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Study: Mechanical Properties Optimization of AISI 3115 Alloy During the Electrical Discharge Machining

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Abstract: Products used in critical industries like aerospace, automotive and power plant require specific and critical limits of the mechanical properties. In aircraft a very slight deviation from required specifications may result in the loss of both lives and equipment's. One of the important materials used in aerospace, automotive and electrical power industries is AISI 3115, it is used in structural components, heat exchangers, electrical resistance applications such as dynamic braking and overload resistors and etc. Through the Electrical Discharge Machining (EDM) process of the material AISI 3115, mechanical properties can be affected, these effects cause the product performance degradation and can lead to failure of the products in industry. Most of research done on EDM process optimization, focused on same traditional process responses such as (surface roughness, material removal rate, tool wear). It is likely not enough work has been done on how to optimize and reduce the change in product mechanical properties its self such as (generating residual stress, decreasing hardness, decreasing flexure strength, degradation of fatigue strength, affecting the fracture toughness, reduction in corrosion resistance). Also, it has been noted from literature review that no work has been done for optimization of both process responses and nor the mechanical properties of the AISI 3115 material during the EDM manufacturing process. The aim of this research is to discuss and propose the use of metaheuristic algorithms and propose using new electrode material to optimize the mechanical properties of AISI 3115 and to minimize and eliminate product failures in industry due to degradation of mechanical properties.

Key words: EDM process, metaheuristic, mechanical properties optimization, flexure strength, microstructure change, AISI 3115 workpiece material (silver-tungsten) alloy electrode material

INTRODUCTION

The quality of the product depends on the material and manufacturing process. optimization techniques play an essential role to increase the quality of the product. Hence, mostly previous EDM optimization researcher have focused on the optimization of process responses. The objective of this paper is to review the previous work done in field of optimization the responses of EDM and then define the exist gap and what product properties should be focused and optimized.

EDM process: EDM is a controlled thermos electrical process in which there is spark generation between the cutting tool and work piece. There is no physical contact between work piece and the electrode, for this spark generation both electrode and work piece should be conduct electrically. The electrode is cutting the work piece in EDM process with the shape of the electrode. The tool and work piece are connected to a power source. There is a gap between electrode and the work piece and submerged in a dielectric liquid. When conductors close to each other, then the flash creates between them and the material is removed from research piece due to spark erosion. The process is proceeded until the shape of electrode is formed on the work piece. Figure 1 shows main components of EDM process.

Main factors of EDM: Most important factors in EDM process are:

- The working voltage
- The maximum current
- The pulse on time the duration for which the voltage pulse is applied
- The pulse off time the duration for which the voltage pulse is not applied

But another new parameters can be investigated to optimize the product properties, like using another types of electrode materials.

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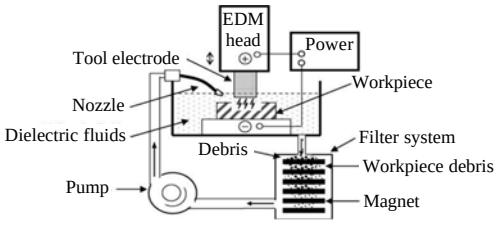

Fig. 1: Main elements of EDM process

Electrodes used in EDM: Material of electrodes used in EDM process should has the following specifications: high electrical conductivity, high melting point, less cost. Different electrode materials are used commonly in the industry and most of researches used more than one sort of electrodes materials but the permanent materials are used in research work are copper, graphite. So, it can said that another material types can be used and investigated to optimize more effectively the product mechanical properties such as: silver-tungsten alloy.

Microstructure change: The microstructure can be evaluated from the metallographic analysis. The mechanical properties affected with increasing temperature because the increase in amount of different thermal phases in the steel. Like, martensite, ferrite, martensite, also 'dual-phase steel's could be created during increasing the steel temperature that both the soft and ductile ferrite matrix and strong and tough martensite particles play an important role in determining the dual-phase properties, especially continuous yielding behavior of the steel. The fractographic analysis can discuss this changes (Table 1).

AISI 3115 alloy steel

Typical applications: Alloy structural steels are widely used in the field of ship, vehicle, airplane, guided missile, weapons, railway, bridges, pressure vessel, machine tools, mechanical components with a bigger sectional size and so on. Power generation: turbine fasteners, boiler support rods process plant: fasteners mechanical gears, gear shaft, main axis, valve rods mechanical parts: connecting rods, bolts and nuts, multi diameter shafts.

