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Review Paper

Application of Grey Based - Taguchi Method to Determine Multiple Performance Characteristics in Drilling of Aluminium Alloys – Review

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Abstract

Metal cutting processes are important due to increased consumer demands for quality metal cutting related products (more precise tolerances and better product surface roughness) that has driven the metal cutting industry to continuously improve quality control of metal cutting processes. Aluminium 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 either dry machining or machining with less lubricant. In this study, minimum quantity lubricant mixing with water technique in drilling process using Grey based - Taguchi method is used. 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 drilling of Aluminum alloys.

Keywords: Drilling process, grey based Taguchi method, aluminium alloys, review.

Introduction

The 6061 alloy of aluminum is primarily composed of magnesium and silicon. This gives 6061 aluminum alloy superior welding ability over other alloys of aluminum, which are traditionally difficult to weld because of their chemical makeup and lack of conductivity. Some other elements of 6061 aluminum alloy include small amounts of iron, copper, manganese, magnesium, chromium, zinc and titanium. The 6061 composition of aluminum is an extensively used material for the construction of a wide variety of materials. Bicycles, airplane parts, automotive parts and aluminum cans are all constructed utilizing 6061 aluminum. In many cases, the foil interior wrapper on food containers is also made with 6061 aluminum alloy. Because the material is extremely workable, it is an ideal material for use in these products. Due to its good mechanical properties such as machinability and low density, Aluminum is commonly used in a wide range of industries and constitutes about 40% of all metal-cutting operations[1]. Drilling is a cutting process in which a hole is originated or enlarged by means of a multipoint, fluted, end cutting tool typically aided by cutting fluids as the drill is rotated and advanced into the work piece; material is removed in the form of chips that move along the fluted shank of the drill. Chips are produced within the work piece and move in direction opposite to axial movement of the drill. Although long spiral chips usually result from drilling, adjustment of the feed rate can result in chips with a range of shapes and sizes. Consequently, chip disposal in drilling and the effectiveness of cutting fluids are important.
Burr is plastically deformed projected material, generated on the part edge during drilling. Both roughness and burr cause reliability problems and performance degradation especially in precise assemblies. Burr formation requires additional manufacturing operations with additional cost and time for disassembly and de-burring. Factors which may contribute burr formation in drilling is shown in figure-1.

The geometry and drilling process parameters of classical drilling have been well studied over the years and gained more importance lately. Some researchers[2,3,4] experimentally verified simulation to predict burr height, force and temperature for 2024-T351 and 7075-T6 aluminum and concluded that feed rate, chisel edge to drill diameter ratio, drill diameter, yield strength and point angle are the most significant parameters affecting burr height. Other researchers[5,6] investigated tool wear as a function of cutting speed and coating material, Most of the engineering applications, including drilling process, would comprise of multiple responses such as surface roughness and burr height. Moreover, variability of process or product has to be minimized and mean has to be optimized. Optimizing multiple responses simultaneously is a difficult task that has been tackled by many researchers. One of the early methods proposed by Taguchi used for multi-response optimization advocates the use of signal-to-noise ratios (S/N).

