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Measurement and optimization of surface roughness and tool wear via grey relational analysis, TOPSIS and RSA techniques

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ABSTRACT

Magnesium alloy (Mg alloy) is one among the lightest materials and which has wide applications in the production of aircraft engines, airframes, helicopter components, light trucks, automotive parts and computers parts for its attractive properties. In this paper, a study to analyze the turning properties of magnesium alloy AZ91D in dry condition with polycrystalline diamond (PCD) cutting inserts is presented. Firstly, to investigate turning of magnesium alloy using grey relational analysis and TOPSIS of optimum cutting parameter values. Secondly, to determine using response surface analysis of mathematical model depending on cutting parameters of surface roughness and tool flank wear in turning. The adequacy of the developed mathematical model is proved by ANOVA. The findings from the investigation showed that feed rate and cutting speed are the dominant factors for surface roughness and tool flank wear respectively.

1. Introduction

Light materials such as aluminium and magnesium have always attracted automotive applications due to their advantage of low density which leads to fuel economy [1]. In the case of magnesium, its density (1740 kg/m^3) is considered the lowest density among all the industrial metals and only plastic is the nearest contender. [2]. When heavy materials are replaced by light materials, it should not affect the product properties, being necessary to consider specific material properties [3]. For structural applications, after aluminium and steel, magnesium alloy is the most preferred material [4,5]. Magnesium alloy has many attractive properties like high resistances to deformation, low density, very high specific strength, light weight, and extraordinary corrosion/oxidation resistance, which makes it suitable for many crucial applications in different industrial sectors such as aerospace, automotive, electronic and medical [6,7]. Also traditionally, magnesium alloy is thought as an easy material for processing as it requires low cutting force and low cutting power during machining. During increased cutting speeds chip ignition occurs due to rise in cutting temperature. In machining processes, the temperature first increases to certain level and then decreases due to the increase in cutting speeds [8]. The main problem involved in machining Magnesium alloy is chip ignition. During machining of magnesium alloys, chips can easily autoignite as its auto ignition temperature (430 °C) is lower than its melting temperature (650 °C). If autoignition occurs, using water based coolant is not advisable as it will chemically react with magnesium and create hydrogen. The flammable and explosive nature of hydrogen may entail the risk of firing or explosion [9–11]. The tool wear reduces the cutting tool life and also decreases surface quality of the work piece. Tool wear occur due to

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adhesion, abrasion, fatigue, tribo-chemical process, dissolution and diffusion [12]. Machining process characteristics like chip forming mechanism and chip morphology provide important information on the machined surface quality. Flank wear that occur on the cutting edge due to usage also increases with longer duration of machining time. This in turn reduces surface quality and increases cutting force leading to deterioration of product quality [13].

Investigations have been carried out on the turning properties of Mg alloy by using kentanium cutting tool in dry condition. It has been reported that cutting feed had the greatest impact on surface roughness and the primary wear of the main flank surface was abrasive and diffusive. The crumb formation revealed that cutting feed was most effective on the shape of crumbs. Also it was reported that with the increasing of the speed and feed, fractures would appear on the surface of crumbs, and would be changed into cracked crumbs gradually [14]. While turning of AZ31B magnesium alloy under the environments of dry machining and cryogenic refrigeration conditions, surface roughness values obtained were below 0.2 μm, being worse compared to the results obtained when using dry machining [15]. Investigation on facing of Mg alloy (UNSM11917) in dry condition, all the observed values for surface roughness were in the range of 0.19–0.82 μm [16]. At present, references and database about machining of magnesium alloy are scarce in India. The issue about how to process the material efficiently, safely, precisely and with low wear is essentially to be solved.

To determine the quality of a product, surface finish is an essential component for production industries. Surface quality can also assure reduction in manufacturing cost [17]. Surface roughness is one of the significant performance characteristic for turning process. The machining input factors that affect surface quality include workpiece material, workpiece dimensions, cutting depth, cutting speed, tool geometry, flank, relief angle, rake angle, feed rate, cutter runout and coolant environmental temperature [18,19]. Researchers have investigated the surface quality obtained during different machining processes on composite material and its effect on the mechanical behavior of composite structures. The impact of surface quality on mechanical behavior is influenced by machining processes [20–23].

Several research attempts have been made by employing different methods and carrying out investigation of input effects for the improvement of surface quality, tool life and other performance factors for alloys and composite materials [24–27].

The turning operation normally removes stock from the material and produces rough surface. Therefore, surface quality is another significant indicator to assess the machining characteristics and quality of product. In this work the average surface roughness (Ra), has been considered for analysis. The type of material machined and the type of cutting tool used also play important roles in the kind of surface characteristics produced [28,29].

Carou et al. [30] worked on intermittent turning of UNS M11917 magnesium alloy, analyzed different machining conditions along with the use of dry machining and minimum quantity lubrication (MQL) system. Full factorial experimental designs are used and their results are analyzed using the Analysis of Variance (ANOVA). Asilturk and Neseli [31] have worked on the multi response optimization of CNC turning parameters via Taguchi method-based response surface analysis. Finally, the adequacy of the developed mathematical model was proved by ANOVA. Asilturk and Akkus [32] worked on optimization of cutting parameters for turning operations based on the Taguchi method to minimize surface roughness (Ra and Rz). The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. Kıvak [33] studied the effect of cutting parameters on surface roughness and flank wear. He conducted several experiments using the L18 full-factorial design with a mixed orthogonal array. The analysis results revealed that the feed rate was the dominant factor affecting surface roughness and cutting speed was the dominant factor affecting flank wear. Linear and quadratic model have been formed to predict the outcomes of the experiment. The predicted values and measured values were very close to each other. Hence in this attempt magnesium AZ91D alloy was machined with Polycrystalline diamond (PCD) cutting inserts to optimization of surface roughness and tool flank wear using grey relational analysis and TOPSIS. Next prediction equations are generated using response surface analysis.

2. Design of experiment

2.1. Machining parameters

Taguchi's philosophy is mainly explored for designing the experimental procedure to investigate the effects of the entire machining parameters through limited number of experimental runs. Taguchi's orthogonal array design of experiment is economic as well as less time consuming. In this study, three governable process parameters: cutting speed, feed and depth of cut have been selected and varied in three different levels as shown in Table 1. In the present work, the experiments were performed using Taguchi's L27 orthogonal array [34,35].

2.2. Response surface analysis

Response surface analysis is the collection of experimental strategies, mathematical methods, and statistical inferences that enable an experimenter to make efficient

Table 1
Turning parameters and their levels.

Control parameters	Symbol	Levels		
		1	2	3
Cutting speed (v), m/min	A	40	80	120
Feed (f), mm/rev	B	0.10	0.15	0.20
Depth of cut (d), mm	C	0.50	0.75	1.00