



CONFERENCE PAPER

ADVANCING SUSTAINABLE ENGINEERING THROUGH TI-CU ELECTRICAL DISCHARGE COATING OF AA6062 ALUMINUM ALLOY

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Abstract

Electrical discharge coating (EDC) is a reverse polarity process that uses strategic deposition of electrode materials such as Titanium (Ti) and Copper (Cu) onto AA6062 aluminum, providing advanced surface modification in microfluidic and thermal applications. Using a Face-Centered Central Composite Design, this study illustrates that although peak current and pulse-on time are the most important factors to maximize the Deposition Rate (DR), the optimal pulse-off times are highly important to ensure stability in the discharge. In addition to checking elemental diffusion through SEM, Electron Backscatter Diffraction (EBSD) enables a more detailed understanding of the development of the coating microstructure and ensures that both electrical calibration and a more uniform grain distribution with better continuity of the matrix result in a more uniform distribution of the coating. Through crystallographic orientations, the research confirms the efficacy of EDC as a promising technique to fill the gap between the traditional machining and the innovative functional coating, making sure that the deposited layers have the structural integrity required to produce high-performance industrial components.

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Introduction:-

EDM uses high-intensity thermal energy, which can be as high as 12,000 C, to cut conductive material, but can often damage surface integrity by creating a brittle recast layer [1, 2]. To overcome these shortcomings, Electrical Discharge Coating (EDC) uses reverse polarity to enable the hard phase materials and carbides to migrate onto the substrate thereby enhancing surface properties, hardness, and wear resistance to a large extent [3, 4]. Although lightweight Aluminum alloys are indispensable in aerospace and automotive industries, their susceptibility to high-temperature corrosion and wear provide a reason to employ advanced surface engineering [5, 6]. Conventional modification methods such as Chemical Vapor Deposition (CVD), Physical Vapor Deposition (PVD),

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Thermal Spraying, and Laser Cladding usually involve prohibitive prices, the high-vacuum surroundings, and multi-phase systems [7,10]. On the other hand, EDC offers a simple, less expensive option that enables the coating process to be controlled micro-level [11]. Comprehensive studies have confirmed that raising the peak current and pulse-on time is effective to increase the Material Transfer Rate (MTR) and the layer thickness, and the use of solid lubricants or post-processing is one more way to improve the final surface finish [12-14]. Regardless of these developments, there is still a gap in the research in terms of systematic optimization of process parameters when using a combined Titanium-Copper (Ti-Cu) green compact electrode. This study therefore aims at a multi- attribute analysis to identify the best set-up in Ti-Cu composite coating, which would fill the existing gap in the high performance literature on surface modification [15].

Methodology and Experimental Design:-

Aluminum alloy 6062 (AA6062) was used as the major substrate in the current research. A tailor made composite electrode was prepared by a precise 60:40 mixture of Titanium (Ti) and Copper (Cu) powder in order to increase the wear resistance of the material and give it self-lubricating properties. The mixture was then carefully homogenized by crushing the elemental powders, and then the mixture was pressed together in a punch and die machine with a high compaction load of 10 tons to make a dense green compact. In order to promote strong inter-particle cohesion as well as structural integrity of the electrode, it was then subjected to a thermal treatment phase. This curing was carried out in a tube furnace that was filled with an inert gas and the temperature of the furnace was kept at about 130 C with a period of 20 minutes. The active face of the fabricated electrode was carefully ground and polished before it commenced the main experimental investigations, to ensure a uniformly smooth and flat working surface.

