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A grey-fuzzy modeling for evaluating surface roughness and material removal rate of coated end milling insert

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ABSTRACT

The prime factor for selecting equipment is its performance capability and reliability without compromising on quality. Materials for aerospace application such as aluminum and its alloys have limited applications because of their complications in machining, effectively and economically. There is no further development in raising the effectiveness above the optimal level in cutting tool materials. The surface roughness influences the determination of the quality of the product. The present study focuses on finding optimal end milling process parameters by considering multiple performance characteristics using grey fuzzy approach. In this work, Aluminum Alloy 6082T6 (AA6082T6) is used as workpiece material which was end milled using Aluminum Chromo Nitride (AP3) coated milling insert. Three process performance parameters namely Centre Line Average Roughness (*Ra*), Root Mean Square Roughness (*Rq*) and Material Removal Rate (MRR) were optimized. The grey output is fuzzified into five membership functions and also with twenty-seven rules. Grey Fuzzy Reasoning Grade (GFRG) is developed and the optimal values were found out from the Grey relational grade. The result of the Analysis of Variances (ANOVA) shows that the maximum contribution in the depth cut is (31.785%) followed by feed (28.212%). Moreover, Adaptive Neuro-Fuzzy Inference System (ANFIS) model has been developed with the help of the same input values compared to the performance of the fuzzy logic model. With the help of detailed analysis, it has been found that the fuzzy logic based model gives more reasonable results when compared to ANFIS model.

1. Introduction

The metal cutting process is an industrial process in which metal parts are shaped by the removal of unwanted material. It mostly refers traditional chip forming process like turning, milling, grinding, and drilling process. In milling process, materials are removed from the workpiece by rotating the milling cutters. Among various types of milling, up and down milling have the advantage of peripheral applications [1]. Up milling is usually preferable because the down milling spindle and feed drive exhibit backlash and when the part has large variations in height or hardened outer layer due to sand casting or flame cutting. In down milling, there is a tendency for the chip to become wedged shape insert and cutter, causing tool breakage. While machining the tool gets vibration and affects the cutting forces, tool life, accuracy and surface finish. While machining the edges and shoulders, the tool gets deflected this adversely affects the dimensional and form accuracy. For such applications, solid carbide inserts will

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help to produce greater dimensional accuracy, because of high modulus of elasticity.

The Surface Roughness (SR) is an important quality factor and the best predictor of the performance of the mechanical components. There are different roughness parameters in use, but *Ra* is the commonly used. The other common parameters include *Rq*. Some other additional parameters are also used in certain industries or within countries. *Ra*-centre line average roughness is the most commonly used parameter because they give a simple value for accepting or rejecting the decision. *Ra* is the arithmetic average height of roughness components irregularities from the mean line. *Rq* is geometric average roughness or root mean square. *Rq* is the geometric average height of roughness-component irregularities from the mean line measured within the sampling length. The material removal rate can be defined as the volume of material removed and divided by the machining time. Since the depth of cut is changing, the material removal changes during the process. In some cases, the usefulness of this can be that the cutting force and deflection that changes during the process.

Aluminum Alloy 6082T6 (AA6082T6) is a medium strength alloy with excellent corrosion resistance which has the highest strength in 6XXX series which is selected as a workpiece material. This high strength aluminum alloy is used in highly stressed area and many structural applications. Magnesium and silicon are combined to form a compound magnesium silicide (Mg_2Si), which in term forms a simple eutectic system [2] with Aluminum. The machining of aluminum alloy produces tight coils of swarf when chip breakers are used.