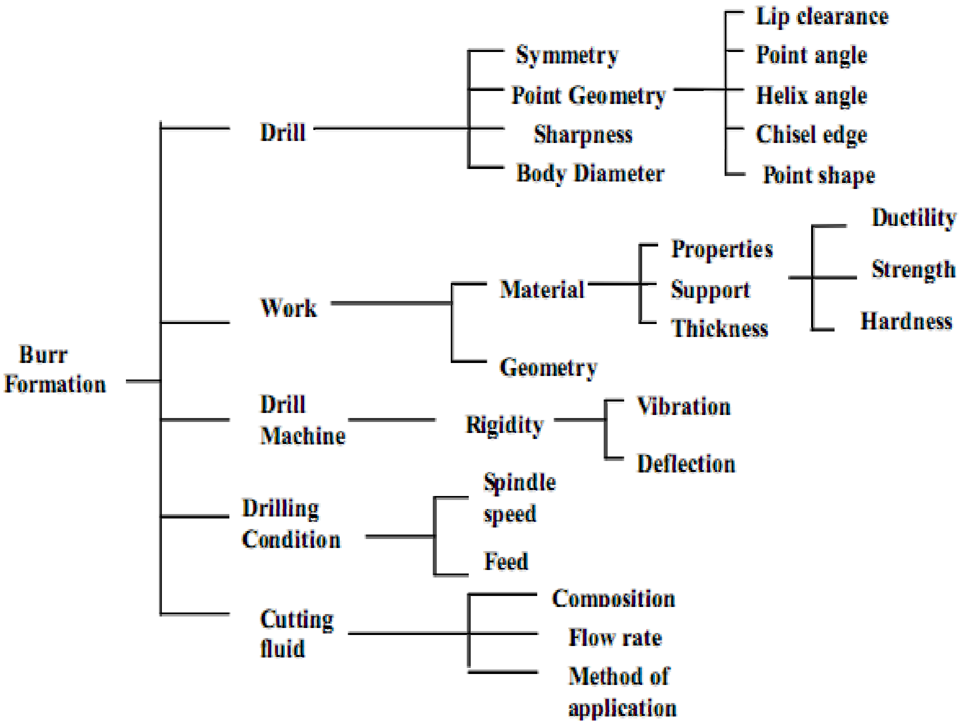

Figure-1
Factors which may contribute burr formation in drilling

This methodology specifically utilizes both experimentation and optimization methods to determine the system optimum operating conditions to minimize performance variability and deviation from target value of interest. Many detractors[7]challenged S/N ratio methodology and question Taguchi choice of experimental designs and methods of statistical analysis.

Optimization Techniques

An optimization is a procedure which is executed iteratively by comparing various solutions till the optimum or satisfactory solution is found. Accepting the best solution after comparing a few design solutions is the indirect way of achieving optimization in many industrial design activities. There is no way of guaranteeing an optimal solution with this simplistic approach. Optimization algorithms on the contrary, begin with one or more design solutions supplied by the user and then iteratively check new design solutions, relative search spaces in order to achieve the true optimum solution. Some of the widely used techniques in optimization are conventional Genetic Algorithm, Particle Swarm Optimization and Simulated Annealing etc.

Artificial Neural Network: Artificial neural network[8] is developed with a systematic step-by-step procedure which optimizes a criterion commonly known as the learning rule. The input/output training data is fundamental for these networks as it conveys the information which is necessary to discover the optimal operating point. In addition, non linear natures make neural network processing elements a very flexible system. Basic, an artificial neural network is a system shown in figure2. A system is a structure that receives an input, process the data, and provides an output. Commonly, the input consists in a data array which can be anything such as data from an image file, a WAVE sound or any kind of data that can be represented in an array. Once an input is presented to the neural network, and a corresponding desired or target response is set at the output, an error is composed from the difference of the desired response and the real system output.

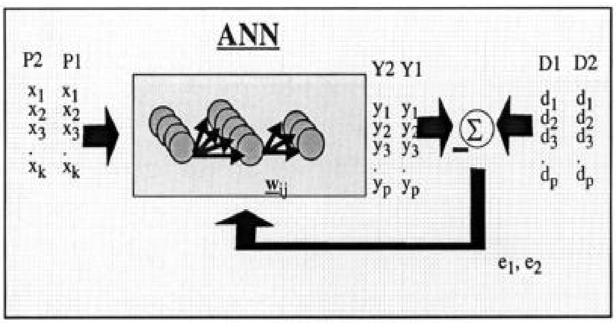

Figure-2
Basic Artificial Neural Network system

The error information is fed back to the system which makes all adjustments to their parameters in a systematic fashion (commonly known as the learning rule). This process is repeated until the desired output is acceptable. It is important to notice that the performance hinges heavily on the data. Hence, this is why this data should pre-process with third party algorithms such as DSP algorithms. In neural network design, the engineer or designer chooses the network topology, the trigger function or performance function, learning rule and the criteria for stopping the training phase. So, it is pretty difficult determining the size and parameters of the network as there is no rule or formula to do it. The best we can do for having success with our design is playing with it. The problem with this method is when the system does not work properly it is hard to refine the solution. Despite this issue, neural networks based solution is very efficient in terms of development, time and resources, artificial neural networks provide real solutions that are difficult to match with other technologies.

