International Journal of Innovation and Scientific Research
ISSN 2351-8014 Vol. 13 No. 1 Jan. 2015, pp. 126-135

http://www.ijisr.issr-journals.org/

Experimental Investigations and Taguchi Analysis with Drilling Operation: A Review

***Rajiv Chaudhary*[1]*, M. S. Ranganath*[2]*, R. C. Singh*[1]*, and Vipin*[2]**

[1]Mechanical Engineering,
Delhi Technological University, Delhi, India

[2]Production and Industrial Engineering,
Delhi Technological University, Delhi, India

ABSTRACT: Surface Roughness is an important aspect in mechanical engineering design depending on the application of the component in usage. Friction, wear and power transmission depend on material surface and contact environment. Objective Consideration may be with respect to aesthetic view, stress condition, precision fits, smooth motion etc. However, the critical constraints are surface roughness, tolerances and nominal size for the selection criteria of the parts. Since Taguchi method systematically reveals the complex cause and evolves the relationship between design parameters along with taking consideration of performance. Many researchers have used Taguchi techniques for design of experimental studies. The present study focusses on the investigations made on drilling using Taguchi Techniques.

KEYWORDS: Drilling, Precision, Wear, Vibration, Thrust, Torque, Taguchi Analysis.

1 INTRODUCTION

Drilling operation can be described as a process where a multi-point tool is used for unwanted materials removal to produce a desired hole. It is an important metal cutting operations with which holes are produced in components made of metallic and non-metallic materials. The cylindrical holes of required diameter are cut out of the component with a cutting tool, called drill bit. The different machines available are portable drilling, radial drilling, upright drilling and multiple spindle drilling etc. It is essential to optimize quality and productivity of with respect to drilling operation as it being very common operation in manufacturing. Many researchers have worked on drilling operation. Optimum values of input parameters such as speed, feed, as well as different cooling condition are calculated to obtain required surface roughness value with maximum material removal rate. Most of the research in the area of drilling are mainly related to hole precision, thrust force, torque, vibrational wear, work material characteristics and drill material studies. Drill wear is an important issue since wear on drill affects the hole quality and tool life of the drill. A considerable amount of research has been done on the effects of drilling on composite materials. Most of these have been targeted toward the study of delamination. Surface Roughness is indicated as an important design feature in many situations such as parts subject to fatigue loads, precision fits, along with aesthetic requirements. In addition to tolerances, surface roughness imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning. Since Taguchi method systematically reveals the complex cause and effect relationship between design parameter along with performance, so many researchers have used Taguchi techniques for design of experimental studies. The present study focusses on the investigations made on drilling using Taguchi Techniques.

2 LITERATURE REVIEW

Chih-Wei Chang and Chun-Pao Kuo [7] evaluated laser-assisted machining (LAM) as an economically viable process for manufacturing precision aluminum oxide ceramic parts. It was locally heated by an intense laser source prior to material removal, LAM lead to higher material removal rates, as well as improved control of workpiece properties and geometry. For assessing the feasibility of the LAM process and better understanding its governing physical phenomena, experiments were conducted to obtain different measures of surface roughness for Al2O3 workpieces machined by laser-assisted turning using a Nd:YAG laser. The experimental results were analyzed using the Taguchi method, which facilitated identification of optimum machining conditions. The findings indicated that rotational speed, with a contribution percentage as high as 42.68%, had the most dominant effect on LAM system performance, followed by feed, depth of cut, and pulsed frequency. LAM's most important advantage was its ability to produce much better workpiece surface quality than conventional machining, together with larger material removal rates (MRR) and moderate tool wear. Irfan Khan et al, [19] presented the use of Taguchi method to achieve the minimum hole size expansion in drilling of acrylic sheet. The purpose of this paper was to investigate the effect of cutting parameters, such as cutting speed and feed rate, and point angle on hole size(without considering the thermal effect). The analysis of experiments showed that Taguchi method can successfully verify the optimum cutting parameters. The level of the best of the cutting parameters on the hole expansion was determined. It was also found that cutting speed was the major factor on which hole size expansion depends. It was lower with higher cutting speed. Feed was another important factor which causes hole expansion but its dependence was lesser as compared to the speed. Tool angle was the most complex factor. It was suggested that for achieving minimum hole expansion on the Acrylic always higher feed rates and higher cutting speeds were preferred with non-standard angles.

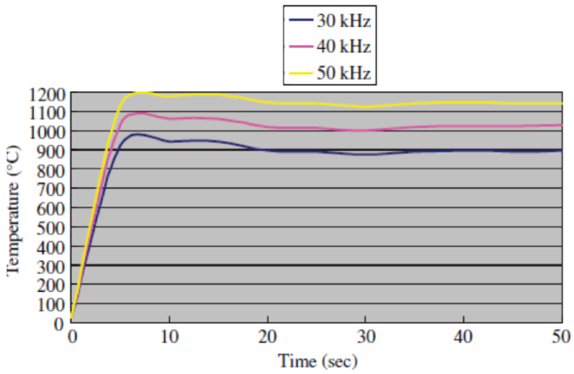

Fig. 1. Variation of surface temperature.[7]

Fig 2: Final Image of work piece [50]