Recently Kovac et al. [3] experimentally studied the multi-inputs–multi-outputs fuzzy inference system using Gaussian membership function and found that the deviation of the tool life is 11.6% while the cutting temperature is 3.28%. Ramanujam et al. [4] carried out turning process with PVD ALTIN coated tungsten carbide cutting tool. The parameters like speed, feed, depth of cut and the process parameters of the arithmetic mean (*Ra* and *Rt*) and cutting force F_z are studied. The result shows that the feed contribution is high. Lin and Lin [5] applied the grey fuzzy logic in the electrical discharge machining process, and multi-response processes were reported. The machining parameters like pulse time, duty factor, and discharge current were employed, and the multi-responses are carried out for finding material removal rate and surface roughness. The optimized parameters are found from grey fuzzy logic. Krishnamoorthy et al. [6] analyzed the HSS drills with three different angles used for carbon fiber reinforced plastics composites. Grey fuzzy analysis is used to find the optimal drilling parameters for quality holes. They identified the feed rate, which is of the most important factor in the drilling of carbon fiber reinforced plastics. Dhas and Satheesh [7] studied the multi-objective optimization of submerged arc welding process parameters using grey based fuzzy logic. They concluded that welding current is the most significant values (30.76%). Ahilan et al. [8] studied the CNC turning process and the optimal values were found from grey fuzzy logic. The significant performance was also investigated with the help of fuzzy logic techniques. Yang and Huang [9] have projected Grey Fuzzy Taguchi Approach (GFTA) for multi-objective properties namely coefficient of friction, wear rate, deposition rate and water contact angle of Zr-DLC coating. They have concluded that 35% gain from the initial condition, by using GFTA method. Performance index has increased from 0.46 to 0.81. Ozek et al. [10] applied fuzzy logic in plasma arc cutting process of AISI 4140 steel. Fuzzy rule-based modeling was employed for prediction of surface roughness. The experimental results were compared with fuzzy logic and identified that the cutting speed is an important factor in plasma arc process.

Rajmohan et al. [11] investigated the optimal machining parameters of drilling of hybrid aluminum metal matrix composite using the grey-fuzzy algorithms. The result shows that feed rate and speed which are the most significant parameters with a contribution as 89% and 5%. Vasudevan and Naresh [12] carried out four process parameters, and three output parameters were selected with turning of PCD cutting tool. The multi-objective optimization algorithm involving grey-fuzzy with Taguchi method is used. A multi-performance characteristics index is maximized validating the results. Hanafi et al. [13] considered and optimized the machining of reinforced polyetheretherketone with 30% of carbon fibers (PEEK-CF30). An orthogonal array and grey fuzzy logic are applied to study the multi-response. In this study, the optimization procedure has greatly improved the manufacturing processes which are reported in this study. Manna [14] applied Taguchi method, Fuzzy logic, and Grey relational analysis in e-glass-fiber–epoxy composite during electrochemical spark machining. The optimal results in DC supply voltage 70 volts and electrolytes concentration 80 g/l and 180 mm gap between the tool and the auxiliary electrode. The result shows that the material removal rate is high in the spark process. Parida and Pal [15] had taken eight input parameters and five output parameters of the friction stir welding process, and they carried out the optimization problem solved by Grey Fuzzy Taguchi method. They have given best results. Kuram and Ozcelik [16] have described the micro milling of AISI 304 stainless steel with ball nose end milling by using regression and fuzzy logic. The result showed that both regression and fuzzy logic modeling could be efficiently utilized for tool wear, cutting force and surface roughness.

Krishna et al. [17] studied the comparison of ANFIS and ANN model to predict the surface roughness in hard turning. The result shows that ANFIS gives the best result than Artificial Neural Network (ANN). Abdulshahed et al. [18] expressed that the thermal error effects on CNC machine tool accuracy to compare the results of the ANFIS-Grid model and ANFIS-FCM model. They have concluded ANFIS-FCM model is superior regarding the accuracy of its predictive ability with the benefit of fewer rules. Sahoo et al. [19] applied this to predict the surface roughness and material removal rate in turning of grey relational analysis and regression analysis. The result shows that the grey relational grade improved 0.284. Tomadi et al. [20] investigated and optimized the end milling of AlSi/AIN MMC using Taguchi methods with grey relational analysis. The uncoated carbide insert gave good optimum result and