanorods, nanoribbons, and nanofibers. Because these one-of-a-kind structures can make microstructures stronger and more precise, this study looks into the mechanical behaviour of AA7010. Joining these different alloys could help make structural, automotive, and aerospace parts because they are lightweight, strong, and easy to make.

2. Materials and Method

The core metals used in this experiment were an AA7010 alloy with dimensions of 100 mm × 50 mm × 3 mm, respectively. Ms Bandari's metal treading company supplied the base metals. Sigma Aldrich in the United States also carried TiC nanofiber with a diameter of 2.5 μm and a length-to-diameter ratio of more than 20. The nanofiber utilized in this investigation has 3.22 grams per cubic centimetre density. Both metals are used in their native state before welding, with no pretreatment. Figure 1 shows the welded AA7010 alloy base metal. The mechanical properties and the chemical compositions of the base materials are displayed in Tables 1 and 2. The process variables are listed in Table 3.

2.1. Welding Process. Following the process parameters specified in Table 3, friction stir welding of parent metal was carried out on a high-precision vertical machining centre (HMT India) with a bed size of 810 × 400 mm, 45 to 1500 rpm of spinning speed, and 0.25 to 500 mm/min of weld speed. The spinning tool was targeted from one end, and the welding metal was organized in a butt joint pattern. The base metals were bonded using a tool with a taper and a 34° angle. The shoulder is 16 mm in diameter, with a 2.5 mm gap between it and the tooltip. The TiC nanofiber was inserted in the grooves at the edges before welding. 0.5, 1, and 1.5 wt. percent TiC nanofibre was used to determine the significance of particle addition [16, 17]. Figure 2 depicts the welding setup, tool image and the welded AA7010.

2.2. Test Specimen Making. Welded components were sliced by wire cut electrical discharge machining to create ASTM test specimens. Distilled water served as the dielectric medium, and the wire diameter was 0.25 mm. The pulse width was 113 volts on time and 25 volts off time, the current density was 230 volts, the gap voltage was 24 volts, and the pulse width was 113 volts on time and 25 volts off time.

3. Characterization of Welds

Tensile properties of friction-stir-welded plates were examined using universal testing equipment with a 20 ton loading capacity and 1.5 mm/min cross-head speed using ASTM E8M-04. Similarly, the impact hardness of weld beads was measured using an ASTM E23-compliant Charpy impact tester with a 70 J capacity. Vickers hardness setups calculated the hardness of weld nuggets, HAZ, and TMAZ following the ASTM 384 standard. The test variables were 5 Hz working frequency, 0.1 stress ratio, and 23°C working temperature. Finally, an OM and SEM examined the

Figure 1: AA7010 alloy base metal to be welded.

Table 1: Mechanical properties of base metal.

S.no	Material	Tensile strength (MPa)	Elongation (%)	Charpy impact (Joules)	Micro hardness (HV)
1	AA7010	452	1367.5	153	

Table 2: Chemical compositions of AA7010.

S.nos	Elements	%
1	Al	95.45
2	Zn	2.4
3	Mg	1.7
4	Cu	0.11
5	Zr	0.15
6	Fe	0.1
7	Si	0.08

Table 3: Description of FSW parameters.

Process variables	Description
Axial load	5 kN
Traverse speed	30 mm/min
Rotating speed	900 rpm
Length of weld	150 mm
Dwell time (s)	5
Plunge depth (mm)	0.2
TiC nanofiber (wt.%)	0.5, 1 and 2

microstructure of GRADE AA7010 weld joints. TESCAN VEGA 3, UNITED KINGDOM.