Erkan Bahçe and Cihan Ozel [16] investigated, BUEs arisen on the cutting edges and the effect of drilling parameters (rotation speed, feed rate, drill diameter and point angle) on the surface roughness of the work piece experimentally in the drilling process of Al 5005 alloy on CNC milling machine. The objective of the paper is to obtain an optimal setting of the drilling process parameter (cutting speed, feed) resulting in an optimizing axial force in drilling on mild steel. The effect of drilling process parameter on axial force using Taguchi's parameter design approach. Results indicates that the selected process parameter affect the machining characteristics. The result indicate that the selected process parameter affect the mean and the variance of the optimal force. The percent contribution of parameters as quantified in the S/N pooled AVOVA. The percentage contribution of the parameters reveal that the influence of the feed (64.72%) in controlling both mean and variation of axial force is significantly larger than that of cutting speed(33.38%).The predicted optimum axial force is (720N).The result have been validated by confimation experiments.

C.C. Tsao, H. Hocheng [6] predicted and evaluated thrust force and surface roughness in drilling of composite material using candle stick drill. The approach was based on Taguchi method and the artificial neural network. The experimental results indicated 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. In their study, the objective was to establish a correlation between the feed rate, spindle speed and drill diameter with the induced thrust force and surface roughness in drilling composite laminate. The correlations were obtained by multi-variable regression analysis and radial basis function network (RBFN) and compared with the experimental results. The results indicated the RBFN is more effective than multi-variable regression analysis. Turgay Kivak et al, [45] investigated the effect of cutting parameters on the hole quality (circularity and hole iameter) and tool wear during the drilling of super alloy Inconel 718 with coated and uncoated carbide drills. Drilling tests were carried out with uncoated and TiN and TiAlN coated carbide drills of 5 mm diameter using a CNC vertical machining center under dry cutting conditions by drilling blind holes of 8 mm depth and employing four different cutting speeds (10, 12.5, 15, 17.5 m/min) and three different feed rates (0.05, 0.075, 0.1 mm/rev). Regarding hole diameters and the circularity measurements a comparison has been made in terms of the quality of the hole between cutting tools. It was observed that there was a decrease of tool performance and hole quality at high cutting speed and feed rate combinations. A serious increase in tool wear was observed when increasing cutting speed. The Utmost wear type was seen in the form of flank wear and chisel edge wear. Sharad Kumar Shukla and Akhilesh Lodwal [41] proposed to analyse the vibration on radial drilling machine using piezoelectric sensor. Piezoelectric sensors are case mounted using either a permanent bolt, portable magnet or adhesive to hold them in place. They will measure the vibration of the machine and produce output in the form of voltage or current proportional to the vibration. The study reveals that the intensity of vibration varies from point to point. Present work gives the result for a speed of 660 rpm on mild steel using 12 mm drill diameter. The maximum intensity of vibration is at casing due to minimum deflection and vibration decreases at spindle, job, H-V joint and minimum at base. At last on the basis of analysis we conclude that, due to damping (pad) vibration is minimum at the base and maximum at the casing.

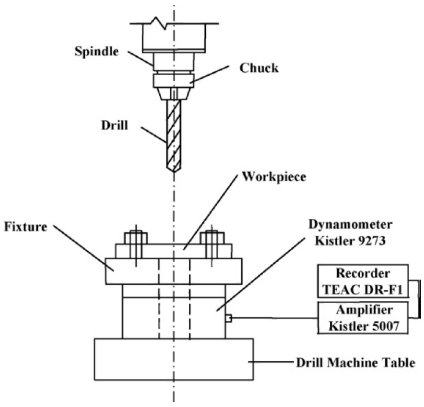

Fig. 3 – Schematic of drilling set-up [6]

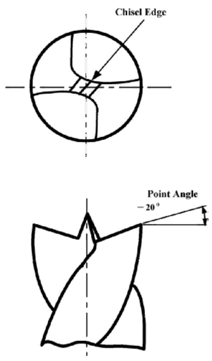

Fig. 4 – Geometry of candle stick drill [6]

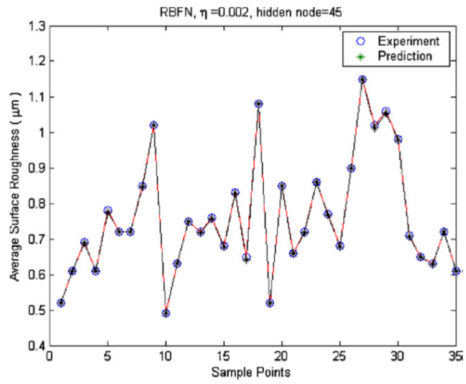

Fig. 5 – Comparison of surface roughness between prediction and experiment. [6]

M. Pirtini and I. Lazoglu [31] in their research, developed a new mathematical model based on the mechanics and dynamics of the drilling process for the prediction of cutting forces and hole quality. A new method was also proposed in order to obtain cutting coefficients directly from a set of relatively simple calibration tests. Moreover, once the drill parameters and cutting conditions are given, by considering the cutting forces and the structural dynamics of the tool and spindle system, the dynamic model can predict the radial displacements under low frequency vibration. The model was able to simulate the cutting forces for various cutting conditions in the process planning stage. In the structural dynamics module, measured frequency response functions of the spindle and tool system were integrated into the model in order to obtain drilled hole profiles. Therefore, in addition to predicting the forces, the new model allowed the determination and visualization of drilled hole profiles in 3D and to select parameters properly under the manufacturing and tolerance constraints. An extensive number of experiments were performed to validate the theoretical model outputs with the measured forces and CMM hole profiles. It was also observed that model predictions agree with the force and CMM measurements. Therefore, hole quality are also predictable in advance. It was also observed that they agree reasonably well. In today's competitive market, process simulator based on the mechanics and dynamics of drilling as presented in this paper helps to decrease cycle times and allows achieving tight hole tolerances.

