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Advancing Steel Component Repair by Investigating the Surface Properties of Mild Steel Plates Coated with Alumina Using Metal Inert Gas Welding

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Abstract. Arc-welding coatings are extensively employed within the informal sectors of many African countries to repair various machine components, such as gear teeth, machine shafts, bushings, and many others. In the pursuit of advancing steel component repair techniques, this study investigates the surface properties of mild steel plates coated with alumina using the Metal Inert Gas (MIG) welding process. Mild steel wire of diameter 1.6 mm, alumina particles of size 1 µm, and mild steel plates were used. The prepared samples were analysed for microstructural, hardness, wear, and corrosion properties. For the first time, and through a traditional welding process, it is demonstrated that the hardness, wear, and corrosion resistance of steel parts can be improved by the inclusion of alumina particles on their surfaces. As such, this work will have an impact on the informal engineering sector (*Jua Kali* sector as known in Kenya) involved in the surface repair of steel components.

Keywords: Alumina; Corrosion; Hardness; Surface properties; Welding; Wear

1. Introduction

Surface engineering can make use of the metal inert gas (MIG) welding technique by coating a workpiece with a dissimilar material. An electrical circuit that creates an arc between the electrode and the workpiece allows the coating material to be deposited on the workpiece. A considerable amount of thermal energy is produced by the electrical arc formed by the high electrical current flowing between the electrode (anode) and workpiece (cathode), melting the electrode and depositing it on the surface of the workpiece [1]. The arc-welding coating offers several advantages, including precision in selecting the desired coating area, strong adhesion between the coating and workpiece, as well as the affordability and simplicity of the equipment used for the coating deposition process.

In arc-welding coating, the material that has been eroded from the anode is transferred to the cathode, where it is then deposited as a coating on the cathode surface. The coating is either made of pure anode material or is the result of mixing the anode with other secondary materials, including metallic particles/powder [2]. Alumina is among these metallic powders, and it has long been used as a protective covering against high-temperature oxidation and corrosion [3]. The technique is widely used in informal sectors of most African countries to repair machine parts such as gear teeth, bushings, crankshafts, and so forth. In terms of research, Muigai *et al.* presented the possibility of utilising the TIG welding process in surface coating and repair of steel plates and demonstrated that the welding parameters influence the quality of the coating [4,5]. In their work, they have indicated that *Jua Kali* Industries (small-scale and informal engineering sectors) in Kenya can benefit from research on improving the repair of steel components through welding; welding is extensively adopted by these industries in repairing machine components, especially for the automotive sector. As such, the repair of surfaces through welding is an interesting topic of research among various research groups today [6–10].

The arc-welding coating is usually associated with an increase in the surface roughness of the workpiece. However, increased surface roughness is not necessarily viewed as a disadvantage. In some situations, troughs in the roughness profile serve as lubricant reservoirs and speed up heat dissipation [11]. In some instances, it has been reported that arc-welding coating enhances the coated sample's microhardness relative to the base metal [5]. Additionally, the arc-welding coated sample exhibits greater resistance to corrosion than the base metal.

In this study, the effect of alumina powder on the surface properties of mild steel coated through welding is investigated. The novelty of the work is that there are no known existing studies (and sector practices) utilising alumina or ceramic powders to improve the properties during the repair of engineering components. As such, the results presented herein shall contribute to the improvement of the quality of repair services provided by the informal engineering sectors in Africa and the rest of the world.

2. Methods

In this work, the welding was undertaken by a certified welder. The welding was undertaken using MIG Cu-coated wires (EN1090) and alumina powder (of particle size 1 µm) on structural mild steel plates (6 mm × 50 mm × 100 mm with composition of C (0.30), Mn (0.62%), P (0.02), S (0.01), and Fe (balance) as provided by the manufacturer).The surfaces of the steel plates were ground with SiC papers of #500 grit to remove the oxides and then cleaned in acetone and dried in high-pressure hot air. The wire diameter was 1.2 mm, the shield gas contained a mixture of 75% argon and 25% carbon dioxide (CO_2) at a flow rate of 15 l/min and the wire feed speed was 3.2 m/min. Two sets of samples were prepared; one without alumina powder (named as Sample 1) and the other containing alumina powder (herein referred to as Sample 2). The welding was conducted using a MIG machine at an operating current of 65A (this is the optimal surface coating condition of the machine as demonstrated by Muigai et al. [5]). Alumina solution was prepared using alumina powder and white spirit to make it easy to introduce into the molten region during the welding process. In this case, a syringe was used to introduce 10 ml of the alumina solution along the molten zone. In this way, it was possible to concurrently undertake welding while introducing the alumina powder into the welded zone.