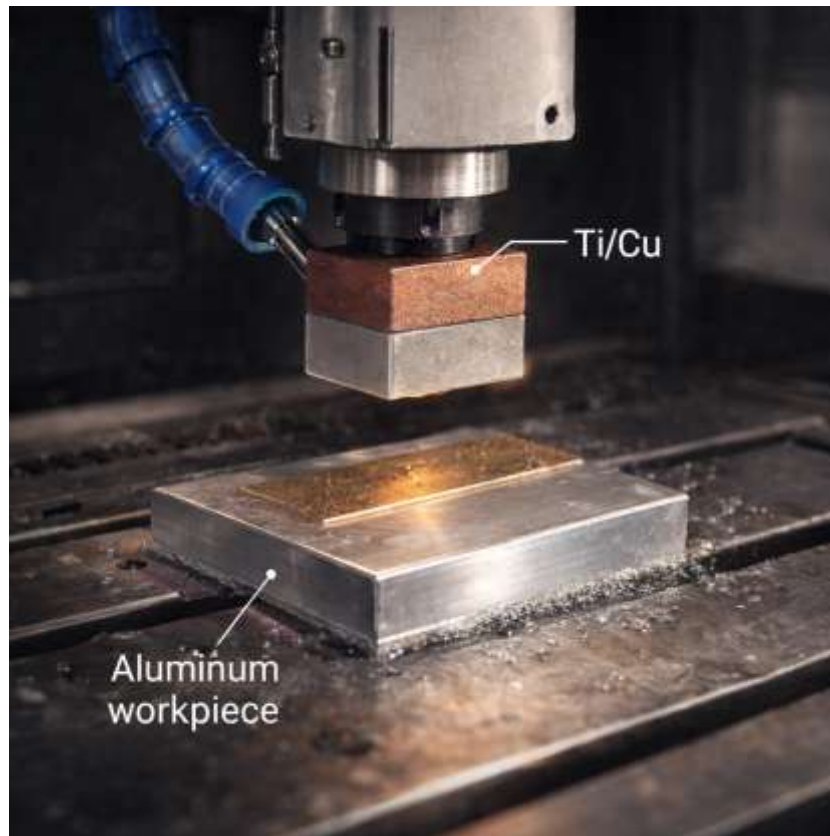


Fig1. Formation of Ti/Cu Coating Layer on Aluminum Using EDC Technique

Result and Discussion:-

Correlation Between Operational Parameters and Material Deposition Rate (DR):-

The research found that the Deposition rate (DR) is directly proportional to the current between 4A to 10 A which overcomes the initially inadequate discharge energy that leads to shallow craters and low deposition. Adding more current (4A or more) produces high thermal energy which suffices to lose more electrode powder, but the high heat

also leads to rapid cooling and non-uniform thermal contraction, producing many micro-cracks in the coating. In terms of pulse timing, lower pulse on time results in a higher DR due to the formation of highly intense and concentrated plasma channel that facilitates rapid and uniform material transfer. On the other hand, a pulse on-time of 70 to 90 micro-seconds results in a drop in the DR since long arc times result in lost pulses, arc freezes and a transition between material deposition and vaporization. This prolonged period results in different sized globules on the surface (Figure 2) as a result of insufficient evaporation and re-condensing, and the overall decrease in DR is further increased by the decreasing thermal energy input over time and constant flushing of debris throughout the longer off-period.