M Nouari et al. [30] provided necessary information about the main factors affecting the hole quality i.e. cutting speed, temperature, feed rate, geometrical parameters as well as the influence of the cutting conditions and the temperature on the tool life in drilling. They suggested that improvement of surface quality and dimensional accuracy of the holes can be got at large cutting speed and a weak feed rate. Kanai and Kanda [25] suggested that different types of drill wear could be recognized as outer corner wear, flank wear, margin wear, crater wear, chisel wear and chipping at the lip. E. Wardany et al. [13] reported that drilling is a complex operation when compared to other machining operation as the two points of the drill wear alternately till they both have zero clearance at the margin, and become lodged within work piece. Riza A. Motorcu [35] investigated the surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools was investigated in terms of main cutting parameters such as cutting speed, feed rate, depth of cut in addition to tool nose radius, using a statistical approach (see Table 6). Machining tests were carried out with PVD coated ceramic cutting tools under different conditions. An orthogonal design, signal-to-noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness. Show-Shyan Lin *et al.* [42], investigated the optimization of computer numerical control (CNC) boring operation parameters for aluminum alloy 6061T6 using the grey relational analysis (GRA) 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 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 found. In the work done by A. Çiçek [2], the effects of deep cryogenic treatment and drilling parameters on surface roughness and roundness error were investigated in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. In addition, optimal control factors for the hole quality were determined by using Taguchi technique. Two cutting tools, cutting speeds and feed rates were considered as control factors, and L8(23) orthogonal array was determined for experimental trials, for the input parameters.

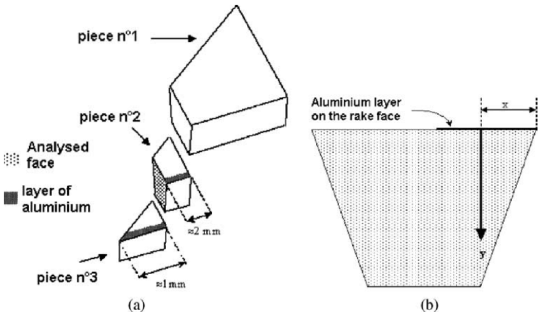

Fig. 6. Section of the carbide tool insert analysed. [30]

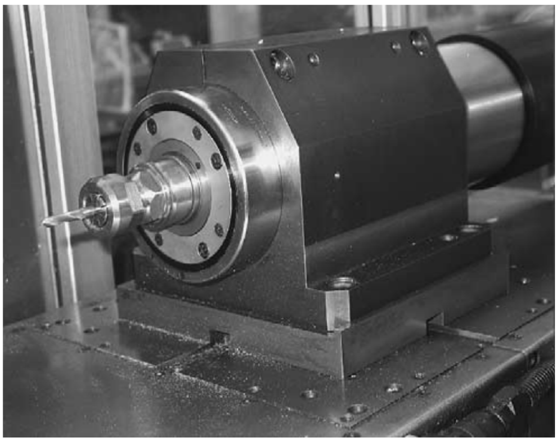

Fig. 7. Instrumented drilling bench.[30]

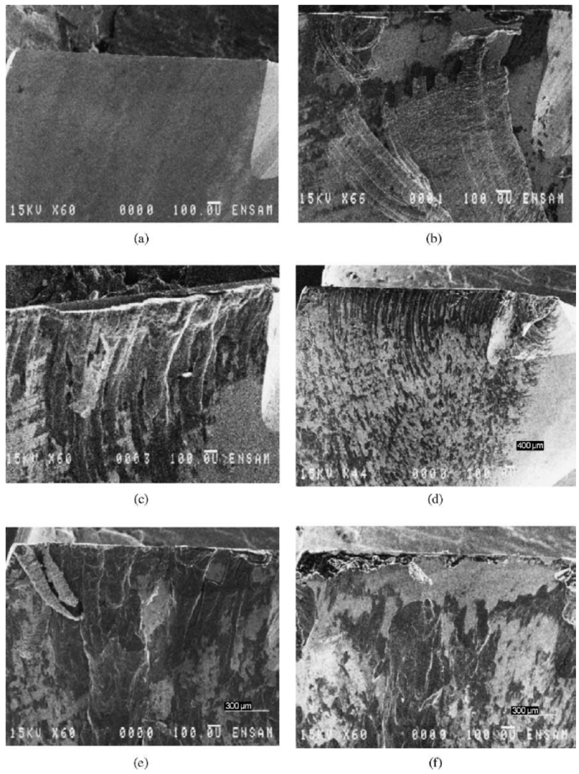

Fig. 8. SEM observations of the aluminium adhesion on the surface of the optimised carbide drill. The cutting conditions are: V = 60 m/min;f = 0.16 m/min; (a) new drill, (b) after 1 hole, (c) after 10 holes, (d) after 48 holes, (e) after 96 holes, (f) after 200 holes. [30]

