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Experimentation investigation of abrasive water jet machining parameters using Taguchi and Evolutionary optimization techniques

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A B S T R A C T

In the last decade, numerous new materials are rapidly emerging and developed; it creates considerable interest in the researcher to search out the optimum combination of machining parameters during machining of these materials using advanced machining processes (AMP). In this work, an experimental investigation is carried out on abrasive water jet machining (AWJM) process for the machining of material AA631-T6 using the Taguchi methodology. Parameters such as transverse speed, standoff distance and mass flow rate are considered to obtain the influence of these parameters on *kerf top width* and *taper angle*. Regression models have been developed to correlate the data generated using experimental results. Seven advanced optimization techniques, i.e., particle swarm optimization, firefly algorithm, artificial bee colony, simulated annealing, black hole, biogeography based and non-dominated sorting genetic algorithm are attempted for the considered AWJM process. The effectiveness of these algorithms is compared and found that bio-geography algorithm is performing better compared to other algorithms. Furthermore, a non-dominated set of solution is obtained to have diversity in the solutions for the AWJM process. The result obtained using the Taguchi method and optimization techniques are confirmed using confirmation experiments. Confirmatory experiments show that both the optimization techniques and Taguchi method are the effective tools in optimizing the process parameters of the AWJM process.

1. Introduction

The technology abrasive water jet machining (AWJM) has been upgraded significantly to meet the necessity of the modern industries. AWJM is used in difficult-to- hard material for material removal by several manufacturing industries. AWJM process provides a high-quality cutting with a great surface finish and therefore it is advantageous in the manufacturing of several components in automotive, aerospace, surgical equipment's and defense sector industries owing to its characteristics. AWJM process utilizes the mixture of water and abrasive to erode material from the target surface. The AWJM process has several machining parameters, i.e., water pressure, transverse speed, abrasive flow rate, standoff distance, abrasive grit size, etc., which affect the performance parameters (i.e., surface quality, kerf top width, taper angle and material removal rate). To obtain the optimum parameter setting for machining process is utmost important to achieve desired quality. Few researchers have reported the influence of the process parameters on the performance characteristics of the AWJM process [1–15].

Kantha babu and Krishnaiah Chetty [1] reported the effects of the process parameters (i.e., abrasive flow rate, pressure and traverse rate) using recycled garnet abrasives during machining of aluminium material on different performance parameters. The result shows that the test specimen performed better with garnet mesh size as 80 to achieve enhanced surface finish and depth of cut. Chen et al. [2] conducted experimentations to reduce striations on the AWJM cut surfaces. Wang and Guo [3] analyzed cutting performance and proposed a brief guide for the proper selection of machining parameters in multi-pass AWJM for industrial ceramic material.

Akkurt et al. [4] conducted experimentation on various specimens composed of different materials such as pure aluminium, AISI 1030, brass-353 and AISI 304 steel and Al-6061 aluminium alloy at different feed rates and found enhancement in surface roughness for these materials. Wang [5] conducted experiments on AWJM to obtain the influence of the parameters such as erosion time, impingement angle and pressure on the erosion rate and average surface roughness (*Ra*) and found that AWJM can reduce grit embedment in the target material due to high water pressure. Wang and Liu [6] proposed mathematical models for the performance characteristics such as depth of cut and kerf taper using the experimental data to obtain the optimum parameters of the AWJM process for alumina ceramic material.

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Wang [7] carried out an experimental investigation to obtain the influence of nozzle oscillation under a diverse combination of the process parameters on the depth of cut. Azmir et al. [8] conducted an experimental investigation on AWJM process considered aramid fiber reinforced plastics (AFRP) as a workpiece material to obtain the influence of the process parameters on kerf taper ratio (*TR*) and *Ra* using analysis of variance (ANOVA). Khan and Haque [9] presented a comparative analysis of the performance characteristic, i.e., width of cut during machining of glass using three different abrasives such as garnet, silicon oxide and aluminum oxide on AWJM process.

Matsumura et al. [10] attempted computational fluid dynamics (CFD) analysis on AWJM process for glass material to obtain crack-free surface during the machining of micro grooves and channels. Zain et al. [11] conducted experimentation on AWJM process and attempted to optimize the process parameters (i.e., transverse speed, water jet pressure, abrasive grit size, standoff distance, abrasive flow rate) using the integration of simulated annealing (SA) and genetic algorithm (GA) to obtain the influence of these considered parameters on *Ra*. Selvan and Sundar [12] estimated the influence of AWJM process parameters (i.e., water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance) on *Ra* during machining of ceramic material and gave useful recommendations to select the appropriate process parameters in the machining of the considered material.