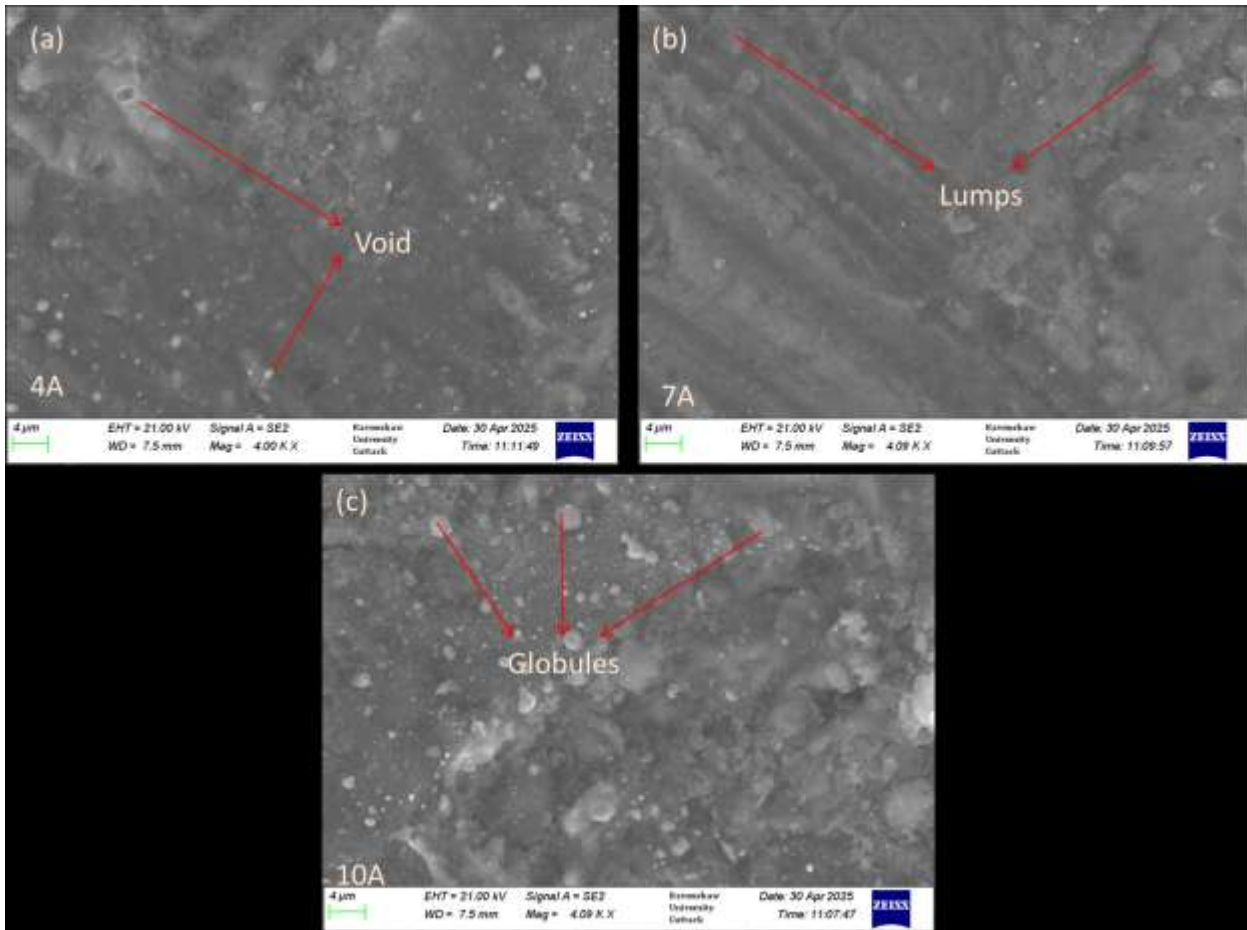
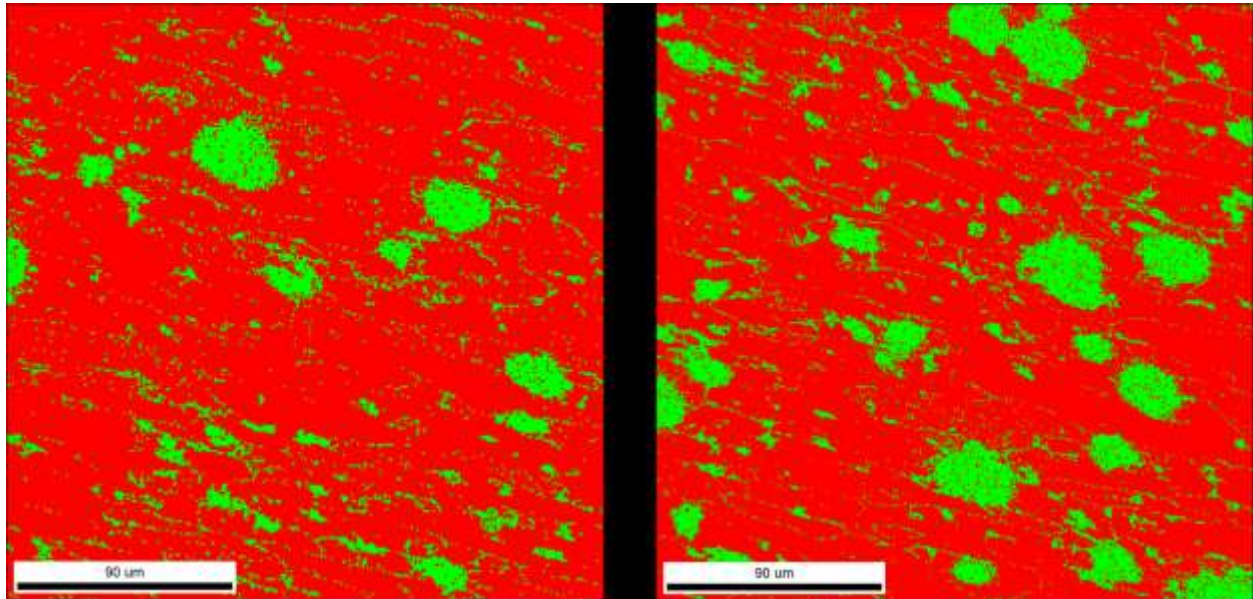