The prepared samples were then cut into 10 mm by 10 mm pieces for metallography, wear, hardness, and corrosion analysis. For these tests, the samples were ground and polished using SiC papers (#500, #800, #1000), diamond polish (91 µm, followed by 6 µm, followed by 3 µm and finally 1 µm), and diamond finish of ¼ µm. The samples were then etched using nitric acid for optical microscopy. The Vickers hardness test was used to determine the hardness of the sample's surface. The samples for the corrosion test were then drilled to accommodate the electrochemical cell and the test was undertaken using 3.5%wt. NaCl solution as the electrolyte, graphite rod as the counter-current electrode, and Ag/AgCl as the reference electrode (ASTM G102-89). Linear polarisation was evaluated for 1 hour and

7 minutes, and open circuit potential was evaluated for 1 hour and 7 minutes. A stereoscope was used to take images of the deteriorated surface after corrosion testing. The wear test was undertaken using a ball-on-disc tribometer (CSM Instruments, Anton Paar, Germany) at room temperature and dry conditions according to ASTM G99 standards. A 6 mm diameter steel ball was used as the abrasive material at a linear speed of 0.08 m/s, a normal load of 2.00 N for 1870 seconds and a total sliding distance of about 150 m.

3. Results and Discussion

The optical images of the welded surfaces of the mild steel plates without and with alumina powder are shown in Fig. 1. In all the images, ferrite, pearlite structures and grain boundaries of the mild steels can be seen. In images (b) and (d) the particles of alumina (white) can be seen embedded between the grain boundaries of the structure.

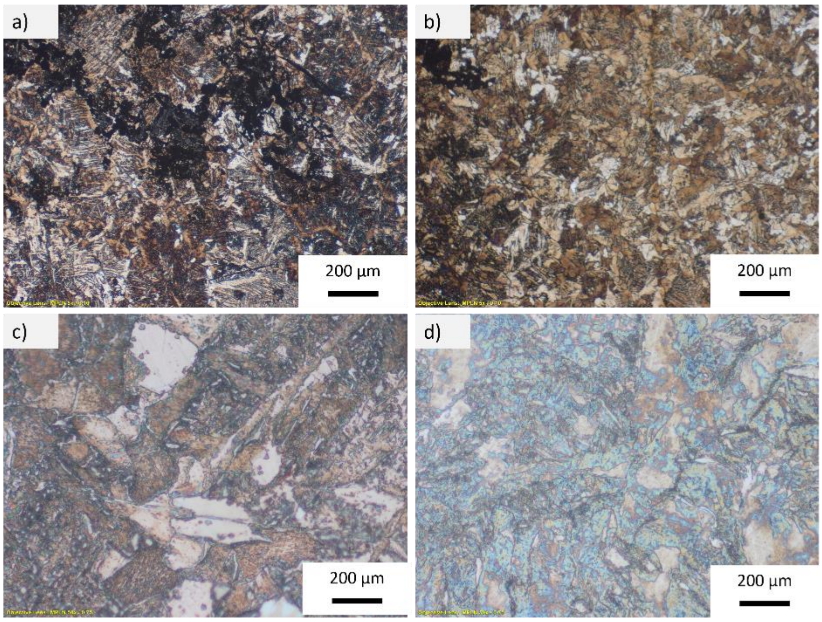

Figure 1. Optical images of the mild steel plates welded (a) without Alumina powder (Sample 1) and (b) with alumina (Sample 2). The corresponding images (c) and (d) represent the surfaces at higher magnification.

