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An Investigation in Abrasive Waterjet Cutting of Al6061/SiC/Al_2O_3 Composite Using Principal Component Based Response Surface Methodology

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ABSTRACT

Abrasive waterjet was found effective in cutting materials like glass, steel and aluminium for various industrial applications. The effect of process parameters on abrasive waterjet cutting (AWJC) of Al6061/SiC/Al_2O_3 composite was disclosed in the present work. The cutting parameters taken for study were traverse speed, abrasive flow rate, water pressure and stand-off distance. Surface roughness, kerf width and bevel angle of cut were observed as the quality characteristics for various cutting trials. Experiments were designed using Taguchi's L_{18} orthogonal array and an integrated technique of principal component based response surface methodology (PC-RSM) was disclosed for designing the parameters. Significant improvements were observed in the quality characteristics obtained with optimal parameter setting identified by PC-RSM approach. Abrasive waterjet parameters like water pressure, stand-off distance and the interaction between abrasive flow rate and traverse speed were found to be influential on the quality characteristics.

KEYWORDS

Abrasive Waterjet Cutting, Al6061/SiC/Al_2O_3 Composite, Bevel Angle of Cut, Kerf Width, Orthogonal Array, Principal Component Analysis, Response Surface Methodology, Surface Roughness, Taguchi

INTRODUCTION

The technology of waterjet machining employs either a pure jet of water or water mixed with abrasives to cut a variety of materials including titanium, steel, brass, aluminium, stone and Inconel. Both formats with good machining capabilities are characterized by the absence of thermal distortion and micro cracking. The process limitation includes a noisy environment and an untidy workplace (Wang and Wong, 1999). In abrasive waterjet cutting (AWJC), the hydrostatic energy of pressurized water is transformed into enormous kinetic energy of the jet, which is focused through a small orifice at supersonic speeds to perform the desired machining operation (Kulekci, 2002). A good abrasive performance is an important criterion, as the cost of abrasive is over weighed by the higher cutting speeds achieved with a better performing abrasive (Khan and Haque, 2007). The depth of penetration of the abrasive waterjet can be improved by an optimal amount of recharging of abrasives (Kantha Babu and Krishnaiah Chetty, 2002). The AWJC parameters like water pressure, traverse rate and abrasive flow rate are identified to influence the quality characteristics of the cut surface including kerf width and surface roughness. Experimental results have proved that higher traverse rate and jet impact angle are associated with an increase in material removal rate, surface roughness and waviness

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values (Wang et al., 2003). The surface finish obtained with Al6061 alloy is better than that observed with pure aluminium in AWJC applications. The elements present in Al6061 alloy are significant for obtaining a better surface finish (Akkurt et al., 2004).

The study of relationship between the parameters and responses is essential to enable quality control in AWJC (Hlavac et al., 2009). While cutting aramid fibre reinforced plastics, traverse feed rate is observed to be more significant than the abrasive flow rate in affecting the surface roughness and kerf taper ratio. A higher kinetic energy of water can produce a better cut quality (Azmir et al., 2009). From the literature, it is understood that the input parameters like stand-off distance, feed rate, flow rate of abrasives and water pressure play an important role in influencing the process responses in AWJC.

The multi response optimization problems can be handled by methods like grey relational analysis (GRA), genetic algorithm (GA), artificial neural network (ANN), response surface methodology (RSM), fuzzy logic, principal component analysis (PCA) and data envelopment analysis (Krishnaiah and Shahabudeen, 2012). Models are available to relate the kerf profile with cutting speed to produce straighter cuts (Ma and Deam, 2006). The nozzle oscillation at smaller angles is found to improve the depth of jet penetration in alumina with proper selection of AWJC parameters (Wang, 2007). LS-DYNA (software) is used to simulate the process of AWJC. The relationship between the processing parameters and the cutting depth is validated using the experimental data (Wenjun et al., 2011).

The regression models generated for the responses are observed to be useful in optimizing the process parameters in AWJC. The nozzle diameter and stand-off distance are identified as the influential parameters affecting the kerf width and surface roughness (Kechagias et al., 2012). Pure mathematical models can predict the responses for a specific set of inputs accurately in micromachining processes (Kamaraj and Sundaram, 2015). The Taguchi method applied along with GRA and properly supplemented by the analysis of variance can predict the optimal parameters in drilling and turning of various composite materials (Vinoth Babu et al., 2015; Arun et al., 2014; Mahamani et al., 2012). The grey Taguchi based RSM and subsequent optimization using desirability analysis is observed to identify the optimal parameters precisely in manufacturing processes (Santhanakumar and Adalarasan, 2014). The principles of grey theory and RSM is applied to optimize the responses in AWJC of ceramic tiles and the combined algorithm is found to be effective in predicting the optimal process parameters (Santhanakumar et al., 2015; Abhang and Hameedullah, 2012). RSM is effective in electrochemical machining of aluminium based composite and the generated plots can relate the process inputs with the responses (Rama Rao and Padmanabhan 2013). Generally, while employing RSM, the experimentation is performed by using the Box-Behnken design (Srinivasulu et al., 2013).

The techniques like GRA, PCA and TOPSIS, either in pure form or in an integrated format are found to be effective in electro discharge machining of various materials (Rajesh Kumar et al., 2014; Shrinivas Balraj and Gopala Krishna, 2014; Bharat Chandra and Arunkumar, 2014). The experimentation using orthogonal arrays and further analysis using optimization techniques is observed to yield the near optimal operating conditions in various machining processes (Lakhwinder Pal Singh and Jaqtar singh, 2013; Sanjeev Kumar Garg and Alakesh Manna, 2012). Generally, these statistical methods are used to arrive at the optimal setting of input parameters by following a standardized and structured approach. The results are obtained quickly with required degree of precision and reliability by using a relatively lesser effort.

Taguchi technique along with desirability analysis is applied in a combined format to identify the near optimal operating condition (Atul et al., 2015). An approach of grey based PCA utilizing the merits of both techniques is found to predict the optimal settings as well (Adalarasan et al., 2014; Adalarasan and Shanmuga sundaram, 2015). RSM is a numerical method for correlating and modelling the responses with respect to the process parameters. The technique can be used to generate

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