Problem statement: Through the product manufacturing by EDM process, mechanical properties and microstructure affected, these effects can lead to a fracture of products machined by EDM which lead to failure of the products in industry. One of the important materials used in aerospace, automotive and electrical power industries is AISI 3115, used in guided missile, weapons, railway, bridges, pressure vessel, machine tools, mechanical components with a bigger sectional size and so on. Most of work done on EDM process optimization, focused on same traditional process responses such as (surface roughness, material removal rate, tool wear). No enough research has been done on optimization of the degradation in product properties its self such as: increasing residual stress and thermal stress, decreasing hardness, degradation of fatigue strength, affecting the fracture toughness, reduction in corrosion resistance, reduction in flexure strength, tensile strength, impact strength.

Table 1: Chemical composition

C	Si	Mn	P	S	Cr	Ni
0.13-0.18	0.2-0.35	0.4-0.6	0.04	0.04	0.55-0.75	1.1-1.4

Also, it has been noted from literature review that no work has been done for optimization of both process responses and nor the mechanical properties of the AISI 3115 material during the EDM manufacturing process. The mechanical properties and microstructure can be evaluated from the mechanical tests and metallographic analysis, respectively.

The aim of this research is to discuss and propose using of metaheuristic algorithms and propose new electrode material (silver-tungsten) alloy to optimize the mechanical properties of AISI 3115 and to minimize and eliminate product failures in industry due to degradation of mechanical properties.

Objective of present work

The objectives of this study are: To discuss importance of (AISI 3115) material and its applications in industries; to review the work done in optimization of EDM responses to identify new EDM responses and focus on product properties its self which not focussed previously such as: increasing residual stress, thermal stress, decreasing hardness, degradation of fatigue strength, affecting the fracture toughness, reduction in corrosion resistance, reduction in flexure strength, tensile strength, compact strength). To analysis the microstructure change at the EDM, through using metallographic pictures. To propose a new electrode materials that can lead to optimize the product properties. To use an integrated approach with both the experimental design and genetic algorithm methodology, to develop a mathematical model and to optimize key parameters of EDM process and the product characteristics.

Literature review: Researchers made attempts to improve EDM performance but as noticed from literature review that most researches focused on same process responses like (surface roughness, material removal rate, tool wear) no work has been done on optimization of product

properties its self during the manufacturing process. Hira Singh and Rajesh Choudhary presented experimental study on electrical discharge machining of titanium alloy grade-5 (Ti-6Al-4V), copper and brass tool electrodes were conducted to investigate the impact of machining parameters: current, gap voltage and duty factor on surface roughness. The research outcome reveals that the surface finish is better in case of brass tool electrode as compared to cooper tool electrode. The surface roughness of the workpiece was found to increase with the increase in peak current and duty factor. The spectrum analysis shows the presence of prominent elements like Carbon (C); Titanium (Ti); iron (Fe); Copper (Cu) and Zinc (Zn) on the machined surface.

Abhinandan and Gaikwad (2016) introduced a numerical approach to estimate material removal rate on work piece in EDM process. In this research, a thermo-physical finite element model for the simulation of single sparks machining was presented to analyze the process parameters and their effect on important responses like material removal rate on work piece die steel in Electrical Discharge Machining (EDM) process and the model was solved by using ANSYS 16.0 Software.

Rao *et al.* (2016) presented investigation and analysis of parameters of wire EDM on residual stresses in the manufacturing of aluminum alloy using Taguchi method. The results obtained of residual stresses is from 8.2-405.6 MPa. It also show the formation of various intermetallics. Microscopic examination show no cracks on surface at the machining process.

Harmanpreet and Dhuria (2015) performed modelling and optimization on EDM process parameters. In this research modelling of the processes were done by artificial neural networking and optimization by genetic algorithm. Regression analysis has been performed for fitness function. Design of experiment with L18 orthogonal array has been considered. Workpiece is INCOLOY-800 electrode is copper, TWR is considered as the response variable. Dielectric fluid with two level, current, pulse on time and voltage considered with three levels as the process parameters. Two types of dielectric fluid considered as kerosene and EDM oil.

Sahu *et al.* (2013) Presented an optimization methodology for the selection of best parameters and responses. Experiments have been conducted on a die-sinking EDM under different values of parameters. A Response Surface Methodology (RSM) was adopted to investigate impact of different parameters such as discharge current Ip, pulse on time Ton, duty factor, Fp Flushing Pressure, on responses: material removal rate, tool wear rate of electrode, surface roughness (Ra) and circularity (R1/2) of machined component. The optimal setting capable of improving all the responses simultaneously was found to be Ip = 7 amp, Ton = 200 Fp = 0.4 kg/cm^2. With best of the experimental values of responses are got, material removal rate = 13.9600 mm^3/min, tool wear = 0.0201 mm^3/min, roughness = 4.9300 0.8401.

Moghaddam and Kolahan (2015) studied the effect of input EDM process parameters on Inconel 718 alloy. The input parameters are voltage, current, pulse on time and duty factor. The process quality measures are surface roughness and material removal rate. The goal is to determine a mix of process parameters to minimize SR and maximize MRR. The results indicated that current then pulse on time are most significant factors affecting the material removal rate.