Reddy Sreenivasalu and Ch.Srinivasa Rao [10], investigated the effect of drilling parameters on surface roughness and roundness error in drilling of Al6061 alloy with HSS twist drill. Optimal control factors for hole quality were determined using Taguchi grey relational analysis. Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio were considered as the control factors.L18 orthogonal array was determined for experimental trials. Grey relational analysis was employed to minimize surface roughness and roundness error. In another similar work, Yogendra Tyagi, Vedansh Chaturvedi and Jyoti Vimal [50] discussed the feasibility of machining Mild Steel by CNC drilling machine with a HSS Tool by applying taguchi methodology. The signal-to-noise ratio applied to find optimum process parameter for CNC drilling machining. A L9 orthogonal array and analysis of variance (ANOVA) were used to study the performance characteristics of machining parameter (spindle speed, feed, and depth) with consideration of good surface finish as well as high material removal rate (MRR). Multiple regression equations were formulated for estimating predicted value for surface roughness and material removal rate.

Dinesh Kumar et al, [11], described the Taguchi technique for optimization of surface roughness in drilling process. In their investigation, Taguchi technique was used as one of the method for minimizing the surface roughness in drilling mild steel. The purpose of this study is to investigate the influence of cutting parameters, such as cutting speed and feed rate, and point angle on surface roughness produced when drilling Mild steel. In the study conducted by Anil Jindal and V. K. Singla [3], the Taguchi optimization methodology is applied to optimize cutting parameters in drilling of glass fibre reinforced composite (GFRC) material. Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. This procedure eliminates the need for repeated experiments, time and conserves the material by the conventional procedure. B. Shivapragash et al. [4] focused on multiple response optimization of drilling process for composite Al-TiBr2. The study provided to minimize the damage events occurring during drilling process for composite material. A statistical approach used to analyze experiment data. Taguchi method with grey relational analysis was used to optimize the machining parameters with multiple performance characteristics in drilling of MMC Al-TiBr2. The results shows that the maximum feed rate, low spindle speed are the most significant factors which affect the drilling process and the performance in the drilling process can be effectively improved by using this approach.

E Capello and V Tagliaferri [12] studied the effect of the drilling on the residual mechanical behaviour of glass fibre reinforced plastic (GFRP) laminates when the hole is subjected to bearing load. In the first part, the influence of drilling parameters on the type and extension of the damage is analyzed. The damage was described at the macro level (delaminated area) and at the micro level (cracks, fibre-matrix debonding, etc.). The Design of Experiments and Analysis of Variance techniques are used in order to determine the statistical influence of the drilling parameters on the delamination area. Moreover, the effects of drilling with or without a support beneath the specimens are analyzed and discussed. Push-down delamination was mainly affected by the feed rate, by the presence of support beneath the specimen, and by the twist drill temperature. C.C. Tsao and H. Hocheng [8] studied the effects of backup plate on delamination in drilling composite materials using saw drill and core drill. The critical drilling thrust force at the onset of delamination is calculated and compared with that without backup. Saw drills and core drills produce less delamination than twist drills by distributing the drilling thrust toward the hole periphery. Delamination can be effectively reduced or eliminated by slowing down the feed rate when approaching the exit and by using back-up plates to support and counteract the deflection of the composite laminate leading to exit side delaminations. The use of the back-up does reduce the delamination in practice, which its effects have not been well explained in analytical fashion. C. C. Tsao and H. Hocheng [9] studied prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill. The approach is based on Taguchi's method and the analysis of variance (ANOVA). An ultrasonic C-Scan to examine the delamination of carbon fibre-reinforced plastic (CFRP) laminate is used in this paper. The experiments were conducted to study the delamination factor under various cutting conditions. The experimental results indicate that the feed rate and the drill diameter are recognized to make the most significant contribution to the overall performance. The objective was to establish a correlation between feed rate, spindle speed and drill diameter with the induced delamination in a CFRP laminate. The correlation was obtained by multi-variable linear regression and compared with the experimental results.