Billingham et al. [13] proposed a model that envisages the surface micro-geometry for coincided footprints and analyzed the error propagation for predicting the material removed in consecutive layers. Gupta et al. [14] conducted an experimental investigation on AWJM to determine the influence of the parameters such as nozzle transverse speed, water pressure and abrasive flow rate on the performance characteristics using Taguchi method. Korat and Acharya [15] reviewed the current trend of research and development in AWJM and suggested some useful facts. They suggested AWJM is widely used in the processing of materials and its application can be prolonged to other materials. Cojbasic et al. [16] proposed a model to predict the *Ra* value using an extreme learning machine (ELM) method and the result shows that the predicted results using ELM are found more proximate to the experiment results than the predicted results obtained using the artificial neural network (ANN) and genetic programming. Haghbin et al. [17] developed a response model to predict the shape and size of the deep micro-channels during machining using AWJM process. Schwartzentruber and Papini [18] have examined the influence of the process parameters on three nozzles of different sizes for the borosilicate glass material that could damage during piercing operations using AWJM process.

Several methods are found to obtain the best optimum condition for effective machining [15]. In this paper, an experimental investigation is reported to obtain the optimum condition of the process parameters for the effective machining using AWJM process. The literature survey reveals that several researchers have demonstrated the effects of process parameters on Ra, depth of cut or examined the cutting surface using scanning electron microscope in the considered AWJM process [2–7,11,12,15,16]. So, in this paper an attempt has been made to analyze the effect of AWJM process parameters, i.e., transverse speed, stand off distance and abrasive flow rate on objectives such as *kerf top width* and *taper angle*. This study focused on the AWJM process of AA6351 aluminium alloy, whose applications are in continuous growth. Consequently, ANOVA is applied to determine the influence of process variables such as transverse speed, stand-off distance and mass flow rate on *kerf top width* and *taper angle* using the design of experiment. The soft computing optimization techniques have been widely applied for mapping input and output parameters of the machining process [19]. In this paper, several soft computing non-traditional optimization techniques, such as particle swarm optimization (PSO), firefly algorithm (FA), artificial bee colony (ABC), simulated annealing (SA), black hole (BH), biogeography-based optimization (BBO) and non-dominated sorting genetic algorithm (NSGA) are applied to the regression model to obtain the optimum set of process parameters and to measure the effectiveness of the applied algorithms. The use of these algorithms makes possible to understand the variability associated with each process parameter with respect to the considered performance parameters. The NSGA has been used to obtain the non-dominated solutions for optimization of AWJM characteristics of the AA6351 alloy.

2. Experiments

2.1. Experiment setup and material

The experiments were conducted on an AWJM process to analyze the effects of the predominant process parameters, i.e., transverse speed, standoff distance and mass flow rate during AWJM operation on the required machining characteristics i.e., *kerf top width* and *taper angle* with improved quality of products. The schematic diagram of the AWJM experimental setup is shown in the Fig. 1. Experiments were conducted using AWJM for AA6351-T6 (AlMgSi1) aluminium wrought alloy as a specimen material. The chemical composition of AA6351-T6 consists of various elements, i.e., 0.907% Si, 0.89% Zn, 0.586% Mg, 0.355% Fe, 0.086% Cu, 0.015% Ti and balance Al. The AA 6351- T6 has several applications in different fields of engineering. This material has found its applications in ship manufacturing, aerospace wings and frames, transport industries, high-pressure gas container, mine skips, column, chimney, rod, pipe, tube, vehicle engine valves, bridge, cranes, roof, etc.

In AWJM process, *kerf top width* and *taper angle* signify the degree of precision. In setting the process parameters of the considered process, predominant in machining operations, the objective is twofold: the maximization of the *kerf top width* and minimization of *taper angle*. To determine the *taper angle*, the value of bottom width is measured experimentally. Usually, to set the process parameters for machining depends on the knowledge of the operator. In real practice, it is challenging to utilize the optimum functions of the machine owing to there being several adjustable parameters [20]. With an aim to assuage this difficulty, a Taguchi method is used to obtain the optimum parameter

Fig. 1. Abrasive water jet machine setup.