INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Numerical and Experimental Investigations on Wire Electrode Health during Wire Electric Discharge Machining Process

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SHORT ABSTRACT

Wire electric discharge machining (WEDM) is a widely used high-precision machining process. With growing demands of manufacturing sector, wire erosion and breakage act as major challenges during WEDM process. Although material removal from the workpiece is desirable to achieve the required shape and contour, wire erosion and damage are detrimental to the overall machining process. Wire wear reduces the wire strength and eventually causes the wire to fail, which is a significant disadvantage in the modern manufacturing sector. Frequent wire breakage adversely affects the product geometric precision, surface integrity, and productivity of the manufacturing establishments. The damages undergone by the wire also have a notable effect on the surface quality achieved by the workpiece during machining. To reinforce and enhance the effective utilization of the wire EDM process, it is very much essential to mitigate the frequency of wire failure. Thus, it is imperative to understand the causes of wire breakage and predict the frequency of its occurrence. Prediction and prevention of wire rupture will definitely provide some useful insights in achieving sustainable manufacturing with the desired product quality.

In this research work, a three-dimensional nonlinear transient thermo-mechanical model for a molybdenum wire used during WEDM has been developed to compute the temperature and the induced stresses. The computational ability of the developed model has been verified by conducting systematic experiments. The merit of the work lies in the use of a three-dimensional thermo-mechanical nonlinear numerical model to compute the wire strength based on the stresses generated during machining. A simple and novel method has been developed, which computes the wire safety index based on the residual stresses generated on the wire electrode surface. The stresses produced on the wire were observed to reach values beyond the yield stress (600 MPa)

of the molybdenum wire at certain process conditions, which causes the reduction in strength of the wire. The wire safety index was evaluated by calculating a ratio (X) between the maximum value of residual stress induced and the yield stress of the wire. If the equivalent residual stresses produced in the wire during the discharge phenomenon is well below the yield strength of the wire, the wire is said to be within the safe limit. As the residual stress values cross the yield point, the strength of the wire starts deteriorating which is harmful to the health of the wire. Formation of microcracks on the wire surface was considered as indicators of wire breakage to estimate the threshold value of wire strength beyond which the wire is considered to be unsafe for machining.

A comprehensive analysis of the wire wear and its deformation mechanism, morphology study of the eroded wire samples is very crucial in restricting wire failure and enhancing the overall efficiency of the operation. This section reports an extensive experimental investigation on the measurement and analysis of molybdenum wire erosion after WEDM of Ti-6Al-4V alloy at varying input levels viz. discharge voltage, discharge current, pulse on-time, pulse off-time, and wire speed. An in-depth discussion on various wire damages and deformation during the discharge phenomenon has been demonstrated. Moreover, the influence of different process conditions on wire erosion and on the surface quality achieved by the component has been investigated. The eroded wire surfaces reported damages in the form of craters, globules, microholes. A wire surface quality index for the tolerable limit of wire surface erosion without causing wire failure was estimated using image processing technique. A relationship between wire wear and product surface quality was also established using the developed technique. The mean of wire image histogram was used as an indicative tool to correlate the intensity of wire wear and the workpiece quality. It was observed that as the mean of image histogram decreases, the intensity of wire surface erosion increases. A histogram mean of 122.17 was observed to be the threshold limit below which the damages on the wire surface are critical thus increasing the probability of wire failure. Wire wear have shown a detrimental effect on the surface roughness of WEDMed components and deteriorate the surface quality by approximately 25-35 %. A comprehensive discussion on wire breakage due to excessive erosion is also presented. The findings presented in this work extend the existing area of knowledge in this field and give better insights to understand the wire erosion mechanism and achieve stable machining without wire breakage.

The work has been extended to study the characteristics of coated wires during WEDM cutting operation. Nowadays, coated wires are extensively used in modern manufacturing industries due to improved properties as compared to uncoated wires. A three-dimensional thermo-mechanical finite element model (FEM) of a zinc coated brass wire electrode during WEDM process was developed. The temperature and stresses generated in the wire at different sets of process conditions are computed using the developed model. The crater volume produced in the wire is calculated when the temperature exceeds the melting point of the wire material. The stresses induced in the zinc coated brass wire were noted to be lower than the yield strength of the core brass material. Thus, the wire strength is estimated based on the amount of material

removed from the zinc coated brass wire. In the end, parametric studies to investigate the effects of input parameters on the temperature, residual stresses and crater volume generated in the wire are carried out.

The final part of the work presents a detailed experimental investigation of the erosion and deformation of a zinc coated brass wire during WEDM experiments on Ti-6Al-4V alloy. A comparative study between the characteristics of molybdenum wire and zinc coated brass wire showed that for the same process conditions, the zinc-coated brass wire suffers severe damages as compared to the molybdenum wire. The outer coating layer of zinc erodes faster due to its low melting temperature of 693 K. The zinc layer offers protection for the brass core against thermal shock and arc discharges produced during the discharge phenomenon. Material erodes from the zinc-coated brass wire substantially as soon as the melting point of brass is also reached. The reason behind the higher wear rate of zinc-coated brass wire in comparison to molybdenum wire is the lower melting point of zinc (693 K) and brass (1203 K) as compared to molybdenum (2896 K). The molybdenum wire is also less prone to breakage in comparison to the zinc coated brass wire due to its high tensile strength. The relationship between wire wear and workpiece surface roughness is also established. Thus, despite the zinc coating around the brass core, the performance of the molybdenum wire can be considered better in terms of wire health and workpiece surface quality. The disadvantage associated with molybdenum wire is its high cost and hence industries may prefer zinc-coated brass wire for bulk machining of products and rough cutting operations for a set of optimized process conditions.