The Vickers hardness test results for the mild steel plates welded without Alumina powder (Sample 1) and with alumina (Sample 2) are shown in Fig. 2. The Vickers hardness value for the mild steel plates welded without Alumina powder was 150 HV while for mild steel plates welded with Alumina powder was 200 HV. There was a 33.3% increase in hardness after the alumina weld coating was carried out. These results imply that the addition of alumina particles into the composite weld coating directly affects its hardness. The presence of hard alumina particles, which act as a barrier to the mild steel matrix's plastic deformation under load, causes the coated surface of the material to become harder [12]. The combined deposition of alumina particles with mild-steel coating transforms the surface morphology and topography of deposits from a smooth state in the pure mild steel coating to a non-smooth state in steel-alumina composite coating. Similar results were obtained by Borisade *et al.* in their study where alumina was used to improve the hardness of Al-6063 [13].

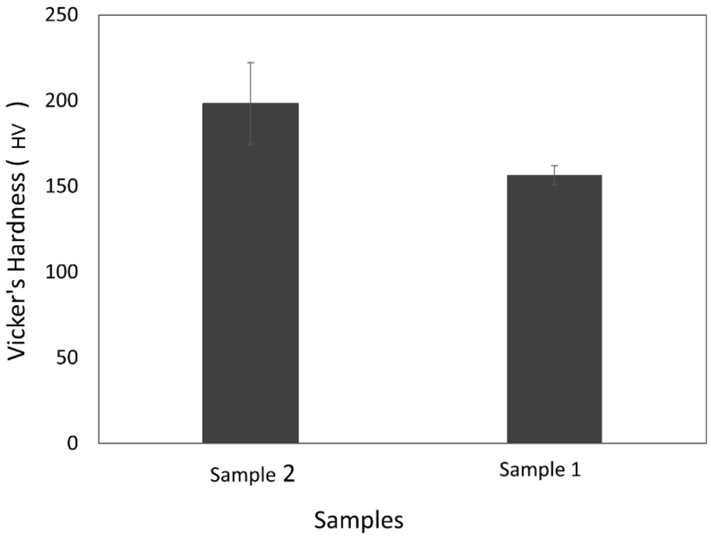

Figure 2. Vickers hardness of samples 1 and 2

The polarisation curves indicating the corrosion properties of the samples are shown in Fig. 3. From the figure, the corrosion potentials (E_{corr}) for samples 1 and 2 are -0.5743 V and -0.6659 V respectively, and corrosion intensities (I_{corr}) for samples 1 and 2 are 1.5562 uA/cm^2 and 0.4499 uA/cm^2 respectively. The corrosion rates can be obtained as 0.02167 mm/yr for sample 1 and 0.00627 mm/yr for sample 2. It is also shown that both materials exhibit the creation of the protective layer in the first few seconds of OCP graph observation (not shown), which is followed by the film's breakdown, allowing the metals to corrode. The alloys corrode up until the voltage is constant, at which point neither the passive film is formed or broken. Sample 2 has a higher potential for corrosion and hence has a lower chance to corrode as shown by the low corrosion rate. As such, the introduction of the alumina particles into the welding zone of mild steel surfaces can improve their corrosion behaviour. The ability of the alumina to form a passive layer helps in corrosion protection of the surface [14-20].

The wear characteristics of the samples were evaluated in terms of coefficient of friction (CoF) versus the sliding distance of the abrasive ball (Fig. 4). Both the CoF curves can be observed reaching a steady state signifying the removal or flattening of the prominent asperities [15]. The CoF of sample 1 varies between 0.25 and 0.4 whereas that of sample 2 varies between 0.45 and 0.55. There exists a surface-counter-face interaction between the ball and the surface and as shown, the addition of the alumina particles increases the coefficient of friction and the resistance to abrasive wear.