4. Results and Discussion

4.1. Mechanical Properties. The mechanical responses of the different welds tested in this study are shown in Table 4. The manufacturer says that the GRADE AA7010 weld has a tensile strength of 262 MPa, yield strength of 202 MPa, a condition of 21.6% elongation at break, and a Charpy impact toughness of 68.2 J. Aluminium becomes less flexible when the amount of aluminum alloy increases and TiC is added. Because of this, the alloy gets more brittle and may be harder to stretch because it loses some of its tensile strength. But when many nanofibers were added to the weld pool, it strengthened the weld. Figure 3(a) shows welds that were made with 0.5 wt., 1.0 wt., and 2.0 wt. The tensile strengths of TiCnf were 284, 326, and 308 MPa, in that order. This is better than a simple weld by 8.39%, 24.4%, and 17.5%. Yield

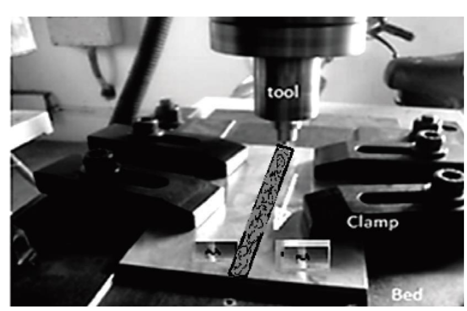

Figure 2: FSW of welding setup plate in bed.

Table 4: Mechanical responses on the weldment region.

Weld composition	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Charpy impact (Joules)
AA7010	262 ± 2.6	202 ± 1.7	21.6 ± 1.9	68.2 ± 2.1
AA7010 + 0.5TiCnf	284 ± 1.9	218 ± 2.1	18.2 ± 1.8	70.4 ± 1.9
AA7010 + 1.0TiCnf	326 ± 2.2	238 ± 1.9	16.4 ± 1.8	71.8 ± 2.2
AA7010 + 1.5TiCnf	308 ± 2.1	221 ± 2.3	17.6 ± 2.1	70.2 ± 2.0

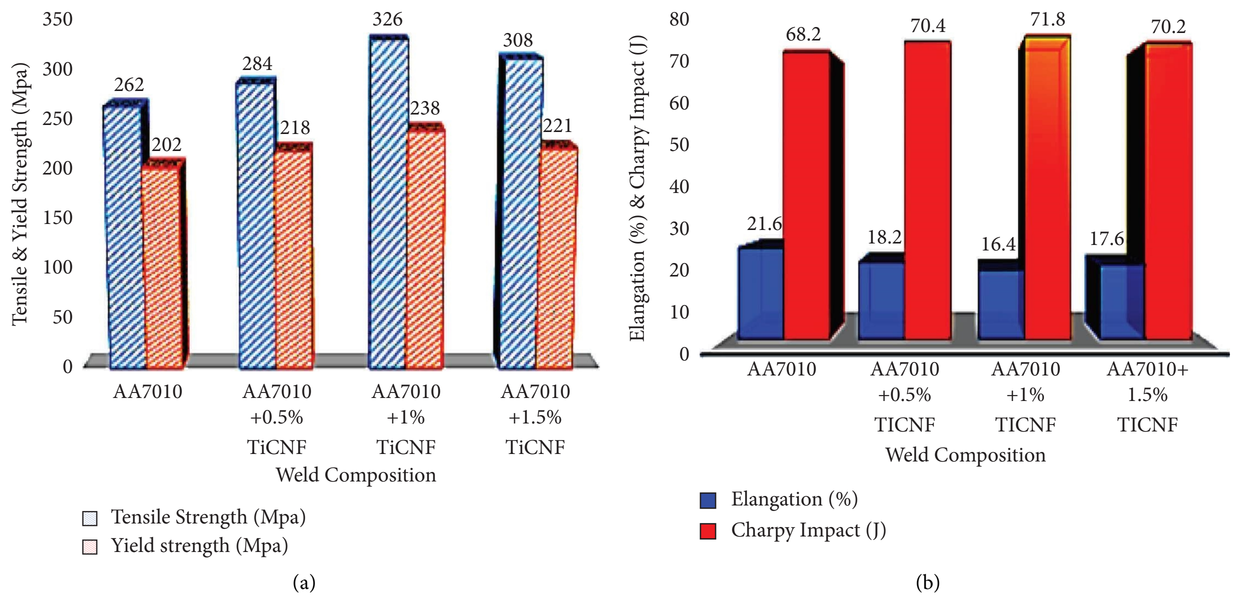

Figure 3: Weld composition of (a) tensile and yield strength (MPa) and (b) elongation (%) and charpy impact (J).

