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Review Paper

Design of Experiments based Grey Relational Analysis in Various Machining Processes - A Review

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Abstract

Machining processes are widely used in the aerospace, aircraft and automotive industries although that non-traditional machining method have improved in the manufacturing industries in response to new and unusual machining requirement that could not be satisfied by conventional methods. Non-traditional machining including ultrasonic machining, abrasive water jet cutting, electrochemical machining (ECM), and chemical machining (CHM) are some of the examples. In machining processes, cutting fluids are used to lubricate the process and reducing the temperature that contributes of wear and tear to the cutting tool. Aluminum alloys widely used for automotive and aerospace industries which durability, strength, and light weight are desired and these materials subjected to machining operations where the criterion of minimization of lubricant or coolant use is becoming more topicality. Manufacturer have desired to work without any lubricant because of reasons such as the cost of using it, supply and maintenance of the lubricant, hazard arising from the lubricant and the disposal of used lubricant, therefore an alternative methods of machining is a dry machining. A statistical technique, fractional factorial experiments and analysis of variance (ANOVA), has been employed to investigate the influence of cutting parameters. This paper presents a literature review on optimization of various machining processes using design of experiments based grey relational analysis.

Keywords: Design of experiments, machining process, grey relational analysis, review.

Introduction

As one of the size error during drilling, projection of material, defined as “Burr” is formed. Burr is plastically deformed material, generated on the part edge during cutting or punching. Burr can be classified as entrance burr and exit burr. The entrance burr is formed around the drilled hole in the form of small wedge and the exit burr is formed on the other side, when the drill pierces work piece by pushing out uncut volume. It must be noted that exit burr strongly affects product quality and assembly process. Due to this reason, additional deburring process is required. Usually the deburring process is done manually because of difficulties in automation. And it also may cause high cost in edge finishing of precision parts. Basic mechanism of burr formation can be found in a literature, describing several ways to reduce effect of burr[1]. Burr formation process explained by three stages and burr formation tendency observed especially to burr height and thickness by changing the cutting speed and feed rate. Several elements forming burr during drilling has studied. The effect of the feed rate, cutting speed, pecking and tool’s material on burr height, thickness and shape using micro drill in stainless steel, and the influence of work piece exit angle on burr formation in drilling intersecting holes are observed .Burr is formed by plastic deformation, and its size depends on cutting conditions like cutting velocity and feed rate. The elements of drill shape, point angle, helix angle, length of chisel edge etc. influence the cutting force, hole accuracy and burr formation as well. In drilling process, parameters such as tool bit geometry i.e. point angle, lip clearance angle and helix angle, material of the drill bit, cutting speed, feed rates, as well as the use of cutting fluids will impact the burr size and machining qualities like the surface roughness and the deviation in the circularity of hole, an orthogonal array and analysis of variance or employed to investigate the burr size. From the aforementioned parameters selected the data of more significant parameters, in order to evaluate burr size using Taguchi Technique. On application of cutting fluids, reduction in deburring cost by choosing optimal cutting speed and feed rates the fact is that most burrs can be prevented or minimized with process control. Research and interest has been focused on problems associated with generation of burrs from machining for sometime but the focus has traditionally been on deburring processes. Understanding the burr formation process is critical to burr prevention. The level of scientific knowledge on burr formation is just in the early stages of development[2] see figure 1. The critical information, associating details of the part performance and functionality with requirements for edge condition, is still not well understood. Standards and specifications are only now being developed for this led by the German automotive and mechanical parts industries.