Pradhan and Biswas (2008) explored the connections and parametric interactions between the control variables on the Material Removal Rate (MRR) utilizing RSM method. Workpiece material is AISI D2 tool steel with copper electrode and factors are discharge current, pulse duration and pulse off time. It was found that discharge current, pulse duration and pulse off time have significant effect on the MRR.

Chikalthankar *et al.* (2013) studied the influence of operating parameters like current, voltage, discharge on time and discharge off time for responses as Material Removal Rate (MRR) and surface Roughness (Ra) on the EDM of workpiece AISI D2 tool steel using the copper electrode material. Design of experiment was conducted with L9 orthogonal array and optimization using Response surface methodology to optimize the responses, it was found that current is the most parameter affecting the material removal rate and surface roughness.

Chitrasen Samantra examined the impact of input parameters of EDM machining process for example peak current, duty cycle and pulse on time on the outputs, MRR and TWR of machining of mild steel. The used technique was taguchi strategy to obtain the process responses. It is exhibited that the most critical and effective factors in the MRR of mild steel work piece machined by copper tool are the peak current and pulse on time whose increase increases the MRR. Fuzzy model was created based on experimental results obtained from the DOE. It can be observed that the optimal parameters setting for machining of mild steel is found out at level combination that peak current at 50 Amp, duty cycle at 10 and pulse on time at 75 μ sec. The parametric combination give the optimal value of MRR as well as TWR (Makino, 2017).

Thillaivanan *et al.* (2010) presented a practical method of optimizing parameters for EDM, under the minimum total machining time based on taguchi method and artificial Neural network. It was found that current has a significant influence on the total machining time. Neural

network was developed for getting the parameters, i.e., current and feed for a required total machining time (Tawfeeq and Altun, 2016; Zainuddin *et al*., 2015; Suryanita *et al*., 2017).

Shandilya *et al*. (2012) Presented a study to optimize the process parameters in machining of 6061 Al metal by using wire electrical discharge machining, using response surface methodology. Four input process parameters, servo voltage, pulse-on time, pulse-off time and wire feed rate, were picked as factors to study the process performance in terms of (surface roughness). It is discovered voltage and wire feed rate are highly significant factors and pulse off time is not significantly. Pulse-on time has irrelevant impact on surface roughness. fine surface finish was gotten when machining was done at a mix of lower levels of input process parameters. It demonstrated that there is extensive decline in surface roughness with reduction in voltage.

Chandramouli and Eswaraiah (2015) developed a model for electrical discharge machining of RENE80 nickel super alloy and to optimize the process parameters utilizing artificial neural networks. The effect of various electrical parameters on the machining performances is investigated. The input parameters considered are current, pulse on time; pulse off time and the outputs are Material Removal Rate (MRR) and Tool Wear Rate (TWR). The result show that current, pulse on time and pulse off time have significant effect on MRR and TWR, the MRR is increasing with increase in current and decreasing initially with increase in the pulse on time and increasing later with an increase in pulse on time. TWR is increasing linearly with increase in the current and decreasing with increase of pulse on time, increasing pulse off time the TWR is increasing.

Salem *et al*. (2011) built up a surface roughness model for the parameters of current, electrode type and work piece material for an EDM process using the experimental design method. It is found the current has very significant impact on roughness. The variety in rate mistakes for Ra were found 4.5%. The model is utilized to predict the machining responses within the experimental region. The surface roughness equation demonstrated that the current is the principle affecting element on roughness.

MATERIALS AND METHODS

Design and optimization techniques: Various optimization and design techniques generally used for improving and optimizing of performance measures of electrical discharge machining process have been listed as:

Experimental Design (ED): The primary objective of Experimental Design (ED) is studying the relations between the responses as a dependent variable with different parameter levels. It gives a chance to think about the individual impacts of every parameter. Design of experiments is a strategy utilized for minimizing the number of experiments to achieve the ideal conditions. this research discuss the design of experiments in EDM process for investigating the impact of different parameters (pulse on time, pulse off time, peak current and voltage) on the product defects (e.g., the residual stress, thermal stress, thermal expansion, cracks, etc.) for modeling, experimental design techniques can be used, like response surface design method, Tagushi design, factorial design. In order to determine the optimization of defects equations, noise to signal technique and genetic algorithm technique can be used.

Taguchi method: Taguchi technique is a deductively system for assessing and executing improvements in products or processes. These improvements are aimed to enhancing the desired qualities by concentrating on the key variables controlling the process and optimizing the procedures to yield the best results. Taguchi prescribes Orthogonal Array (OA) for lying out of experiments. The analysis of ANOVA is the statistical tool applied to the results of the experiments in determining the percent contri bution of each parameter against a responses. Taguchi technique utilizes a statistical measure of performance called signal-to-noise ratio to measure the deviation of the performance from the desired values.