E. S. Lee [15] studied the machinability of GFRP by means of tools made of various materials and geometries was investigated experimentally. By proper selection of cutting tool material and geometry, excellent machining of the work piece is achieved. The surface quality relates closely to the feed rate and cutting tool. When using glass fibre reinforced plastics (GFRP) it is often necessary to cut the material, but the cutting of GFRP is often made difficult by the delamination of the composite and the short tool life. E. Ugo. Enemuoh et al, [14] studied new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material is presented. The approach is based on a combination of Taguchi's experimental analysis technique and a multi objective optimization criterion. The optimization objective includes the contributing effects of the drilling performance measures: delamination, damage width, surface roughness, and drilling thrust force. A hybrid process model based on a database of experimental results together with numerical methods for data interpolation are used to relate drilling parameters to the drilling performance measures. Case studies are presented to demonstrate the application of this method in the determination of optimum drilling conditions for damage-free drilling in BMS 8-256 composite laminate. H. Hocheng and C.C. Tsao [18] studied the critical thrust force at the onset of delamination, and compares the effects of these different drill bits. The results confirm the analytical findings and are consistent with the industrial experience. Ultrasonic scanning is used to evaluate the extent of drilling-induced delamination in fiber-reinforced materials. The advantage of these special drills is illustrated mathematically as well as experimentally, that their thrust force is distributed toward the drill periphery instead of being concentrated at the center. The allowable feed rate without causing delamination is also increased. The analysis can be extended to examine the effects of other future innovative drill bits.

R. S. Jadoun et al, [23] studied the effect of process parameters on production accuracy obtained through ultrasonic drilling of holes in alumina based ceramics using silicon carbide abrasive. Production accuracy in ultrasonic drilling involved both dimensional accuracy (hole oversize) and formed accuracy (out-of roundness and conicity). The parameters considered were workpiece material, tool material, grit size of the abrasive, power rating and slurry concentration. Taguchi's optimization approach was used to obtain the optimal parameters. The significant parameters were also identified and their effect on oversize, out-of-roundness and conicity were studied. The results obtained were validated by conducting the confirmation experiments. Fig. 10 shows a) Bar graphs showing percentage contributions of significant process parameters for hole oversize. b) Bar graphs showing percentage contributions of significant process parameters for out of roundness data. c) Bar graphs showing percentage contributions of significant process parameters for conicity. A Workpiece, B tool, C grit size, D power rating, E slurry concentration. I. Singh and N. Bhatnagar [43] studied to correlate drilling-induced damage with drilling parameters. Tool point geometry is considered a major factor that influences drilling-induced damage. Experiments were conducted and drilling induced damage was quantified using the digital image processing technique. The results also reestablished the cutting speed to feed ratio as an important variable that influences drilling-induced damage. Mathematical models for thrust, torque, and damage are proposed that agree well with the experiments. J. Rubioa et. al [39] studied HSM to realize high performance drilling of glass fibre reinforced plastics (GFRP) with reduced damage. In order to establish the damage level, digital analysis is used to assess delamination. A comparison between the conventional (Fd) and adjusted (Fda) delamination factor is presented. The experimental results indicate that the use of HSM carried out for drilling GFRP ensuring low damage levels.

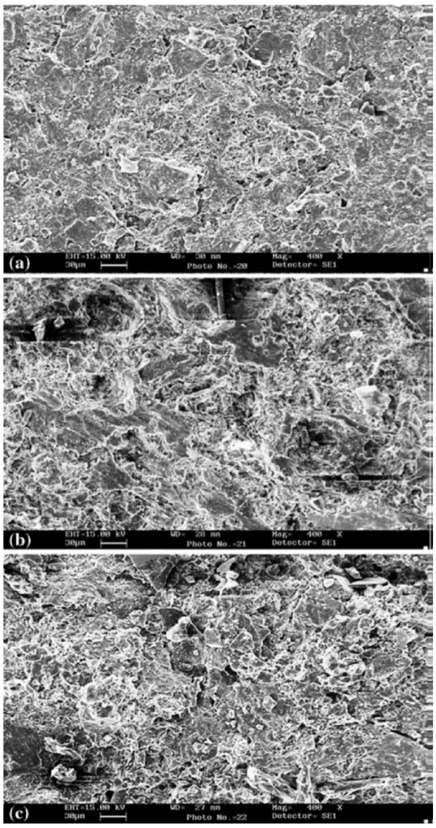

Fig. 9 SEM photographs of workpiece materials before drilling a 50% Alumina, b 60% Alumina and c 70% Alumina [23]

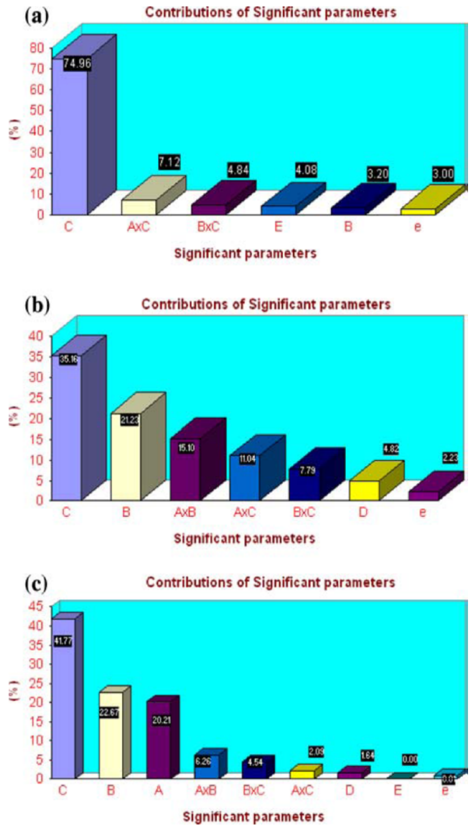

Fig. 10 Bar graphs. A Workpiece, B tool, C grit size, D power rating, E slurry concentration. [23]