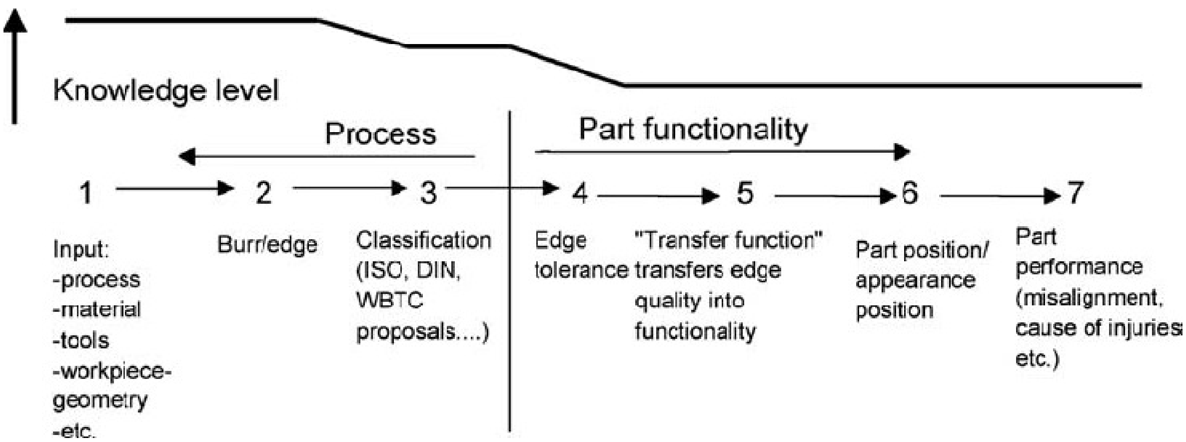

Figure-1

Water miscible cutting fluids are primarily used for machining operations because they have better cooling capabilities. The surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Hence, achieving the desired surface quality is of great importance for the functional behavior of the mechanical parts. A reasonably good surface finish is desired for improving the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product[3,4]. Excessively better surface finish may involve cost of manufacturing. The surface roughness and roundness error are affected by several factors including cutting tool geometry, cutting speed, feed rate, the microstructure of the work piece and the rigidity of the machine tool. These parameters affecting the surface roughness and drilled hole qualities (roundness, cylindricality and hole diameter) can be optimized in various ways such as Taguchi method and multiple regression models[5,6]. Therefore, a number of Researchers have been focused on an appropriate prediction of surface roughness and roundness error.

The Taguchi method has been widely used in engineering analysis and is a powerful tool to design of orthogonal array to investigate the effects of the machining parameters through the small number of experiments. By applying the Taguchi technique, the time required for experimental investigations can be significantly reduced, as it is effective in the investigation of the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence, which one less[7]. Taguchi method and ANOVA to establish a correlation between cutting speed and feed rate with the delamination in a composite laminate. A statistical analysis of hole quality was performed. They found that feed rate and cutting speed have a relatively small effect on the measured hole quality features. With the expectation of hole location error, the hole quality was not predictably or significantly affected by the cutting conditions. Performed the prediction and evaluation of thrust force and surface roughness in drilling of composite material. The approach used Taguchi and the artificial neural network methods. The experimental results show that the feed rate and the drill diameter are the most significant factors affecting the thrust force, while the feed rate and spindle speed contribute the most to the surface roughness. Performed a study of the taguchi design application to optimize surface quality in a CNC face milling operation. Taguchi design was successful in optimizing milling parameters for surface roughness. Taguchi technique is used to determine the optimal cutting parameters for surface roughness in turning of AISI 1030 steel with Ti N coated inserts. Three cutting parameters such as insert radius, feed rate, and depth of cut, are optimized for minimum surface roughness. Taguchi method was employed in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes. The validity of the Taguchi approach to process optimization was well established. The objective of their study is to investigate the effects of the drilling parameters on surface roughness and roundness error, and is to determine the optimal drilling parameters using the Taguchi - Gray relational analysis in drilling

Grey Relational Analysis

In grey relational analysis, black represents having no information and white represents having all information. A grey system has a level of information between black and white. This analysis can be used to represent the grade of correlation between two sequences so that the distance of two factors can be measured discretely. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcoming in statistical regression. Grey relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method[8]. Grey relational analysis is widely used for measuring the degree of relationship between sequences by grey relational grade. Grey relational analysis is applied by several researchers to optimize control parameters having multi-responses through grey relational grade. The use of Taguchi method with grey relational analysis to optimize the face milling operations with multiple performance characteristics includes the following steps: i. Identify the performance characteristics and cutting parameters to be evaluated. ii. Determine the number of levels for the process parameters. iii. Select the appropriate orthogonal array and assign the cutting parameters to the orthogonal array. iv. Conduct the experiments based on the arrangement of the orthogonal array. v. Normalize the experiment results of cutting force, tool life and surface roughness. vi. Perform the grey relational generating and calculate the grey relational coefficient. vii. Calculate the grey relational grade by averaging the grey relational coefficient. viii. Analyze the experimental results using the grey relational grade and statistical ANOVA. ix. Select the optimal levels of cutting parameters. x. Verify the optimal cutting parameters through the confirmation experiment.

In the grey relational analysis, the grey relational grade is used to show the relationship among the sequences. If the two sequences are identical, then the value of grey relational grade is equal to 1. The grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. Therefore, if a particular comparability sequence is more important than the other comparability sequences to the reference, then the grey relational grade for that comparability sequence and reference sequence will be higher than other grey relational grades.