Ant Colony Optimization (ACO): Ant Colony Optimization (ACO) is a paradigm for designing meta heuristic algorithms for combinatorial optimization problems. A Meta heuristic is a set of algorithmic concepts that can be used to define heuristic methods applicable to a wide set of different problems. In other words, a Meta heuristic is a general-purpose algorithmic framework that can be applied to different optimization problems with relatively few modifications. Examples of meta heuristics include simulated annealing In ACO, a number of artificial ants build solutions to an optimization problem and exchange information on their quality via a communication scheme that is reminiscent of the one adopted by real ants. To find a shortest path, a moving ants lay some pheromone on the ground, so an ant encountering a previously trail can detect it and decide with high probability to follow it. As a result, the collective behavior that emerges is a form of a positive feedback loop where the probability with which ants choose a path increases with the number of ants that previously chose the same path.

Response Surface Methodology: This is a method for obtaining an approximate function using results of several numerical calculations to increase calculation efficiency and thereby implement design optimization. In the response surface method[9], design parameters are changed to formulate an approximate equation by the design of experiments method. An approximate sensitivity calculation of a multicrestedness problem can be performed using a convex continuous function and applied to optimization. The Box-Behnken Design is normally used when performing non-sequential experiments. That is, performing the experiment only once. These designs allow efficient estimation of the first and second–order coefficients. Because Box-Behnken designs have fewer design points, they are less expensive to run than central composite designs with the same number of factors. Box-Behnken designs do not have axial points, thus we can be sure that all design points fall within the safe operating zone. Box-Behnken designs also ensure that all factors are never set at their high levels simultaneously.

Simulated Annealing: Simulated annealing was developed in 1983 to deal with highly nonlinear problems the general SA algorithm shown in figure-3 involves the following three steps. First, the objective function corresponding to the energy function must be identified. Second, one must select a proper annealing scheme consisting of decreasing temperature with increasing of iterations.

