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Full Length Article

Investigation for obtaining the optimal solution for improving the performance of WEDM of super alloy Udimet-L605 using particle swarm optimization

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ABSTRACT

The purpose of the current study is to increase the productivity, accuracy and reduce the cost of wire electric discharge machining of super alloy Udimet-L605. The pulse-on time, pulse-off time, peak current, wire tension, spark gap voltage, and wire feed rate have been considered as input variables in the experimental work on the wire electric discharge machining. The experimental work is planned on the basis of Taguchi's L27 orthogonal array and obtained the optimal combination of process variables for high cutting speed and lowest dimensional deviation and wire wear ratio, individually. The linear regression model is used to describe the interplay amid the input and output variables. After that, the PSO algorithm is applied to the developed model to obtain the global best solution for the desirable consequences of cutting speed, dimensional deviation and wire wear ratio. It has been observed that pulse-on time have a momentous effect on the cutting speed, dimensional deviation and wire wear ratio. The SEM and EDX are used to observe the erosion and compositional changes occurred during WEDM.

1. Introduction

Udimet-L605 is a solid solution strengthened cobalt-chromium-tungsten-nickel's austenitic alloy with face centered cubic-crystal structure and non-magnetic behavior. It has exemplary high-temperature strength and sterling oxidation resistance in the condition of immense temperature (1093 °C) and embedded with good welding and forming characteristics. According to Hebsur et al. [3], the Udimet-L605 epitomized with superior resistance to air and oxidizing environments mutually. It has been reviewed that a simple Co-base super alloy (L605) divulges the best impact resistance on an areal weight basis. It is 10 times better than the titanium's best alloy (IMI 550) tested till date. The Udimet L-605 exemplify the sterling impact resistance generally at velocity bigger than 1100 ft/s eventually, the Udimet-L605 could be the superlative alternative of titanium alloy for fan containment appliance in supersonic aircraft. It has sterling sulfidation resistance and resistance to wear, metal galling, marine environments and acids. The Udimet-L605 alloy is notably employed where requiring better oxidation resistance and reasonable strength at high temperature as used in hot sections of aircraft and land-based gas turbines in combustor liners. The alloy is also appropriate in industrial furnace applications such as muffles/liners in high temperature kilns, high temperature ball bearings, bearing races, heart valves and springs, etc. Higher melting points and flatter stress-rupture curves of it results in higher stress capability to higher absolute temperatures than Ni-base or Fe-base alloys. The Udimet-L605 reveals the better thermal fatigue resistance than Ni-base alloy. It also has better hot corrosion resistance in contaminated gas turbine atmospheres due to the presence of higher Cr contents. It exhibits very poor thermal conductivity as 9.4 W/m-K at room temperature. Moreover, many of the problems come across the machining of Udimet-L605 during conventional machining which were associated with the physical interaction between workpiece and tool such as flank wear, crater wear, chipping, catastrophic failure and increased production cost, etc.

Notably, the wire electric discharge machining process is pursued extensively by manufacturing and aeronautical industries due to its excellent characteristics like as surface quality, accuracy, low production cost, high productivity and simultaneously smooth running process. The wire-cut electric discharge machining is a unique process in which the diminutive size of 0.05 mm–0.3 mm [1] diameter wire is employed for separating the infant material

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from the parental plate of material. The sturdy electric current is allowed to flow through the wire and work material which results the generation of sturdy electrical field in the gap provided amid the wire and work material as 0.025 mm–0.05 mm respectively [2]. Due to the high potential difference amid them, current discharge takes place which generates the large number of distinct sparks continuously therefore, the plasma zone is shaped. The material in the plasma zone is melted and evaporated. At the same instant, the molted material is flushed out with a persistent supply of dielectric fluid. Consequently, the erosion of material takes place.