Application of Grey Relational analysis in various fields

Electrochemical machining: Electrochemical machining is one of the widely used non-traditional machining processes to machine complicated shapes for electrically conducting but difficult-to-machine materials such as super alloys, Ti-alloys, alloy steel, tool steel, stainless steel, etc. Use of optimal ECM process parameters can significantly reduce the ECM operating, tooling, and maintenance cost and will produce components of higher accuracy. Effect and parametric optimization of process parameters for Electrochemical machining of EN-31 steel using grey relation analysis investigated[9]. The process parameters considered by them are electrolyte concentration, feed rate and applied voltage and are optimized with considerations of multiple performance characteristics including material removal rate, overcut, roundness error and surface roughness. Analysis of variance is performed to get contribution of each parameter on the performance characteristics and it was observed that feed rate is the significant process parameter that affects the ECM robustness. Finally they showed in their experimental results for the optimal setting there is considerable improvement in the process. The application of this technique converts the multi response variable to a single response Grey relational grade and therefore, simplifies the optimization procedure**.**

Boring Process: The optimization of computer numerical control (CNC) boring operation parameters for aluminum alloy 6061T6 using the grey relational analysis (GRA) method. They are selected L_9 orthogonal array of Taguchi method. The surface properties of roughness average and roughness maximum as well as the roundness were selected as the quality targets[10]. An optimal parameter combination of the CNC boring operation was obtained via GRA. By analyzing the grey relational grade matrix, the degree of influenced for each controllable process factor onto individual quality targets can be investigated. The feed rate is identified to be the most influence on the roughness average and roughness maximum, and the cutting speed is the most influential factor to the roundness. Additionally, the analysis of variance (ANOVA) was also applied to identify the most significant factor; results shows that the feed rate is the most significant controlled factor for the CNC boring operations according to the weighted sum grade of the roughness average, roughness maximum and roundness.

Face milling: Since milling (specially face milling) figures so prominently in the manufacture of so many parts, for example, automotive engines and transmission components, it has been a major focus for burr reduction and prevention for many years. In milling, the kinematics of tool exits from the work piece is a dominant factor in burr formation and, as a result, substantial success has been realized by adjusting the tool path over the work piece.

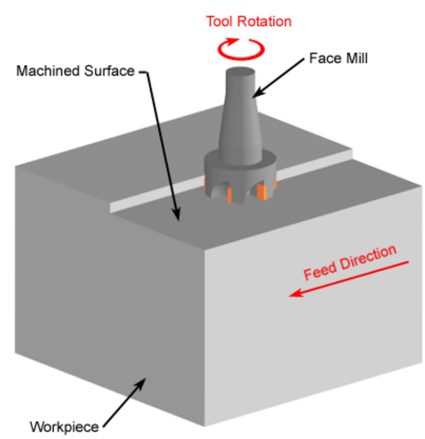

Figure-2

Some researchers[11] focused on the effect of process parameters such as speed, feed, and depth of cut and approach angle of the cutter on cutting force, tool life and surface roughness in face milling of Inconel 718. The experiments were designed based on L9 orthogonal array and carried out under dry conditions. Cutting force, Tool wear and surface roughness were recorded for each experiment. Grey relational analysis is used to optimize the multi performance characteristics to minimize the cutting force and surface roughness and maximize the tool life criteria. The feed was identified as the most influential process parameter on cutting force and surface roughness. Cutting speed is identified as the most influential process parameter on tool life.

Wire Electro Discharge Machining: Effective approaches to optimize process parameters for Wire electro discharge machining (WEDM).WEDM is extensively used in tool and die industries presented in their work. Precision and intricate machining are the strengths. While machining time and surface quality still remains as major challenges. The main objective of this study is to obtain higher material removal rate (MRR) and lower surface roughness (SR). Ton, T off, applied current, Gap voltage, Wire tension and wire feed rate are the six control factors taken each at various levels. Since the process has multiple performance characteristics, the grey relational analysis is used. The grey relational grade normalizes the contradicting performance indices. From eight experiments based on the orthogonal array of L8 the best combination of parameters were found. Compared with Taguchi's method the proposed method is more scientific. The experimental results confirm that the proposed method in this study effectively improves the machining performance of WEDM process[12].