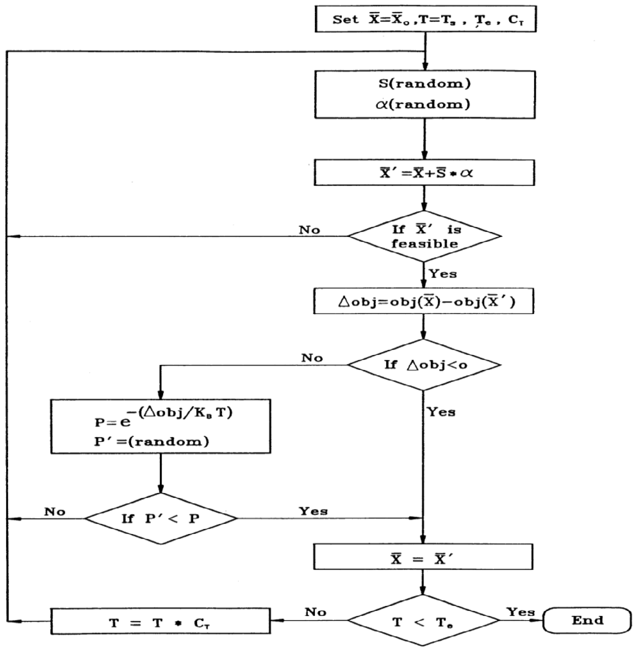

Figure-3
Flow chart for the simulated annealing

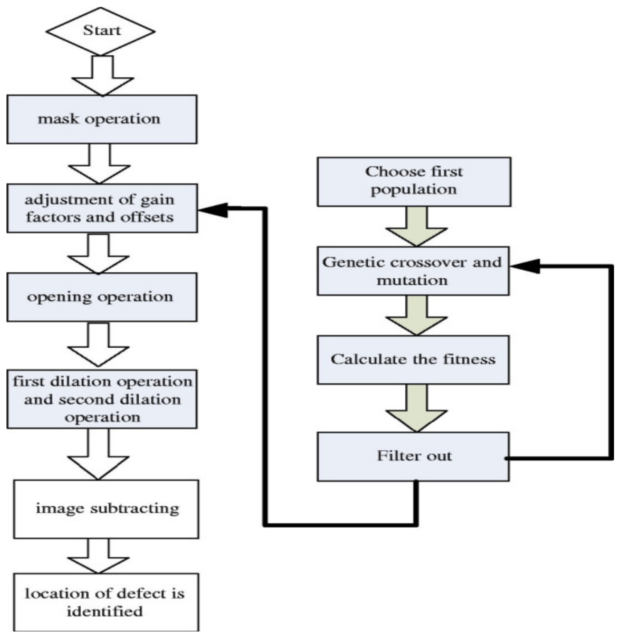

Figure-4
Flow chart for genetic algorithm

Third, a method of generating a neighbor near the current search position is needed. In single objective optimization problems, the transition probability scheme is generally selected by the Metropolis and logistic algorithms simulated annealing presents an optimization technique that can: (a) process cost functions possessing quite arbitrary degrees of nonlinearities, discontinuities, and stochasticity; (b) process quite arbitrary boundary conditions and constraints imposed on these cost functions; (c) be implemented quite easily with the degree of coding quite minimal relative to other nonlinear optimization algorithms; (d) statistically guarantee finding an optimal solution. Simulated annealing combines a downhill search with a random search. In order not to be trapped in a locally optimum region, this procedure sometimes accepts movements in directions other than steepest ascend or descend.

Genetic Algorithm: Genetic algorithms methodology aiming at the selection of the optimized values for cutting conditions in machining process, as turning and drilling aluminium matrix composites is proposed[10]. A hybrid technique based on an evolutionary search over a design space obtained by experimental way is considered. Flow chart for genetic algorithm as shown in above figure-4. The machining forces, the surface finish and the tool wear are experimentally measured considering the feed and the cutting velocity as predefined parameters. The optimization based on genetic algorithms has proved to be useful dealing with discrete variables defined on a population of cutting condition values obtained from time scale dependent experiments. The obtained results show that machining (turning and drilling) of composite material made of metal matrices with PCD tool is perfectly compatible with the cutting conditions for cutting time of industrial interest and in agreement with the optimal machining parameters (cutting forces, work piece surface finish and tool wear). They cited the importance of optimization of machining parameters using numerical and experimental models based on genetic algorithms in matters of scientific interest and large industrial applications.

CAD and Finite Element Analysis Model: A simplified and analytical model was proposed by[11,12] various feed control schemes to minimize burr size using thrust force based model. A FEM model of drilling burr formation process is developed[13;] its simulation gave an insightful description of drilling burr formation. Flow chart for drill CAD program and Integrating burr analysis with drill CAD system framework shown in figure.5. The FEM simulation describes the dominant rolls of negative shearing and bending mechanisms in the drilling burr formation process. The results of numerical simulation codes are not being used today due to the high cost of preparation for the process simulation by finite element analysis. Hence an integrated CAD/FEA system for drill design and drilling burr formation process was proposed[14].