Drilling is probably the machining process most widely applied to composite materials; nevertheless, the damage induced by this operation may reduce drastically the component performance. J. Mathew et al, [22] studied that thrust is a major factor responsible for delamination and it mainly depends on tool geometry and feed rate. Trepanning tools, which were used in this study, were found to give reduced thrust while making holes on thin laminated composites. In this work the peculiarities of trepanning over drilling of unidirectional composites has been emphasized. The models for prediction of critical thrust and critical feed rate at the onset of delamination during trepanning of uni-directional composites based on fracture mechanics and plate theory also have been presented. Mathematical models correlating thrust and torque with tool diameter and feed rate have been developed through statistically designed experiments and effect of various parameters on them have been discussed. It is observed that sub-laminate thickness is the most decisive parameter from the viewpoint of critical feed rates. J. Paulo Davim and Pedro Reis [20] studied the cutting parameters (cutting velocity and feed rate) on power (*P*c), specific cutting pressure (*K*s), and delamination in carbon fibre reinforced plastics (CFRPs). A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in an autoclave CFRP composite laminate. The analysis of variance was preformed to investigate the cutting characteristics of CFRPs using cemented carbide (K10) drills with appropriate geometries. The objective was to establish a correlation between cutting velocity and feed rate with the power (*P*c) specific cutting pressure (*K*s) and delamination factor (*F*d) in a CFRP material. Finally, this correlation was obtained by multiple linear regressions. L-B Zhang, L-J Wang and X-Y Liu [29] studied the analysis for multidirectional composite laminates is based on linear elastic fracture mechanics (LEFM), classical bending plate theory and the mechanics of composites. This paper presents a general closed-form mechanical model for predicting the critical thrust force at which delamination is initiated at different ply locations. Good correlation is observed between the model and the experimental results. L.M.P. Durao et.al [28]studied to minimization of axial thrust force during drilling reduces the probability of delamination onset, as it has been demonstrated by analytical models based on linear elastic fracture mechanics (LEFM). A finite element model considering solid elements of the ABAQUS software library and interface elements including a cohesive damage model was developed in order to simulate thrust forces and delamination onset during drilling. Thrust force results for delamination onset are compared with existing analytical models. N.S. Mohan et al, [32] studied the drilling parameters and specimen parameters evaluated were speed, feed rate, drill size and specimen thickness on FRP. A signal-to-noise ratio is employed to analyze the influence of various parameters on peel up and push down delamination factor in drilling of glass fibre reinforced plastic (GFRP) composite laminates. The main objective of this study was to determine factors and combination of factors that influence the delamination using Taguchi and response surface methodology and to achieve the optimization machining conditions that would result in minimum delamination. From the analysis it is evident that among the all significant parameters, specimen thickness and cutting speed have significant influence on peel up delamination and the specimen thickness and feed have more significant influence on push down delamination.

Mustafa Kurt et al, [24] investigated the effect of cutting parameters and changes in the diameter of the drill on drilling temperature, cutting forces and surface roughness in dry drilling of Al 2024 alloy using diamond like carbon coated drills. The cutting temperature was measured by using a thermocouple. Kistler dynamometer was used for the measurements of the cutting forces during drilling process. The surface roughness of drilled hole surface was determined by using MARH-Perthometer. Finally, the Taguchi technique was employed for the optimization of drilling process. R. Stone and K. Krishnamurthy [36] studied the linear-elastic fracture mechanics theory which proposed critical cutting and thrust forces in the various drilling regions that can be used as a guide in preventing crack growth or delamination. Using these critical force curves as a guide, a thrust force controller was developed to minimize the delamination while drilling a graphite epoxy laminate. A neural network control scheme was implemented which re network identifier to model the drilling dynamics and a neural network controller to learn the relationship between feed rate and the desired thrust force. Experimental results verifying the validity of this control approach as well as the robustness of the design are presented. Visual measurements of the delamination zones were used to quantify the benefits of the thrust force controlled drilling process versus the conventional constant feed rate drilling process. Redouane Zitoun and Francis Collombe [37] studied a numerical FE analysis is proposed to calculate the thrust forces responsible for the defect at the exit of the hole during the drilling phase of long-fibre composite structures, within a quasi-static framework. This numerical model compared with the analytical models studied in the literature – takes into account the tool point geometry as well as the shear force effects in the laminate. F. Lachaud, et. al [17] studied the drilling with a twist drill and a specific cutting tool of structural thin backing plates in carbon/epoxy. The possibility to manufacture carbon/epoxy with a conventional cutting tool was analysed and the limits of the twist drill were shown. Consequently we defined a specific cutting tool. Series of comparative experiments were carried out using a conventional twist drill and this specific cutting tool. The results shown the capabilities of the 18 specific cutting tool because several defects and damages usually encountered in twist drilled holes were minimised or avoided (entrance damage, roundness and diameter defects and plate exit damage). Redouane Zitoune et al, [38] studied the parametric influences on thrust force, torque as well as surface finish, the experimental results shown that the quality of holes can be improved by proper selection of cutting parameters. This is substantiated by monitoring thrust force, torque, surface finish, circularity and hole diameter. For the CFRP, the circularity is found to be around 6 lm at low feed rates, when the feed is increased the circularity increases to 25 lm. The wear tests carried out show that, during first 30 holes, thrust force in CFRP undergoes a more important increase (90%) than thrust force of aluminium (6%).