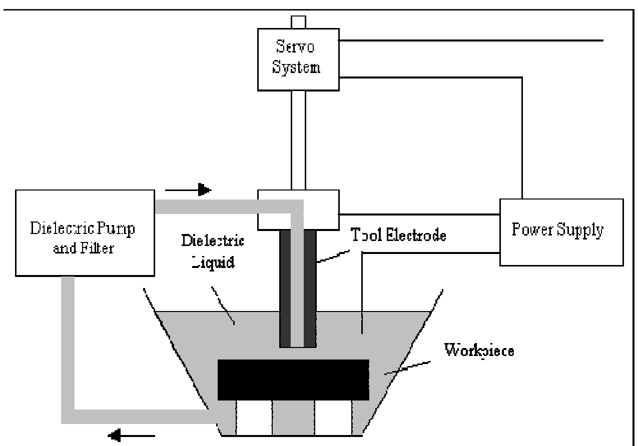

Figure-3

High-speed end milling: The optimization design of the cutting parameters investigated for rough cutting processes in high-speed end milling on SKD 61 tool steel. The major characteristics indexes for performance selected to evaluate the processes are tool life and metal removal rate, and the corresponding cutting parameters are milling type, spindle speed, feed per tooth, radial depth of cut, and axial depth of cut. In this study, the process is intrinsically with multiple performance indexes so that grey relational analysis that uses grey relational grade as performance index is specially adopted to determine the optimal combination of cutting parameters [13]. Moreover, the principal component analysis is applied to evaluate the weighting values corresponding to various performance characteristics so that their relative importance can be properly and objectively described. The results of confirmation experiments reveal that grey relational analysis coupled with principal component analysis can effectively acquire the optimal combination of cutting parameters. Hence, this confirms that the proposed approach in this study can be an useful tool to improve the cutting performance of rough cutting processes in high-speed end milling process.

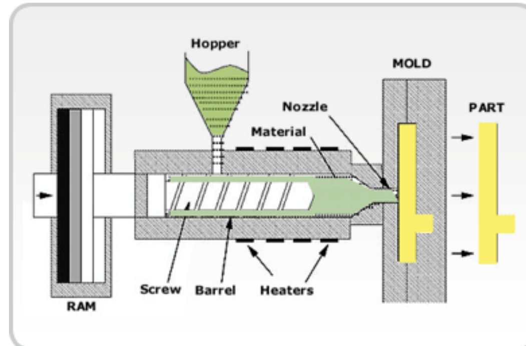

Figure- 4

Injection molding process: Optimization of injection molding process parameters using the grey relational analysis focused [14] on experimental method. Nine experimental runs based on the Taguchi method of orthogonal arrays were performed to determine the best factor level condition. The wear volume losses of fiber-reinforced polybutylene terephthalate in different sliding directions were selected to be the quality targets. Volume losses were obtained using a Schwingum Reibung Verschleiss (SRV) "ball-on-plane" wear tester. The factor levels were assessed according to two chosen wear volume losses. The degree of influence that the controllable process factors exert on the wear volume losses was studied by investigating the correlation between them. By analyzing the grey relational grade matrix, the most influential process factor and the most easily influenced wear property could be picked. Melt temperature was found to be the most influential factor in both wear volume losses of different sliding directions. The wear volume loss of sliding direction perpendicular to injection flow was more easily influenced by process factors than was the wear volume loss of the sliding direction parallel to the injection flow. The sequences of the importance to the wear volume loss in the controllable factors were slightly different for the two sliding directions, but the melt temperature was still the most important factor.

Turning operation: Optimization of CNC turning operation parameters are investigated [15, 16] using the Grey relational analysis method and Taguchi method. Nine experimental runs based on an orthogonal array of Taguchi method were performed. The surface properties of roughness average and roughness maximum as well as the roundness were selected as the quality targets. An optimal parameter combination of the turning operation was obtained via Grey relational analysis. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found. The depth of cut was identified to be the most influence on the roughness average and the cutting speed is the most influential factor to the roughness maximum and the roundness. Additionally, the analysis of variance (ANOVA) is also applied to identify the most significant factor; the depth of cut is the most significant controlled factors for the turning operations according to the weighted sum grade of the roughness average, roughness maximum and roundness.

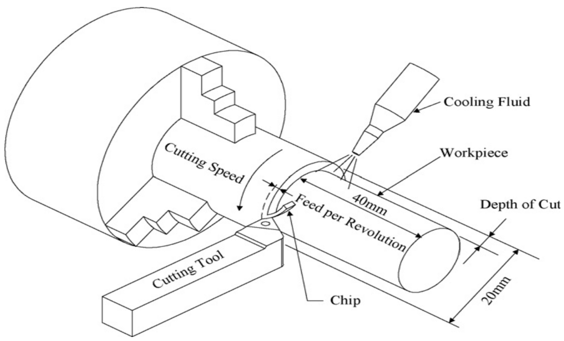

Figure-5

Laser cutting process: An effective approach for the optimization of laser cutting process of St-37 steel with multiple performance characteristics based on the grey relational analysis presented [17]. Sixteen experimental runs based on the Taguchi method of orthogonal arrays were performed to determine the best factor level condition. The response table and response graph for each level of the machining parameters were obtained from the grey relational grade. In this study, the laser cutting parameters such as laser power and cutting speed are optimized with consideration of multiple-performance characteristics, such as work piece surface roughness, top kerf width and width of heat affected zone (HAZ). By analyzing the grey relational grade, it is observed that the laser power has more effect on responses rather than cutting speed. It is clearly shown that the above performance characteristics in laser cutting process can be improved effectively through this approach.