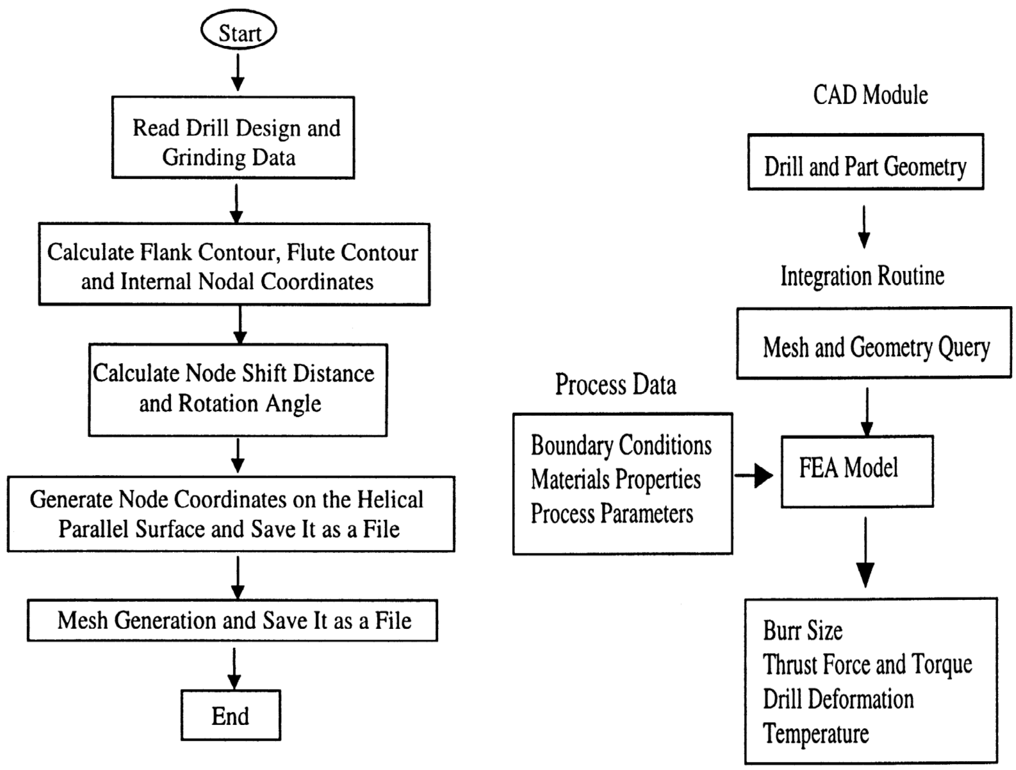

Figure-5
Flow chart for Drill CAD program and Integrating burr analysis with drill CAD system framework

Structure of Taguchi Method: Taguchi method[15] has been criticized in the literature for its difficulty in accounting for interactions between parameters. Another limitation is that the Taguchi methods are offline, and therefore inappropriate for a dynamically changing process such as a simulation study. Structure of Taguchi method is shown in figure-6. Furthermore, since the Taguchi methods deal with designing quality rather than correcting for poor quality, they are applied most effectively at early stages of process development A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way, while using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations.

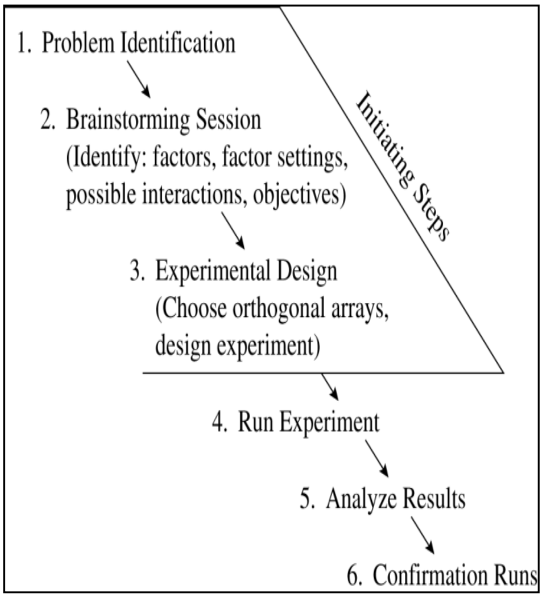

Figure-6
Structure of Taguchi method

Grey Based – Taguchi Method

The integrated grey based taguchi method combines advantages of both grey relational analysis and taguchi method. This method was successfully applied to optimize the multi response of complicated problems in manufacturing processes. Furthermore, ANOVA is performed to see which process parameters are statistically significant. The integrated grey based taguchi method combines the algorithm of taguchi method and grey relational analysis to determine process parameters for multiple responses as shown in figure-7 given below.

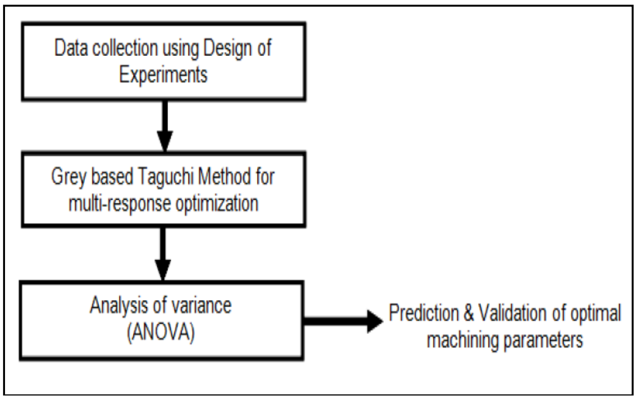

Figure-7
Structure of Grey based – Taguchi method

Motivation of the Research

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, thrust force and hole quality in drilling of aluminum 6061 alloy. 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 based taguchi method 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), thrust force and hole quality (surface roughness and roundness error). No such performance evaluation is conducted throughout the literature. Majority of the works are concentrating only on dry drilling for Aluminum alloys. More over no study has been performed in drilling process using grey based taguchi method. The study, it is hoped will lead to theorizing efficient monitoring and diagnostics in drilling processes. The non-linear nature of the drilling process has compelled engineers to search for more effective methods to attain optimization. Researchers have found efficient optimized processes in nature itself. The studies indicate the importance in analyzing the problem and efforts done to improve the performance of the production or design system even under disturbed conditions. 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.

