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Exploring the Mechanical Properties of Mild Steel by Depositing Metal Oxide Nano Particles during Arc Welding Process

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ABSTRACT

Conventional welding techniques are used to join the conductor metals like copper is a very tedious and costly task as it tends to form oxides during welding which gives a poor weld strength which is not feasible. Alternative means of welding like Arc welding has established itself across a wide range of industries as a cost-effective method for welding these kinds of metals. Welding is commonly used in both automotive and aerospace industries. The objective of this work is to study the strength of the metal before welding and after welding by using different electrodes and depositing metal oxide nano particles during arc welding process. The material chosen for this process is copper of 1.5 mm thickness, mild steel of 4 mm and 5 mm thickness for welding purpose. Hardness of the welded area will be calculated by using Rockwell Hardness Test. Microstructures of the welded area were done by using optical microscope.

Keywords: Rockwell hardness, metallurgical microscope.

I INTRODUCTION

In recent years, advanced material engineering approaches have been explored to overcome these limitations. One such promising approach is the incorporation of metal oxide nanoparticles into the weld pool during the welding process. Nanoparticles such as aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), and silicon dioxide (SiO_2) possess high thermal stability, excellent hardness, and strong interfacial bonding characteristics. When introduced into the molten weld pool, these nanoparticles act as

heterogeneous nucleation sites, promoting finer grain structures during solidification. Nanoparticle reinforcement has been shown to enhance mechanical properties by refining grains, reducing the width of the heat-affected zone, and improving tensile strength, hardness, and impact resistance. Furthermore, nanoparticles improve weld pool fluidity and heat distribution, thereby reducing weld defects and enhancing overall weld quality.

As a result, nanoparticle-assisted arc welding is gaining attention as an effective method to improve the performance of welded mild steel joints. Despite its widespread industrial application, conventional arc welding of mild steel often produces weld joints with inferior mechanical properties compared to the base metal. The major challenges include coarse grain formation in the weld metal and HAZ, reduced toughness, and susceptibility to weld defects such as porosity and cracking. These issues limit the structural reliability and service life of welded components.

II. LITERATURE REVIEW:

A Welding Fundamental: Welding is a permanent joining process in which two or more metal parts are fused together by the application of heat, pressure, or a combination of both. Among various welding techniques, arc welding is one of the most widely used fusion welding processes due to its simplicity, flexibility, and cost-effectiveness. In arc welding, an electric arc is generated between an electrode and the base metal by supplying electric current. This arc produces intense heat, typically in the range of 5,000–6,000°C, which is sufficient to melt the base metal and filler material. The molten metal forms a weld pool that solidifies upon cooling to create a strong joint.

B Arc Generation: The electric arc is formed when the electrode is brought close to the work piece, causing ionization of the surrounding air gap. The ionized gas becomes electrically conductive, allowing current to flow and generating the arc. The stability of the arc plays a crucial role in determining weld quality, bead shape, and penetration depth.

C Heat Flow in Welding: Heat flow during welding governs the thermal cycles experienced by the weld metal and the heat-affected zone (HAZ). The heat input depends on welding parameters such as current, voltage, and travel speed. Excessive heat input can lead to excessive grain growth, distortion, and residual stresses, while insufficient heat may result in poor fusion and weak joints. Proper control of heat flow is essential to achieve desirable microstructure and mechanical properties.

D Metal Solidification: After welding, the molten weld pool undergoes solidification as heat dissipates into the surrounding base metal and atmosphere. The solidification behavior determines the final microstructure of the weld metal. Rapid cooling may produce fine grains and higher strength, while slow cooling often leads to coarse grains and reduced toughness. The solidification process is strongly influenced by chemical composition, cooling rate, and presence of nucleating agents.

III Experimental Details:

A Deposition of Metal Oxide Nanoparticles in Mild Steel at Weld Zones

The first objective of this study is to introduce selected metal oxide nanoparticles, such as aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), or silicon dioxide (SiO_2), into the weld zone of mild steel during the arc welding process. The nanoparticles are deposited using a suitable technique to ensure their uniform distribution within the molten weld pool. This deposition aims to modify the weld metal composition and promote microstructural refinement during solidification. Proper incorporation of nanoparticles is essential to enhance weld quality and achieve improved mechanical performance.

B To Evaluate Mechanical Properties of the Welded Joints: Another important objective of this work is to evaluate the mechanical properties of nanoparticle-reinforced weld joints and compare them with those of conventional welds. Mechanical testing includes:

1. Tensile testing to determine yield strength, ultimate tensile strength, and elongation, which indicate the load-carrying capacity and ductility of the welded joint.
2. Hardness testing to measure resistance to indentation across the weld metal, heat-affected zone, and base metal.
3. Impact testing to assess the toughness and energy absorption capacity of the welded joint under sudden loading conditions.
4. These tests help in understanding the effectiveness of nanoparticle reinforcement in improving weld strength and durability.

C To Observe Microstructural Changes Using Optical and SEM Microscopy:

The third objective is to analyze the microstructural characteristics of the weld metal and heat-affected zone using optical microscopy and scanning electron microscopy (SEM). Metallographic examination is carried out to observe grain size, phase distribution, and morphological changes caused by the presence of nanoparticles. SEM analysis provides high-resolution images that reveal nanoparticle dispersion, grain refinement, and fracture behavior. Microstructural observations are correlated with mechanical properties to understand structure–property relationships.

IV MATERIALS AND METHODS

A Materials: The materials selected for the present investigation were chosen based on their wide industrial application, availability, and suitability for studying the influence of nanoparticle reinforcement on welded joints. The materials used in this study are described below.