The design and optimal combination of variable of WEDM of hard material is the speculative and intricate practice to procure the immense productivity, accuracy with minimum cost. In the past, the researchers have consummated bounteous exercise to enhance the performance characteristics of wire electric discharge machining process. Tosun and Cogun [4] ascertained the effect of input variables on wire wear in WEDM of AISI 4140 steel. Manna and Bhatacharya [5] recommended the use of the Gauss elimination method and Taguchi method for analyzing the effect of explanatory variables on SR, MRR, SG and gap current in WEDM of Al/SiC-MMC. Rao and Pawar [6] anticipated the RSM modeling to examine the correlation amid the process variables and response variables. The particle swarm optimization approach is used to obtain the optimal combination of process variables for high cutting speed and lowest surface roughness. Rao et al. [7] employed the non-traditional optimization techniques like as PSO, ABC and HS for obtaining the global best solution for ultrasonic machining. Antar et al. [8] worked on the machining of superalloy of nickel and titanium using two different types of coated wire in WEDM and compare their performance. Mukherjee et al. [9] applied six advanced, fashionable approaches like as GA, PSO, sheep flock algorithm, ACO, ABC and biogeography based optimization for multi objective optimization of WEDM process and get the best combination of variables for the optimal response. Yusup et al. [10] studied about the previous work has been consummated on optimization of machining process using GA, SA, PSO, ACO and ABC approaches. Kumar and Batra [11] investigated the effect of tungsten powder mixed with dielectric fluid during the electric discharge machining process. Goswami and Kumar [12] worked on wire electric discharge machining of Nimonic-80 and employed the grey relational analysis approach for obtaining the optimal value of the response variable. Sivaprakasam et al. [13] ascertained the effect of the voltage (A), feed rate (C), interaction of voltage and capacitance (AB) and pure quadratic on the performance characteristics of WEDM and obtained the optimal combination of process variables using the desirability approach and genetic algorithm. Bobbili et al. [14] investigated the behavior of Al 7017 and RHA steel in WEDM and proposed the Buckingham pi theorem for modeling the WEDM process. The effect of process variables on the surface of the machined samples were epitomized by employing SEM. Unune and Mali [15] analyzed the effect of process variables on MRR and kerf width in low frequency vibration assistant micro-WEDM machine. Nayak and Mahapatra [16] recommended the use of the ANN model for investigating the interplay amid the input and output variables of WEDM and obtained the optimal solution for minimum angular error by employing the bar algorithms. Nain et al. [17] recommended the application of the SVM algorithm for modeling the WEDM process and optimize the process using grey relational approach. Consequently, hardly any work has been reported on the machinability evaluation of Udimet-L605 in WEDM.

Due to elite performance of Udimet-L605 over the IMI 550 alloy (best titanium alloy) and its prevalent exploit in aerospace industries, it was decisive to investigate the machinability of Udimet-L605. Eventyally, an effort has been made to study the changes in the surface properties of the machined sample of Udimet-L605 during WEDM [17]. Now in the current study, the aim is to improve the productivity coupled with the desired accuracy and cost of machined sample. The maximum productivity, minimum cost and accuracy are the vital demands of each industry. Therefore, it is essential to attain the optimal combination of input variables for obtaining the global best solution for increasing the performance of WEDM. Keeping in view the elite performance, the current study is utilized to appraise the machinability of Udimet-L605 in wire electric discharge machining and improve the performance of WEDM by employing the advance multi-optimization approaches like particle swarm optimization. In addition to this, the SEM and EDX is used to confirm the wire wear and identified the compositional changes occurred on the surface of machined sample due to wire wear.

2. Material and method

2.1. Material

In current studies, the Udimet-L605 is preferred as work material due to its exemplary properties and extensive use in aeronautics industries. Ubiquitously, the Udimet-L605 is the decisive material and it was mandatory to disclose the behavior of material in the environment of high thermal energy. The rectangular plate of specification 400 mm × 150 mm × 6 mm is mounted on the table of WEDM and total 81 pieces of dimension 12 mm × 12 mm × 6 mm were incises the rectangular plate. The chemical composition and mechanical properties of Udimet-L605 were uttered by Tables 1 and 2.

2.2. Experimental set up

The wire electric discharge machining is the superlative machining method which divulged the behavior of Udimet-L605 in the environment of high thermal energy with high cutting speed, accuracy and least expensive. The experiments were performed on Electronica sprint-cut 734 wire-cut electric discharge machine manufactured by Electronica machine tool Ltd., India, which is furnished in advance manufacturing laboratory at NIT Kurukshetra, Haryana, India as revealed by Fig. 1. In the current study, the plane, brass wire of dimension 0.25 mm diameter is used as a cutting tool. The dielectric fluid is utilized at a constant temperature and pressure of 25 ^{0}C and 15 kg/cm2 respectively. The experimental set-up and working of WEDM is revealed by Figs. 1 and 2.

The selection of input variables and limit was decided based on preceding research and pilot experimentation, considering five levels for each variable. The pulse-on time (Ton), pulse-off time (Toff), peak current (IP), wire tension (WT), spark-gap voltage and wire feed rate concurrently with three interactions like Ton × Toff, Ton × IP and Toff × IP were designated for investigating the effect on cutting speed (CS), wire wear ratio (WWR) and dimensional deviation (DD) of WEDM of Udimet-L605 as work material. Each variable is comprises of three levels as revealed in Table 3.

The Taguchi method is pursued for intending the experimental work. Each individual variable possessed two degrees of freedom and each interaction possessed four degrees of freedom respectively. Comprehensively, total degree of freedom pertained to the six input variables, three interactions and error terms being as 26 (6∗2 + 3∗4 + 2). Eventually, the L27 orthogonal array is preferred to depict the experimental layout. Based upon the premeditated experimental design as specified in Table 4, total 27 experiments have been performed randomly and each experiment was repeated