and length qualities both got better. These important changes are due to the effective stir zone and better reinforcing effect of TiC nanofiber [18]. The higher tool speed of the circular taper tool head made it possible for the primary metals and TiCnf reinforcement to mix more evenly [19]. Also, when the weld bead is put under tensile stress, the TiC long fibre structure increases the load-bearing capacity by making it easier for the Al-Mg molecules at the weld bead to lock together [20]. Also, the production of hard intermetallic compounds during the joining process tends to reduce elasticity. However, the presence of TiC nanofibers reduced the excessive formation of these intermetallic compounds and formed a nanocomposite layer on the top of the weld bead [21]. As a result, there was more behaviour that could carry weight. Still, a large amount of nano reinforcement added to the weld pool has almost no effect on the ability to stretch and absorb energy. Figure 3(b) shows a small drop for a GRADE AA7010 weld with 2.0 wt% TiCnf. This drop makes it easier for IMCs to form on the surface of nuggets [22]. When a thick IMC layer forms, it has a terrible effect on the mechanical properties of the weld [9]. When the tool's spinning speed is set, and the welding speed is slowed down, the IMC layer gets thicker, which means the strength of the joint is going down [23]. As a result, there is a big drop in the strength of the weld.

Figure 4 shows the optical microscope images of aluminium and its composites. The grains are coarser with the residues of nanofibers. The grain boundaries are strengthened, and the grains are stiffer. Thus, the crack wouldn't propagate faster through the boundaries; higher strength is noted. Table 3 shows that the Charpy impact toughness levels are significant [24]. The ordinary dissimilar weld has an impact energy of 68.2 J. When the TiC nanofiber was added to the weld pool at the time of joining, the energy absorption increased. This improvement is responsible for lowering ultra-hard brittle intermetallic phases at the weld contact [25]. As a result, weld nugget brittleness increased, resulting in little energy absorption.

In contrast, inserting nano-TiC fibres into the weld pool reduces IMC thickness while retaining flexibility in the nugget zone [26]. As a result, there may be an increase in energy absorption. For 1.0 wt. % TiCnf addition, the highest energy absorption of 21.8 J was found, which is a 19.7% increase over the plain weld [27].

4.2. Hardness Characteristics. Figure 5 shows how the hardness of many different welds varies. The Vickers hardness of a plain weld is 89 HV at the weld nugget, 84 HV at the TMAZ, and 82 HV at the HAZ. When joined, this