S.R. Karnik et.al [26] studied the delamination behaviour as a function of drilling process parameters at the entrance of the CFRP plates. The delamination analysis in high speed drilling is performed by developing an artificial neural network (ANN) model with spindle speed, feed rate and point angle as the affecting parameters. A multilayer feed forward ANN architecture, trained using error-back propagation training algorithm (EBPTA) is employed for this purpose. Drilling experiments were conducted as per full factorial design using cemented carbide (grade K20) twist drills that serve as input–output patterns for ANN training. The validated ANN model is then used to generate the direct and interaction effect plots to analyze the delamination behavior. The simulation results illustrate the effectiveness of the ANN models to analyze the effects of drilling process parameters on delamination factor. The analysis also demonstrates the advantage of employing higher speed in controlling the delamination during drilling. S. C. Lin and I. K. Chen [40] studied the effects of increasing cutting speed on drilling characteristics of carbon fiber-reinforced composite materials. The effects of increasing cutting speed ranging from 9550 up to 38650 rev min”1 (from 210 to 850 m min”1) on average thrust force, torque, tool wear and hole quality for both multifacet drill and twist drill are studied. It was found that increasing cutting speed will accelerate tool wear. And the thrust force increases as drill wear increases. Although tool geometries change quickly due to the fast development of tool wear and the thrust force increases drastically as cutting speed increases, an acceptable hole entry and exit quality is maintained. This is because relatively small feeds are used in these tests. It was concluded that tool wear was the major problem encountered when drilling carbon fiber reinforced composite materials at high speed. U. A. Khashaba studied the [27] Delamination-free in drilling different fiber reinforced thermoset composites was the main objective of research. Therefore the influence of drilling and material variables on thrust force, torque and delamination of GFRP composites was investigated experimentally. Drilling variables were cutting speed and feed. Material variable include matrix type, filler and fibre shape. Drilling process was carried out on cross-winding/polyester, continuous-winding with filler/polyester, chopped/polyester, woven/polyester and woven/epoxy composites. A simple inexpensive accurate technique was developed to measure delamination size. The thrust forces in drilling continuous-winding composite are more than three orders of magnitude higher than those in the crosswinding composites. Delamination, chipping and spalling damage mechanisms. A. Çiçek et al, [1] investigated the effects of deep cryogenic treatment and drilling parameters on surface roughness and roundness error were in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. In addition, optimal control factors for the hole quality were determined by using Taguchi technique. Two cutting tools, cutting speeds and feed rates were considered as control factors, and L8 (23) orthogonal array was determined for experimental trials. Multiple regression analysis was employed to derive the predictive equations of the surface roughness and roundness error achieved via experimental design. Minimum surface roughness and roundness error were obtained with treated drills at 14 m/min cutting speed and 0.08 mm/rev feed rate. Confirmation experiments showed that Taguchi method precisely optimized the drilling parameters in drilling of stainless steel.

U.A. Khashaba et al, [46] studied the effects of the drilling parameters, speed, and feed, on the required cutting forces and torques in drilling chopped composites with different fibre volume fractions. Three speeds, five feeds, and five fiber volume fractures are used in this study. The results show that feeds and fibre volumes have direct effects on thrust forces and torques. On the other hand, increasing the cutting speed reduces the associated thrust force and torque, especially at high feed values. Using multivariable linear regression analysis, empirical formulas that correlate favorably with the obtained results have been developed. These formulas would be useful in drilling chopped composites. The influence of cutting parameters on peel-up and push-out delaminations that occurs at drill entrance and drill exit respectively the specimen surfaces have been investigated. No clear effect of the cutting speed on the delamination size is observed, while the delamination size decreases with decreasing the feed. Delamination-free in drilling chopped composites with high fibre volume fraction remains as a problem to be further investigated. Velayudham A, Krishnamurthy R and Soundara pandian T [48] studied the dynamics of drilling of high volume fraction glass fibre reinforced composite. At high fibre volume, fibres do not show much relaxation and normal hole shrinkage associated with polymeric composites was not observed during drilling. Peak drilling thrust, dimension of holes drilled and vibration induced during drilling are observed to correlate with each other. Vibrations study has been attempted through wavelet packet transform and the results demonstrated its capability in signal characterisation.V. Krishnaraj, S. Vijayarangan and A. Ramesh Kumar [47] studied the damage generated during the drilling of Glass Fibre Reinforced Plastics (GFRP) which was detrimental for the mechanical behaviour of the composite structure. This work was focused on analysing the influence of drilling parameters (spindle speed and feed) on the strength of the GFR woven fabric laminates and further tostudy the residual stress distribution around the hole after drilling. Holes were drilled at the centre of the specimens in a CNC machining centre using 6 mm diameter micro grain carbide drill for various spindle speeds (1000 4000 rpm) and feed rates (0.02, 0.06, 0.10 and 0.20 rev/min). Degree of damage depends on the feed rate and spindle speed. Experimental results indicate that failure strength and stress concentration are related to the drilling parameters and a drilling parameter (3000 rpm and 0.02 mm/rev), which gives better mechanical strength. Wen-Chou Chen [49] studied the concept of delamination factor *F*d (i.e. the ratio of the maximum diameter Dmax. in the damage zone to the hole diameter *D*)is proposed to analyze and compare easily the delamination degree in the drilling of carbon fiber-reinforced plastic (CFRP) composite laminates. Experiments were performed to investigate the variations of cutting forces with or without onset of delamination during the drilling operations. The effects of tool geometry and drilling parameters on cutting force variations in CFRP composite materials drilling were also experimentally examined. The experimental results shown the delamination free drilling processes may be obtained by the proper selections of tool geometry and drilling parameters.

