Optimization of Electrochemical Grinding Parameters for Effective Finishing of Hybrid Al/(Al₂O₃+ZrO₂) MMC

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ABSTRACT

In this study, the Taguchi method, a powerful tool in the design of experiment is used to optimize electrochemical grinding (EGC) parameters for effective finishing of hybrid Al/(Al₂O₃+ZrO₂) MMC using a resin bonded copper impregnated diamond grinding wheel. An orthogonal L₂⁷(3¹³) array is used for 3⁵ factorial design and analysis of variance (ANOVA) is employed to investigate the influence of grinding wheel speed, electrolyte concentration, D.C. supply voltage, current density and work-piece speed on the surface finish, Rₐ and Rₜ respectively. Test results reveal that the Rₐ and Rₜ both are lesser at moderate grinding wheel speed i.e. 9000 rpm with current density 0.25A/mm² and 30% electrolyte concentration. Taking all five parameters considered for experimentation and using multivariable higher order regression, mathematical models for surface finish, Rₐ and Rₜ are established to investigate the influence of Electrochemical Grinding (ECG) parameters during finishing of hybrid Al/(Al₂O₃+ZrO₂) MMC. Confirmation test results established that the developed mathematical models are appropriate for effective representing the surface finish criteria, Rₐ and Rₜ (μm).

Keywords: Analysis of Variance (ANOVA), Electrochemical Grinding (ECG), Hybrid-MMC, Mathematical Models, Surface Finish

1. INTRODUCTION

Particulate reinforced hybrid metal matrix composites are gaining wide spread applications due to their inherent better unidirectional strength to weight ratio, higher strength and better wear resistance properties at adverse operating condition. The aluminium alloy reinforced with discontinuous ceramic reinforcement is rapidly replacing conventional materials in various automotive, aerospace and automobile industries as stated by Allison and Cole (1993); Manna and Bhattacharyya (2003). But ceramic reinforced metal matrix composite machining is one of the
major problems, which resist its wide spread engineering applications as stated by Manna and Bhattacharyya (2003); Cronjager and Meister (1992). The hard reinforced particles of MMC, which intermittently come into contact with the hard surface and act as small cutting edges like those of grinding wheel on the cutting tool edge, which in due course becomes worn out by abrasion, resulting in the formation of a poor surface during conventional machining of MMC as stated by Manna and Bhattacharyya (2004). Various non-conventional machining processes such as, ECM, EDM, WEDM, etc. are also not effectively used for the machining of particulate reinforced metal matrix composites. Machining of Al/SiC-MMC by EDM requires a huge amount of current and discharge of SiC/Al is more irregular as stated by Hocheng et al (1997). Thus machining problems like low material removal rate, high surface roughness, heat affected zone and poor dimensional accuracy etc on finished parts remains unresolved. Manna and Bhattacharyya (2006) stated that the advance non-traditional machining techniques such as abrasive jet machining, water jet machining, laser beam machining etc can be applied for the machining of Al/SiC-MMC. Cost effective manufacturing of mini and micro dimensional part of slurry casted hybrid Al/(Al₂O₃+ZrO₂) MMC with satisfactory tolerance by any well known machining processes is still very difficult. Hence, an applied research investigation is highly important to identify the optimum machining process condition to produce cost effective parts from Al/(Al₂O₃+ZrO₂) MMC. Conventional grinding produces components with good surface finish and dimensional tolerances but such components are also associated with burrs, heat affected zone (HAZ) and thermal residual stresses, whereas these defects are not found in electrochemical grinding process as stated by Jain, V.K (2002). Lauwers, B., (2011) studied the surface integrity in hybrid machining processes and concluded that surface integrity can be improved considerably by enhancing the advantages and minimizing the potential disadvantages of individual technique. Author concluded that by lowering process force and tool wear, surface integrity can be enhanced with increase in productivity but it needs good understanding of the process-material interaction and process parameters must be selected in a proper way to eradicate strong negative effect generated during hybrid machining. Ultra precision grinding is primarily used to generate high quality and functional parts usually made from hard and difficult to machine materials as stated by Brinksmeier et al. (2010). Lupak and Zaborski, (2009) stated that the specific energy consumption during mechanical grinding is higher than electrochemical grinding. Authors concluded that the increase of inter electrode voltage results in an increase in energy consumption for electrochemical grinding.

2. PLANNING AND DESIGN FOR EXPERIMENTAL STUDY

An electrochemical grinding setup has been designed, fabricated and utilized for experimental investigation. Figure 1 shows schematic block diagram of the designed and fabricated electrochemical grinding (ECG) setup, which has four different units. Figures 2, 3(a), 3(b) and 4 show the details of the schematic diagram of each unit of fabricated ECG setup i.e. main power supply unit, tool rotational and feed motion unit, work-piece rotational and x-y movement unit, and electrolyte flow control unit respectively.

The different sets of experiments have been performed on developed fabricated electrochemical grinding setup. According to the Taguchi method based robust design as explained by Ross, P.J. (1989), an orthogonal L²⁷ (3¹³) array is used for 3³ factorial design for finishing of hybrid Al/(Al₂O₃+ZrO₂) MMC. A total of five ECG parameters with three levels for each parameters such as factor A (grinding wheel speed), factor B (electrolyte concentration), factor C (D.C. supply voltage), factor D (current density) and factor E (work-piece speed) are considered as the controllable parameters for optimality analysis during finishing of hybrid Al/(Al₂O₃+ZrO₂) MMC (Table 1). The sodium...
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