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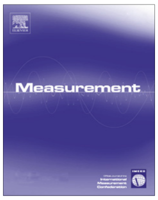

Experimental investigation and multi-objective analysis on drilling of boron carbide reinforced metal matrix composites using grey relational analysis

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ABSTRACT

In this study, machining parameters were evaluated and optimized with grey relational analysis in drilling B_4C reinforced metal matrix composites (MMCs) produced by powder metallurgy. HSS, TiAlN coated and uncoated cementide carbide drills were used under dry cutting conditions. The drilling parameters such as feed rate, spindle speed, drill material and wt.% of B_4C particles were optimized based on multiple performance characteristics including thrust force, torque and surface roughness. The experimental study showed that increasing the weight fraction of the B_4C resulted in a considerable increase in the thrust force. Furthermore, average surface roughness of drilled hole decreased with increasing particle content for carbide tools and increased for HSS tools. Among the tools used, TiAlN coated carbide drills showed the best performance with regard to the surface roughness. Moreover, ANOVA analysis indicated that the most effective factor on grey grade was found to be weight fraction and followed by drill material, feed rate and spindle speed, respectively.

1. Introduction

Due to high strength-to-weight ratio, superior wear resistance, better damage tolerance, lower thermal expansion and lightweight, composite materials are widely used as a substitute for conventional materials, provided they can be machined to required sizes and shapes at an acceptable cost and quality [1–6]. Recently, B_4C has attracted the attention of researchers due to low density (2.51 g/cm^3); high stiffness (445 GPa); high melting point (2450 °C); high hardness (3800–4200Hv) and good thermal stability [5,7]. Various production methods such as Powder Metallurgy (PM) route, infiltration and stir casting are used to produce MMC composites. PM has some important advantages such as simplicity, cheap processing and its ability to produce near net shape products [8]. Selecting and combining of suitable reinforcement and matrix qualification are key factors in their fabrication. However, machining of MMCs with required tolerances and surface quality is difficult since hard ceramic particles cause serious abrasive wear in cutting tool during the machining process [4,9–12]. There are several parameters that affect the cutting forces and drilled surface quality of these composites such as feed rate, cutting speed, tool type and particle fraction. Optimum drilling conditions is need for improving the drilling efficiency, reducing the cost and improving the quality of drilled surface [13].

The most important factor affecting the drilling forces is the feed rate rather than the cutting speed [2,14,15]. In addition, particle weight fraction and the drill material are of great importance for the thrust force; and lowest forces are obtained with polycrystalline diamond (PCD) tools [2]. Coated carbide drills produce more forces than

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uncoated (solid) carbide drills [14] and lower forces are produced when through-tool cooling is applied [16].

From the earlier studies on the drilling MMCs it is stated that the surface roughness of the drilled hole decreases with an increase of the cutting speed, and surface roughness increases with increasing feed rates [2,3,14,17,18]. Nevertheless, the latter results are inconsistent with some researchers [5,19,20]. Nearly all researchers conclude that the feed rate has a more dominant influence than cutting speed from the point of view of surface roughness.

The next important factor affecting the drilled surface quality is cutting tool material. Generally, coated carbide drills produces better surface quality than uncoated carbide tools [14]. Past studies reveals that PCD diamond drills shows the best performance [21] and HSS tools is not suitable for MMCs due to causing excessive tool wear and poor surface quality [2,19,20]. However, the high cost of the PCD tools limits the preferability of these tools [16]. Diamond-like carbon (DLC) tools may also exhibit similar surface roughness results with PCD tools [18]. On the other hand, a previous study states that Al–5%SiC–5% B_4C composites can be drilled by HSS drills under the combinations of lower cutting speeds and lower feed rates [5]. Available past studies regarding the influence of particle weight fraction, reveal that higher particle weight fraction improves the surface quality [22]. Otherwise, heat treatment negatively affects the surface quality when drilling MMCs [23].

In the previous studies on the drilling of MMCs, ceramic particles play a role of a chip breaker, resulting in formation of sawtoothed chips [1,14]. It is stated that reducing the ceramic particles in the composite materials causes the production of long continuous chips. Besides, after reinforcement particulates are added, the produced chips are short and no curls are formed.

The aim of the present study is to introduce the use of grey relational analysis in determining optimum drilling conditions on multi-performance characteristics such as thrust force, torque and surface quality. For this purpose, drilling of MMCs containing –Al–5Zn–3.5Cu–2.5Mg alloy reinforced with three different wt.% B_4C is carried out. The drilling parameters are set by Taguchi experimental design method. The thrust force, surface roughness and chip formation phenomena after the drilling experiments with HSS, TiAlN coated and uncoated carbide drills are investigated. In addition, analysis of variance (ANOVA) is conducted for the process parameters, and their contribution rates are determined.

2. Experimental procedure and method

2.1. Composite production

In this work, composite materials containing of 10 wt.% B_4C, 15 wt.% B_4C, 25 wt.% B_4C and remaining –Al–5Zn–3.5Cu–2.5Mg were produced by PM technique in prismatic dimensions of $50 \times 70 \times 12\ mm^3$. This method was similar to the fabrication route used by previous researchers [10–12,24]. For this aim, powders of aluminium, copper, zinc, magnesium and B_4C with fewer than 325-mesh were weighed with Symmetry EC4000 electronic balance having 0.1 gr accuracy and then uniformly mixed in a mixing bowl. The ball milling method, having 36 zirconia balls, for mixing of the powders was used. After packing the mixture with aluminium foil, it was cold pressed into the mold under 25 MPa. Later, in order to fill the voids between metal and ceramic powders with zinc, the furnace temperature was kept 540 °C and composite specimens were fabricated for a half hour. Finally, the mold was kept inside the furnace until 250 °C furnace temperature and then placed in the open air to complete the cooling. Hardness and tensile tests also were performed on the produced composites.

2.2. Plan of the experiments

In this research, Taguchi method which is a useful tool for the design of performance characteristics was used [13,25]. L_{27} (3^{13}) orthogonal array was chosen since it has the ability to control the interactions among the factors [3,26,27]. The control factors and the levels of each parameter were given in Table 1.

2.3. Experimental procedure

The machining conditions and properties of the cutting tools are presented in Table 2. Coating thickness of TiAlN coated tool and hardness of coating material were 5 μm and 2800HV, respectively. A Kistler dynamometer was used for recording the thrust force and torque. Fig. 1 shows the schematic image of the drilling setup [28]. Picture of the produced composite, attached to the specially developed and manufactured fixture, after drilling with CNC controlled vertical machining center is depicted in Fig. 2. In order to obtain optimum surface roughness values of the drilled holes, the hole length should be smaller than 3 times the drill diameter [29]. The drill diameter of 8 mm and hole length of 12 mm were selected. The surface roughness of the drilled composites was measured at four different

Table 1
Drilling parameters and levels.

Control parameters	Units	Levels		
		1	2	3
Wt.% B_4C (A)	%	10%	15%	25%
Feed rate (B)	mm/rev	0.1	0.2	0.3
Spindle speed (C)	rev/min	1500	2000	2500
Drill material (D)	Hv	HSS 800Hv	Carbide 1500Hv	TiAlN coated carbide 2800Hv