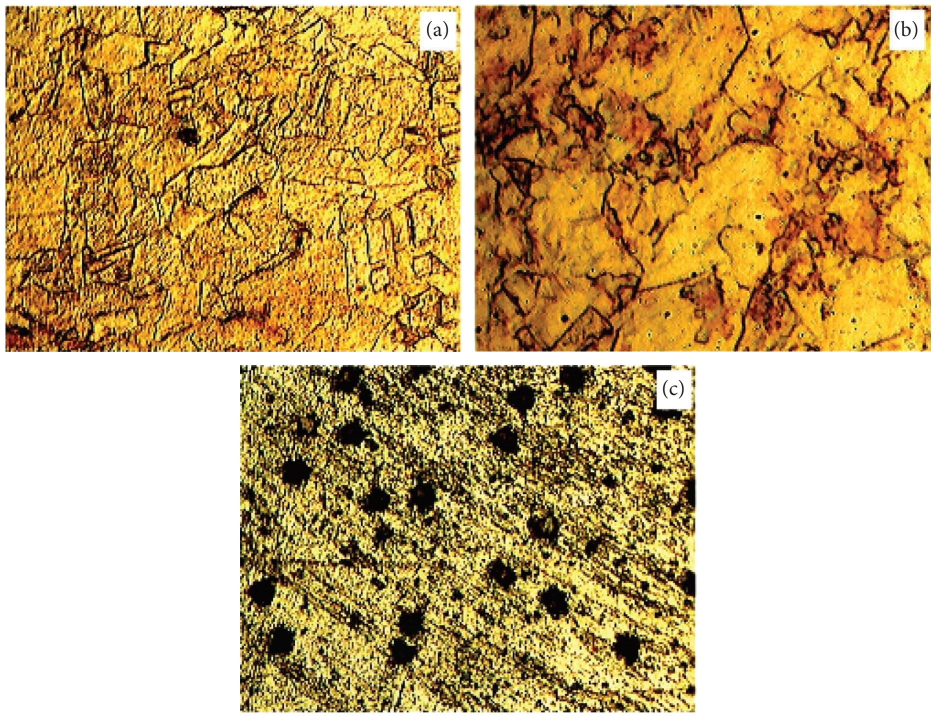

Figure 4: Optical microscope image of composites.

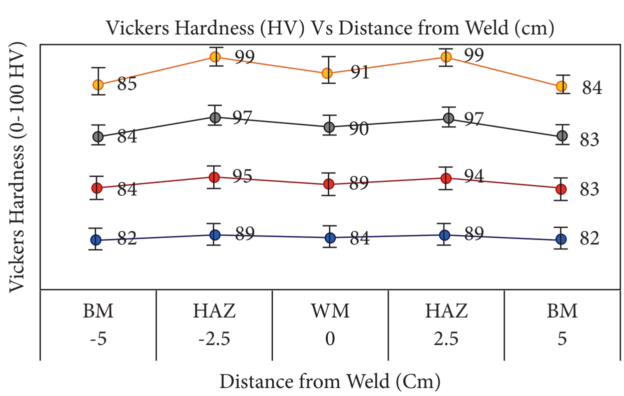

Figure 5: Vicker's hardness of dissimilar welds with TiC.

slightly higher hardness makes for better compounds between metals [28]. This is because the top layer of the joint is covered with too many intermetallic compounds, which makes it more challenging. But adding a lot of TiCnf made it a little bit stronger. The higher speed of the tool's rotation ensures that the TiC nanofibers are spread out evenly in the weld pool area, which has a pleasing reinforcing effect [29]. With 1.5 wt% TiCnf, the friction stir weld has a hardness of 99 HV. It is important to note that the microhardness of the nugget zone is the highest of any weld [30]. Both sides reported slightly less hardness in weld stages like TMAZ and HAZ, which are close to each other. This difference in hardness leads to the intermetallic density at the weld [31]. The higher precipitates IMCs at the weld nugget explain why they are higher than on the other sides. Because of this, the nugget is more complex than the phases around it [32].

5. Conclusions

This work used titanium carbide nanofibers to investigate the mechanical performances of friction stir welded AA7010 alloy. The precise outcomes made as a result of this investigation are as follows:

(i) TiC nanofiber was used to construct sound weld joints in GRADE AA7010 alloys. To achieve very homogeneous welds, predetermined process variables were applied.

(ii) The addition of TiCnf to the weld pool of the GRADE AA7010 alloy improved its tensile characteristics. The maximum tensile strength of 326 MPa was observed for 1 wt % TiCnf reinforced weld beads.

(iii) The addition of TiCnf significantly enhanced the hardness of the nuggets. The hardness has significantly increased. There was no unusual increase in hardness. This demonstrated that incorporating TiCnf into the weld bead reduced the highly saturated IMCs.

(iv) As a result, adding TiCnf to the GRADE AA7010 weld beads significantly improved the joint strength properties. As a result, the inclusion of TiCnf is notable for producing sound weld connections with about 70% joint efficiency.

Data Availability

The data used to support the findings of this study are included within the article and are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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