Objective of the Paper: To conduct experiments in minimum quantity lubricant mixing with water technique in drilling process using Grey based - Taguchi method. To determine the optimal combination of drilling parameters using grey relational analysis. To identify the optimum drilling parameters based on the minimum burr size, surface roughness, thrust force and roundness error. Make use of other published work in the literature in order to prove the effectiveness of the proposed Grey based-Taguchi approach in minimum quantity lubricant mixing with water technique drilling for Aluminum 6061 alloys. To confirm the experimental results by statistical analysis using ANOVA technique

Experimentation

Experimental Design: Experimental design is a scientific approach to planning an experiment using statistical techniques [17,18]. The process of planning an experiment is performed so that the experimental data collected can be analyzed in order to obtain valid and objective conclusions. In general, experimental data are subject to experimental errors and statistical approach is the only objective approach to analyze such data. Three basic principles of experimental design that must be emphasized when designing an experiment are the principles of replication, randomization, and blocking.

Replication is the repetition of an experiment. It allows the experimenter to estimate the experimental error, which is used as a basis for determining whether observed differences in the data are really statistical differences. In addition, experimenter is usually interested in estimating the effect of different levels of experimental factors. More importantly, replication enables the experimenter to estimate and model variability in terms of standard deviation or variance.

Randomization is an important concept underlying the use of statistical methods in experimental design. It should be applied to two aspects of the experiment, which are i. to randomly allocate the experimental units (e.g. work piece, material, etc.) to different experimental settings, and ii. to randomly determine the order in which the individual runs are to be performed. Statistical methods usually require that the experimental errors be independently distributed random variables. Randomization helps assuring that this assumption is met. Furthermore, properly applying randomization would balance out the effect of extraneous factors that may be present.

Blocking is a technique used to increase the precision of an experiment's result. A block is a portion of the experimental units that is more homogenous than the entire set of experimental units. Blocking involves making comparisons among the conditions of interest in the experiment within each block.

Drilling Experiment: Machining processes, in general, have many parameters that significantly affect the performance of the processes. The influences could be on the machine performance, the tool used to perform the processes, and/or the products produced. In any machining process, like any production machine, the ultimate goal is to produce high quality products with minimal cost. The primary objective of the drilling experiment conducted in this paper is to establish a relationship between the quality of the machined holes and machining variables. This is because, to the best of the authors' knowledge, there is no relationship (i.e. empirical or physics models) that has been established for predicting the quality of drilled holes by using the machining parameters. In general, machining processes have numerous parameters. Some parameters related to the machine such as machine dynamics and accuracy, other parameters related to the tool such as the ability of the tool to perform a cut with certain cutting conditions, and finally parameters related to the work pieces such as the mechanical and physical properties of the work piece materials, and the geometry of the work piece.

Figure.8
Experimental setup for Drilling of Al 6061 Alloy

For the drilling process, as shown in figure.8 in particular, there are many methods used to produce a hole. The first step is to machine a center for the hole using combination center tool. The depth of the center is a function of the diameter of the hole. Depending on the diameter and length of the hole, the procedure to produce the hole varies. The diameter of the hole could be machined using a drill with the same diameter, or the hole could be machined in two or more drilling sequences by using drills with different sizes to reach the desired diameter of the hole. On the other hand, depending on the depth of the hole, it could be drilled in one sequence or one tool feed, or using peck procedure.

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 Aluminum 6061 alloy. 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. Taguchi-Grey based method can be chosen based on the multi performance characteristics of the drilling and the optimal combination of parameters to optimize the burr size (height and thickness), hole quality (surface roughness and roundness error) thrust force and torque. 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.

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