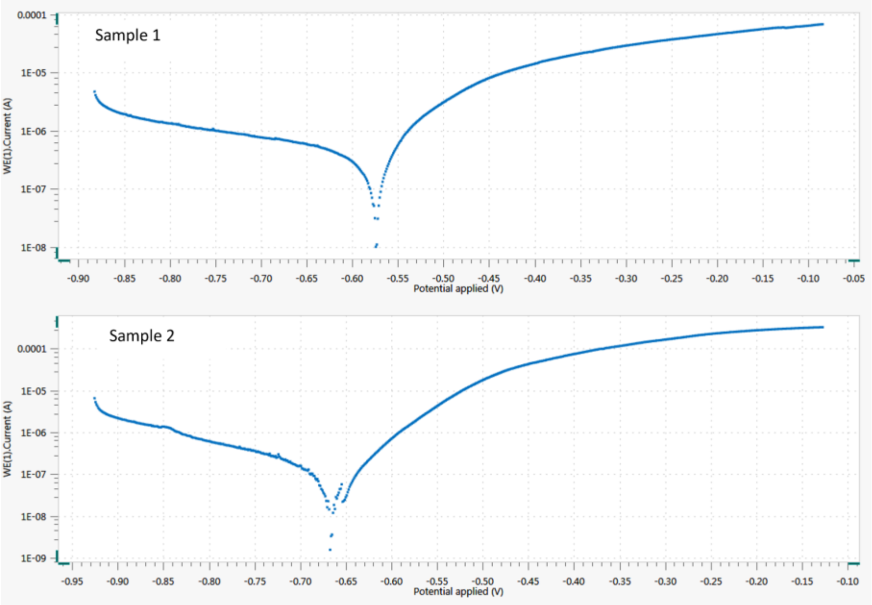

Figure 3. Potentiodynamic polarisation curves for samples 1 and 2

It can be seen from the wear scars that for sample 2 the alumina is strongly impregnated onto the structure of mild steel even after abrasion by the sliding loads. On the contrary, the surface of the mild steel (dark background) is exposed upon exposure to wear loads. This means that alumina improves the wear properties of the mild steel plate surfaces. This aligns with a study conducted by Godino et al., in which they concluded that alumina exhibits ductile behavior upon contact, primarily attributed to the influence of elevated temperatures and pressure. This phenomenon serves to mitigate wear on machine parts and contributes to an extended lifespan for these components [10].

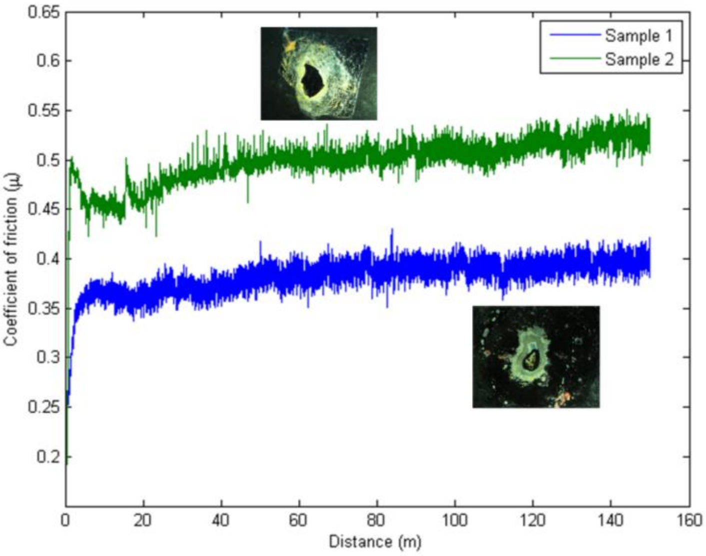

Figure 4. Coefficient of friction against the sliding distance for the surface-coated samples with and without alumina particles. The wear scars for each sample are shown next to each curve (inset)

4. Conclusions

In this article, the microstructure, hardness, wear, and corrosion properties of mild steel plate surfaces coated via manual metal gas welding process have been reported. The samples were prepared by a certified welder using mild steel standard welding wire for the MIG process. One sample was prepared with the addition of alumina powder while the other was prepared without the addition of alumina particles. The objective was to investigate the effect of alumina on the surface properties of the coating. Optical microscopy shows that particles of alumina form around the grain boundaries and improve the hardness of the surface of the mild steel plates. It is also shown that alumina improves the wear and corrosion resistance of mild steel plate surfaces. These preliminary results indicate that alumina may be utilised in surface weld repairs for steel components such as gear teeth, shafts, and so forth.

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