



INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Electric discharge alloying (EDA) is one of the evolving and promising techniques in the field of surface alloying. In EDA, deliberate transfer of tool material over the workpiece surface along with decomposed dielectric is anticipated to form a hard alloyed layer over the workpiece. The process mechanism of EDA lies in the basic concept of re-solidification of the melted tool and workpiece material which is resulted from electric discharge generated between them. This process could find its application in industrially important material, namely AISI P20 – DIN 1.2311 – SCM4, a low-alloy tool steel which is widely used as thermoplastic molds, extrusion dies, injection molds, and die-casting dies. It is essential to improve the surface characteristics of the dies and molds in terms of its hardness, wear, and corrosion resistance as it suffers from mechanical wear, corrosive environment during the casting process. Considering these aspects, electric discharge alloying is found to be economical and less time-consuming for surface modification, as the same set-up will be used for both the fabrication and repair of the molds.

The main focus of the present work is to enhance the surface characteristics of AISI P20 mold steel in terms of its hardness, corrosion resistance, and wear resistance by using the electrical discharge alloying process. It was envisaged to achieve this by alloying titanium, aluminium, and nitrogen over AISI P20 mold steel by using a green compact powder metallurgy tool with a composition of 50 % titanium and 50 % aluminium compacted at a compaction pressure of 443 MPa. Three types of dielectric media, namely hydrocarbon oil, deionized water,

and urea mixed deionized water, were considered. The present work investigates the EDA process both experimentally and numerically. The study was carried out to investigate the influence of the EDA processing conditions viz. discharge current, discharge duration, and the type of dielectric medium onto the alloyed layer thickness, material deposition rate, surface roughness, elemental distribution, hardness, wear-resistance, and corrosion resistance. Further, an integrated FEM-ANN model has been developed for quick and accurate computation of the alloyed layer thickness in EDA of AISI P20 mold steel using different dielectric media viz. hydrocarbon oil, deionized water, and urea mixed deionized water.

In the initial part of the work, experimental investigations were successfully carried out to alloy titanium and aluminium with AISI P20 steel by using hydrocarbon oil as the dielectric medium. The alloyed workpieces were characterized by using energy-dispersive X-ray spectroscopy (EDS), and results showed that up to a maximum of 18 % Ti and 18.7 % Al could be observed over the alloyed workpiece surface. Further, elemental mapping of the alloyed surface over the top surface, as well as the cross-sectioned region, indicated that the tool elements present are uniformly distributed in the alloyed region. Apart from the elemental transfer, the formation of Fe_3C and TiAl at the alloyed region was confirmed from the X-ray diffraction pattern. The thickness of the alloyed layer formed was observed to be dependent on the discharge current and pulse on-time, and a uniform layer of up to $70\ \mu\text{m}$ could be achieved. The alloyed layer showed improvement in hardness of four times more than that of the parent material, i.e., $300\ \text{HV}_{0.3}$ to $1125\ \text{HV}_{0.3}$, and this ascertains the usefulness of the EDA process in improving the surface characteristics of the parent material. Further, it was observed that the material deposition rate and surface roughness is dependent on the EDA processing conditions. An increase in the discharge current and pulse on-time resulted in a higher material deposition rate, and the surface roughness of the alloyed workpieces exhibit a roughness value in the range of 4.5 to $8.5\ \mu\text{m}$.

The work has been extended to study the alloying process in water-based dielectric medium, i.e., by using deionized (DI) water and urea mixed deionized water. It was observed that a maximum of 16.5 % Ti with 12 % Al, 35.02 % oxygen and 4 % nitrogen could be observed for the workpiece processed in urea mixed deionized water, while for that of the workpiece processed in deionized water, a maximum of 27.2 % Ti with 7.6 % Al and 40.3 % oxygen was observed. Formation of an alloyed layer composed of TiAl , Fe_3O_4 , and Ti_4AlN_3 has been observed for the workpiece processed using urea mixed DI water, while for the workpiece processed in deionized water, the alloyed layer is composed of TiAl and Fe_3O_4 . The study on the alloyed layer thickness indicated that the thickness is more for the workpieces processed using DI water as compared to that of the urea mixed. Alloyed layer of $60.19\ \mu\text{m}$ thickness could be observed for the workpiece processed using DI water, while that for urea mixed deionized water was $53.25\ \mu\text{m}$. The difference in the hardness value of the alloyed layer was observed to be marginal for the workpiece processed in the two dielectric media. While using deionized water, the hardness of the alloyed layer was obtained to be $579.83\ \text{HV}_{0.3}$, while for that of urea mixed

deionized water, the value was 604.35 HV_{0.3}. The material deposition rate is mainly affected by the discharge current. An increase in discharge current results in a higher deposition rate for both deionized water and urea mixed deionized water. The surface roughness extends a range of 5.94 μm to 12.45 μm for the workpiece processed in deionized water, while that of urea mixed deionized water, the range is 5.98 μm to 12.54 μm showing that the addition of urea does not have a significant difference in the roughness value.

A comparative study in terms of wear and corrosion resistance for the workpieces alloyed in the three different types of dielectric media has been made. Results indicated that there is minimal wear for the workpieces processed in hydrocarbon oil, followed by workpieces processed in urea mixed deionized water, unprocessed workpiece, and workpiece processed in deionized water. Further, the mass loss after the wear test for the workpiece processed in hydrocarbon oil was significantly reduced by 46 % from that of the unprocessed workpiece. The change in mass loss is quite marginal for the unprocessed workpiece and the workpieces processed in the water-based dielectric. In addition to the wear test, an electrochemical corrosion test was conducted for the workpieces processed in different dielectric media, and results showed that the impedance modulus and the maximum phase angle are the highest for the workpiece processed in hydrocarbon oil, indicating the highest polarization resistance. The corrosion resistance value for the workpiece processed using hydrocarbon oil was almost double the corrosion resistance of the unprocessed workpiece. There was a 110 % enhancement in the corrosion resistance for the workpiece processed in hydrocarbon oil from that of the unprocessed workpiece.

Further, an integrated FEM-ANN model was used to compute the alloyed layer thickness by considering accurate values for fraction of energy distributed to the workpiece, F_A . These values were computed by using the inverse estimation method and the ANN-based model. The neural network of 3-10-1 architecture was found to be the optimum network. The developed methodology suggests that the fraction of energy F_A varies from 0.129 to 0.215. This can be employed in the thermal analysis of the electric discharge-based manufacturing processes. The performance of the developed FEM-ANN was verified by carrying out the experiments. It was found acceptable with an average prediction deviation of 6.55 %. Overall, the present work facilitates a simple and quick methodology for accurate computation of the alloyed layer thickness for complex manufacturing processes such as EDA. This provides an efficient and economical alternative to the costly, tedious, and time-consuming experimental work.