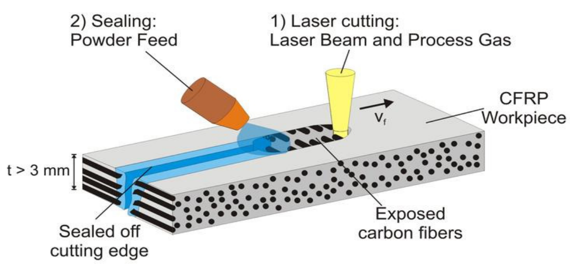

Figure-6

Drilling process

The theory of grey systems is a new technique for performing prediction, relational analysis and decision making in many areas. The use of grey relational analysis for optimizing the drilling process parameters for the work piece surface roughness and the burr height is introduced. Various drilling parameters, such as feed rate, cutting speed, drill endpoint angles of drill were considered. An orthogonal array was used for the experimental design. Optimal machining parameters were determined by the grey relational grade obtained from the grey relational analysis for multi-performance characteristics (the surface roughness and the burr height). Experimental results have shown that the surface roughness and the burr height in the drilling process can be improved effectively through the new approach[18].

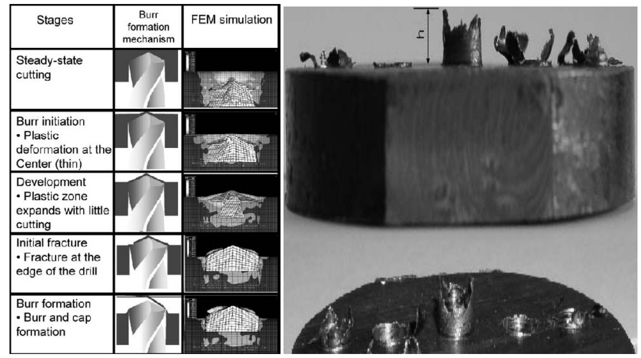

Figure-7

Some of the researchers[19,20,21] focused on drilling of fiber reinforced polymers using taguchi method integrated with ANN, they conducted lot of experiments, but they are not concentrating on multiple influential process factors. Recently, Taguchi method with grey relational analysis was used to optimize the machining parameters with multiple performance characteristics in drilling of hybrid metal matrix Al356/SiC-mica composites[22]. Experiments were conducted on a computer numerical control vertical machining centre and L18 orthogonal array was chosen for the experiments. The drilling parameters namely spindle speed, feed rate, drill type and mass fraction of mica were optimized based on the multiple performance characteristics including thrust force, surface roughness, tool wear and burr height (exit). The results show that the feed rate and the type of drill are the most significant factors which affect the drilling process and the performance in the drilling process can be effectively improved by using grey relational analysis approach.

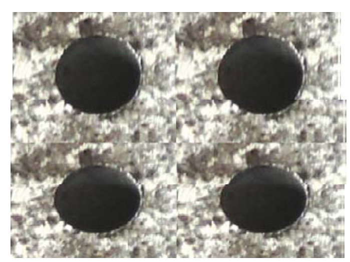

Figure-8
Photograph of machined composites

Conclusion

Based on the literature survey performed, venture into this research was amply motivated by the fact that a little research has been conducted to obtain the optimal levels of process parameters that yield the burr size and hole quality in drilling of Aluminum6061alloy. Most of the researchers have investigated influence of a limited number of process parameters on the performance measures of drilling process. In this work, minimum quantity lubricant mixing with water technique in drilling has been incorporated to enhance the effectiveness of the drilling process. A grey relational analysis can be chosen based on the multi performance characteristics of the drilling and the optimal combination of parameters optimize the burr size (Height and Thickness) and hole quality (surface roughness and roundness error). No such performance evaluation is conducted throughout the literature. Researchers are responsible to conceive new and improved analytical tools to solve a problem. When a new tool is available the problem should be re-examined to find better and more economical solutions. In recent years grey relational analysis have been gaining more importance and giving promising results in industrial applications. These issues motivate in applying such paradigms for analyzing and improving the performance of drilling process for enhancing quality and economy.

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