Fig2. Microstructural Defects in Ti/Cu Coated Aluminum Surface

Variation of coating microstructure with respect to duty factor:-

It was a systematic study of the influence of duty factor on the microstructure of coating through a variation of 30 percent to 90 percent of a TiCu (50:50) mixture at a given constant peak current of 10 A. The duty factor determines the duration of discharge and the thermal energy input at the electrode-workpiece interface in the process of EDC. With lower duty factors (30% and 50%), the discharge energy was not sufficient to maintain a stable plasma channel, and the copper matrix was not fully melted, leading to poor dispersion of Ti particles and poor interfacial bonds, which gave rise to a discontinuous and porous coating. Conversely, a medium duty of 70% provided a stable plasma, which permitted uniform melting and transfer of Ti-Cu material, thus creating a dense, smooth and homogeneous coating with lower porosity and better adhesion. Nevertheless, with a higher duty factor of 90, the excess energy of discharge resulted in highly intense sparking, overheating, and arcing, resulting in the accumulation of molten debris, uneven deposition, and the development of large voids. In general, a duty factor of 70% gave the best tradeoff between the thermal input and deposition rate, giving a high-quality composite microstructure and improved coating functionality.

EBSD Analysis of Phase Dispersity and Matrix Homogeneity:-**Fig3. Microstructural and Phase Analysis at 4A and 11 A Peak Current**

The phase distribution maps also clearly show that the peak current setting of 4A gives a structure integrated and uniform coating than that of the 11A setting of the phase distribution maps. The red matrix (indicating the primary metallic phase) at 4A (left) has much more continuity and connectivity, and the green Ti-based clusters are also well-dispersed, localized reinforcements. This implies a regulated thermal pump that will allow unobtrusive transfer of materials without splashing. Conversely, the 11A map (right) reveals a most disaggregated matrix with much bigger and irregular in shape green agglomerates and greater boundary porosity. It means that over-melting and turbulent plasma behavior (at higher discharge energy of 11A) results in coarse phase segregation and a loose microstructure, which probably has a lower adhesive strength and greater brittleness. Therefore, the current of 4A is ideal in order to obtain a dense and cohesive metallurgically stable layer of composite.

Conclusion:-

The electrode utilisation of titanium and copper powder metallurgy in the EDC process was successfully used to increase the integrity of surface and usefulness of the AA6062 aluminum substrate. It was found that the rate of deposition (DR) directly depended on peak current with more thermal energy enhancing melting and vaporization of the electrode material and less pulse-off time maintaining an energetic plasma channel, which enabled efficient transfer of material. Micro-hardness (MH) was found to rise with increased current and pulse-on time owing to extended thermal exposure and high-intensity discharge energy, which promoted electrode disintegration and a dense and hardened composite layer was formed at solidification. But microstructural examination showed that 4 A was the optimum current to achieve the best structural integrity with a smooth and consistent coating. Conversely, morphology was coarse and fragmented with a higher current of 11 A. The 4 A condition also provided superior phase distribution and metal continuity, reduced phase segregation and brittle nature, which enhanced mechanical dependability and metallurgical stability of the coating.

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