B Mild Steel Plates: Mild steel plates conforming to ASTM A36 specification were used as the base material. The plates had a thickness of 10 mm, which is suitable for arc welding and mechanical testing. ASTM A36 mild steel is widely used in structural and fabrication industries due to its good weldability, moderate strength, ductility, and cost-effectiveness. The chemical composition and mechanical properties of this steel make it ideal for evaluating improvements achieved through nanoparticle-assisted welding.

C Welding Electrodes: Commercially available E6013 electrodes were used as the filler material for the arc welding process. E6013 electrodes are commonly employed for welding mild steel due to their stable arc characteristics, smooth weld bead appearance, and ease of operation. These electrodes produce low spatter and moderate penetration, making them suitable for controlled welding experiments.

D Metal Oxide Nanoparticles: Metal oxide nanoparticles, namely aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), and silicon dioxide (SiO_2), were used as reinforcing additives in the weld zone. The average particle size of these nanoparticles ranged from 20 to 50 nanometers. These nanoparticles were selected due to their high thermal stability, hardness, and ability to act as heterogeneous nucleation sites during solidification. Their incorporation into the weld pool is expected to promote grain refinement and enhance mechanical properties.

V RESULTS AND DISCUSSIONS:

A Tensile Property: Tensile testing was conducted to evaluate the influence of metal oxide nanoparticle deposition on the strength and ductility of arc-welded mild steel joints. The tensile properties of conventional welds and nanoparticle-reinforced welds are presented in Table 6.1.

Table 1 Tensile Property of Welded Samples

Sample	Yield Strength (MPa)	UltimateTensile Strength (MPa)	Elongation (%)
Control Weld	320	460	18
Al_2O_3 Reinforced	350	510	20
TiO_2 Reinforced	345	500	19
SiO_2 Reinforced	338	490	19

The results clearly indicate an improvement in both yield strength and ultimate tensile strength for nanoparticle-reinforced welds compared to the conventional weld. Among the tested samples, the Al_2O_3-reinforced weld exhibited the highest tensile strength, showing an increase of approximately 11% in ultimate tensile strength compared to the control weld. The elongation values also showed a marginal improvement, indicating that strength enhancement was achieved without compromising ductility.

The increase in tensile properties can be attributed to grain refinement and uniform dispersion of nanoparticles, which strengthen the weld metal through dispersion strengthening and grain boundary strengthening mechanisms.

B Hardness Profile

Hardness measurements were carried out across the weld metal, heat-affected zone (HAZ), and base metal using the Vickers hardness tester. The hardness profile revealed a noticeable increase in hardness within the weld bead and HAZ for nanoparticle-reinforced samples compared to the control weld.

The hardness map showed that the maximum hardness occurred in the weld zone, followed by the HAZ, and then the base metal. The presence of metal oxide nanoparticles restricted grain growth during solidification, resulting in a finer microstructure and increased resistance to indentation. Among the reinforced samples, Al_2O_3 exhibited the highest hardness values, correlating well with tensile test results.

C Impact Toughness: Charpy impact tests were performed at room temperature to assess the toughness of the welded joints. The nanoparticle-reinforced welds showed higher impact energy absorption compared to the conventional weld. This improvement in impact toughness is primarily due to the refined grain structure produced by nanoparticle addition. Finer grains increase the number of grain boundaries, which act as barriers to crack propagation and enhance energy absorption during fracture. The improved toughness indicates that nanoparticle-assisted welds are more resistant to brittle failure under sudden loading conditions.

D Microstructural Observations: Microstructural examination of the welded samples was carried out using optical microscopy after proper polishing and etching. The photomicrographs of conventional welds showed relatively coarse ferrite and pearlite grains in the weld metal and HAZ. In contrast, nanoparticle-reinforced welds exhibited significantly refined grain structures, with uniform distribution of ferrite and pearlite phases. The presence of metal oxide nanoparticles acted as heterogeneous nucleation sites during solidification, promoting fine grain formation. The refined microstructure was more prominent in Al_2O_3- and TiO_2-reinforced welds, which directly contributed to improved mechanical properties.

Discussion: The overall improvement in mechanical and microstructural properties of nanoparticle-reinforced welds can be explained by the following mechanisms:

Nanoparticles as nucleation sites: Metal oxide nanoparticles provide additional nucleation sites during weld metal solidification, leading to finer grain structures.

Refined ferrite–pearlite structure: Grain refinement enhances strength and toughness in accordance with the Hall–Petch relationship.

Lower crack propagation: Increased grain boundary density hinders crack initiation and propagation, improving resistance to fracture and fatigue.

The results demonstrate that nanoparticle deposition during arc welding is an effective method for enhancing the mechanical performance and structural integrity of mild steel welds.

VI CONCLUSION:

The present experimental investigation was carried out to study the influence of metal oxide nanoparticle deposition on the mechanical and microstructural properties of arc-welded mild steel joints. Based on the results obtained from tensile testing, hardness measurements, impact testing, and microstructural analysis, the following conclusions can be drawn: The addition of metal oxide nanoparticles into the weld zone significantly enhanced the tensile strength and hardness of mild steel welded joints when compared to conventional arc welding. The improvement in mechanical properties is mainly attributed to grain refinement and dispersion strengthening effects introduced by the nanoparticles.

The refined microstructure resulted in improved resistance to deformation and enhanced load-carrying capacity of the welded joints. Among the different metal oxide nanoparticles investigated, aluminum oxide (Al_2O_3) exhibited the most significant improvement in mechanical properties. Al_2O_3-reinforced welds showed the highest yield strength, ultimate tensile strength, and hardness values. This superior performance is due to the high thermal stability and effective nucleation capability of Al_2O_3 nanoparticles, which promote uniform grain refinement during weld metal solidification.

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