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Effect of Nanoparticles Addition During Friction Stir Welding of Al-FSW Welds

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The demand for lightweight and high-performance materials in product design has increased recently in the automotive, marine, transportation, and aerospace industries (Schweitzer, 2003; Kaufman, 2000). In these kinds of enterprises, losing weight is necessary to increase fuel efficiency, increase payload capacity, and comply with greenhouse gas emission regulations. Using more sophisticated light materials is the most efficient technique to reduce weight without compromising design performance (Mouritz, 2012, Singh et al. 2019a-c). The industry offers a wide range of lightweight technical materials, such as alloys made of titanium, magnesium, and aluminium. Aluminium alloys are widely utilised in the aerospace, transportation, shipbuilding, and other industries due to their high strength to weight ratio and resistance to corrosive agents.

Since the last ten years, the development of Metal-Matrix Composites (MMCs) as an advanced material has opened up a wide range of opportunities to create structural parts or components that are lighter in weight (Kaczmar et al., 2000, Rawal, 2001). The MMCs replaced high strength aluminium alloys in aircraft structures, aero engines, and automobiles because of their excellent strength-to-weight ratio, high stiffness, high thermal conductivity, and great resistance to wear and corrosion. The most popular uses for MMCs include door panels for cars, roller coaster braking systems, communication satellites, and tubing on space shuttle orbiter fuselage (Heinz et al., 2000, Prater, 2014, Kunze and Bampton, 2001, Singh et al. 2019d).

The largest barrier to MMC joining is the size of the welded pieces and the mechanical qualities that deteriorate when fusion welding is used. The emergence of intermetallic unwanted brittle phases is caused by the breakdown of ceramic particles and chemical interactions between them and the molten metal matrix. In addition, the irregular dispersion of supplementary particles inside the foundation matrix restricts MMCs' ability to be joined, leading to inadequate weld strength (Chawla and Chawla, 2006, Kunze and Bampton, 2001, Singh et al., 2021). This is the reason for the industries' constant push for MMCs to use lighter materials, which calls for sophisticated joining methods as friction stir welding (FSW), also known as solid-state welding (Prater 2014).

In December 1991, this procedure was copyrighted and validated by tests conducted at The Welding Institute (TWI) in the United Kingdom. Friction, adiabatic heat inputs, and plastic deformation—a result of solid-state diffusion and extrusion-forging-shearing—are all factors in FSW. The non-consumable rotating tool rotates along the joint line as it plunges into the workpiece interface throughout this procedure. This action causes the material to become pliable (in the deformed plasticized state), which is then further forged from the tool's front to create a solid-state joint without melting the workpiece that needs to be joined (Khaled, 2005, Threadgill et al., 2009, Mishra and Ma, 2005, Starink et al., 2008).

NASA originally used the FSW technique, which was initially created for welding aluminium alloys, to combine the extremely lightweight exterior tanks of space shuttles (Threadgill et al., 2009). The fusion welding procedure can now be used to combine alloys like AA2xxx, AA6xxx, and AA7xxx that were previously thought to be non-weldable (impractical to join) due to the expanding development of FSW (Cavaliere et al., 2009, Lee et al., 2006). FSW is also thought to be a feasible method for joining Metal-Matrix Reinforced Welds

(MMRWs) for several high strength Al-alloys (AA2xxx, AA6xxx, and AA7xxx) because of its adaptable nature (Paidar et al., 2018, Hamdollahzadeh et al., 2015, Singh et al. 2022 and Rouhi et al., 2016).

Similar to this, multiple MMRWs with various metal combinations were also created using FSW, with little regard for basic material composition compatibility. This results in a breakthrough in the traditional fusion welding method that helps to prevent weld zone problems. As a result, the current situation necessitates that the FSW process continue to focus on the creation and connecting of welds employing nanoparticles. The FSW process can result in effective and long-lasting welds with reduced porosity, crack nucleation, weld distortion, and particle dissolution during the process, according to the research that has already been done to join such materials using various welding processes (Mouritz, 2012, Singh et al. 2019a, d, Kaczmar et al., 2000, Rawal, 2001).

Furthermore, Orion crew exploration vehicles, Delta IV, Altas V, and Falcon IX rocket structural and design components were all joined using the FSW technique (Prater, 2014). Since aluminium alloy-based FSW welds with nanoparticles have a high modulus, high wear resistance, high thermal conductivity, high stiffness, and a high strength to weight ratio, they have become more popular and are considered a new class of MMCs. This has several advantages for various cutting-edge applications in the transportation, automotive, and aerospace sectors (Rosso, 2006, Lloyd, 1994).

However, the main barriers to growing interest in the aerospace sectors are concerns about these materials' weldability when using the fusion welding technique. Due to the presence of particles incorporated into the base matrix, the main obstacle to welding such materials employing FSW compared to Al-alloy is the small process window (Singh et al. 2019a,d, Singh et al. 2020).Even though the FSW technique to link reinforced aluminium welds has advanced significantly in recent years, there are still problems (Ellis, 1996, Tjong, 2007, Ma et al., 1996, Singh et al. 2020). There isn't much information in the literature currently available about the fractography, wear behaviour, and tensile characteristics of FSW welds reinforced by aluminum-based nanoparticles.

The intricate mechanical and microstructural behavioural phenomena that took place throughout the FSW process is blamed for this. Furthermore, the various combinations of process welding parameters (such as tool geometry, traverse speed, power/load applied, and tool rotational speed) have a major impact on the final joint qualities.

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