Response Surface design Methodology (RSM): The Response Surface Methodology (RSM) is an mathematical and statistical technique and strategy helpful for the modeling and investigation problems which a response is affected by several factors and the goal is to improve the response. It is used in the development of relationship between a response of interest, the control (or input) variables.

Genetic Algorithm (GA) optimization: The Genetic Algorithm GA is produced on the probabilistic basis, also used to solve linear and non-linear problems by investigating all regions of the state space or chromosomes that are randomly generated or selected, a GA begins with randomly initializing the parent chromosomes represented in a string, fitness of these chromosomes is then calculated based on the objective function. The objective of reproduction procedure is to permit the genetic data, stored in the artificial strings have great fitness. The chromosomes are then assessed by

utilizing a certain fitness criteria and the best ones are kept while the others are removed. The procedure is repeated until getting the best solution with best fitness to meet the objective function criteria is gotten. So an integrated optimization approach between experimental design techniques and genetic algorithm tool can be utilized to improves and optimizes the product mechanical properties in EDM.

RESULTS AND DISCUSSION

The product mechanical properties that affected during edm process: Many industries like aerospace, automobile and casting molds have needed the EDM process to make many of the components. "The aerospace industry used EDM process to manufacture some aircraft parts because of the intricate shapes, tough alloys and very tight tolerances involved but it also recognized the dangers of the damaged surfaces and product defects resulting from the process".

Many attempts have been made to model and optimize performance of Electrical Discharge Machining (EDM) process, mostly researchers have focused on optimizing Material Removal Rate (MRR), surface roughness, tool wear but almost no enough work was done to optimize the product properties its self that affected during the EDM process, these properties are:

Increase the residual stress: The residual stresses created on the parts and products at EDM process, less work was focused on The examination and analysis of EDM parameters impact on residual stresses. The remaining stresses generated on the components should be eliminated or reduced as low as possible, it depends on the setting of process parameters and the material to be machined. An attempt should be made to investigate the effect of EDM process parameters on the residual stresses for different metals. Residual stress can be measured using X-ray diffraction method.

Dimensional deviation, accuracy of work: As manufacturing companies seek higher-quality products, they spend much of their efforts monitoring and controlling dimensional accuracy of produced parts, optimization approaches can be used for dimensional deviation prediction of workpiece in EDM process. The process parameters should be took as input parameters and dimensional deviation of worked part as an output response.

Change in the hardness: Hardness refers to the ability to resist abrasion, cutting action or permanent distortion. Hardness may be affected by EDM manufacturing. Thus, it should be controlled and optimized during the EDM manufacturing process.

Degradation of fatigue strength: EDM processing can cause degradation of fatigue strength of metals and alloys but it can be reduced by optimizing EDM factors, fatigue is important for aerospace application as well as other applications. This strength degradation is found to correlate directly to the thickness and roughness of recast layers during EDM. Cycle constant stress amplitude fatigue test is used to measure fatigue strength of the materials. It is very important to reduce the degradation of fatigue strength from the beginning at EDM processing to save cost and time.

Affecting the fracture toughness: New engineering materials are considered as the unique materials. It used in automotive and aerospace applications. It is very important to understand the possible effect of EDM process on fracture toughness. So, it is important to conduct a study on the effect of EDM on the fracture toughness of this aerospace material. Test using Compact Tension (CT) is used to measure the fracture toughness.

Reduction in corrosion resistance: Chemical and mechanical properties changes can be happened at EDM process, one of these properties affected is corrosion resistance. Experimental techniques can lead to optimizing the value of the corrosion resistance of products manufactured by EDM, corrosion resistance of metals is influenced by the quality of finished surface. Due to differences in structure and chemical composition the white layer on surface of machined products is transformed. The corrosion resistance of the machined surfaces is evaluated by electrochemical tests.

Reduction in flexure strength: Electrical Discharge Machining (EDM) is used to manufacture complex shaped parts but as disadvantage of this process, some mechanical properties such as flexural strength of the machined products can be affected, the EDM process may causes decrease in flexural strength. So, this study suggest to focus the optimization effort for of these properties, not only traditional EDM responses.

CONCLUSION

Following discussion and conclusion can be drawn: the EDM applications have been found in aerospace, automobile and die manufacturing industries. In general it is found that most of the research work focused on

optimization of traditional process responses and not enough work focused on optimization of product properties during the EDM process, like (residual stress, reduction of flexure strength, reduction of corrosion resistance, affecting the fracture toughness, degradation of fatigue strength and change in crystal construction).

No optimization work has been done, specifically of the material (AISI 3115) for both process responses and product mechanical properties. Using a new electrode materials can be done like Copper-Tungsten alloy material. using integrated experimental design techniques with other optimization and modeling methodologies such as genetic algorithm can give effective optimization tool.

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