3 Conclusions

Out of the studies made the important conclusions may be drawn as: In industrial applications, it is essential to determine the optimal cutting conditions for a given tool–workpiece combination. Taguchi technique has proved to be the best tool for determining the optimum machining conditions, improving performance characteristics, their main effects and in finding out other significant factors. The multiple performance characteristics such as tool life, cutting force, surface roughness as well as the overall productivity can be improved by using Taguchi Techniques. It can also be concluded that at quite large cutting speeds with smaller feed rate, good surface quality along with dimensional accuracy can be achieved.

References

[1] A.Cicek, T. Kivak and G. Samtas, Application of Taguchi Method for Surface Roughness and Roundness Error in Drilling of AISI 316 Stainless Steel, Journal of Mechanical Engineering, Vol. 58, No. 3, 2012, pp. 122-129.

[2] Adem Cicek, Step Based Geometric And Topological Similarity Assessment Of Mechanical Parts, Mathematical and Computational Applications, Vol. 12, No. 3, pp. 141-150, 2007.

[3] Anil Jindal, Dr. V. K. Singla, Experimental Investigation of Process Parameters in drilling operation using different software technique, Research Cell: An International Journal of Engineering Sciences ISSN: 2229-6913 Issue July 2011, Vol. 1/135-154

[4] B. Shivapragash, K. Chandrasekharan, C. Parthasarathy and M. Samuel, Multiple Response Optimizations in Drilling Using Taguchi and Grey Relational Analysis, International Journal of Modern Engineering Research, Vol. 3, No. 2, 2013, pp.765-768.

[5] Bonifacio, M.E.R., & Diniz, A.E. (1994). Correlating tool wear, tool life, surface roughness and tool vibration in finish turning with coated carbide tools. Wear, 173, 137-144.

[6] C. Tsao and H. Hocheng, Evaluation of thrust force and surface roughness in drilling composite material using Taguchi analysis and neural network, Journal of Materials Processing Technology, Vol. 203, No. 1-3, 2008, pp. 342-348.

[7] Chih-Wei Chang, Chun-Pao Kuo, Evaluation of surface roughness in laser-assisted machining of aluminum oxide ceramics with Taguchi method, International Journal of Machine Tools & Manufacture 47 (2007) 141–147

[8] C.C. Tsao, H. Hocheng, The effect of chisel length and associated pilot hole on ination when drilling composite materials, International Journal of Machine Tools & Manufacture 43 (2003) 1087–1092

[9] C.C. Tsao, The effect of pilot hole on delamination when core drill drilling composite materials, International Journal of Machine Tools and Manufacture, 2006, Vol. 46, No. 12-13, pp. 1653-1661.

[10] Ch.Deva Raj Reddy Sreenivasulu, Dr. Ch.Srinivasa Rao, Optimization of operating parameters to minimize burr size in drilling using taguchi method & grey relational analysis for A1 6061 ,International Conference on Challenges and Opportunities in Mechanical Engineering and Management Studies (ICCOMIM), Bonfring/829-833

[11] D. Kumar, L.P. Singh and G. Singh, , Operational Modeling For Optimizing Surface roughness in Mild Steel Drilling Using Taguchi Technique, International Journal of Research in Management, Vol. 2, No. 3, 2012, pp. 66-77.

[12] E. Capello and V. Tagliaferri, Drilling damage of GFRP and residual mechanical behavior- Part I: drilling damage generation, Journal of Composites Technology and Research, 2001, Vol. 23, No. 2, pp. 122-130.

[13] El-Wardany, T. I., Mohammed, E., Elbestawi, M. A.; “Cutting temperatures of ceramic tools in high speed machining of difficult-to-cut materials”, In: Int. J. Machine Tools and Manufacture, pp. 611-634; 1996; Vol. 36, no. 5,

[14] E. Ugo. Enemuoh, A. Sherif El-Gizawy, A.Chukwujekwu Okafor “An approach for development of damage-free drilling of carbon fiber reinforced thermosets”, International Journal of Machine Tools & Manufacture 41 (2001) pp.1795–1814

[15] E. S. Lee, Precision Machining of Glass Fibre Reinforced Plastics with Respect to Tool Characteristics, The International Journal of Advanced Manufacturing Technology, Vol 17, Issue 11,2011, pp 791-798

[16] Erkan Bahçe and Cihan Ozel (2013). Experimental Investigation of the Effect of Machining Parameters on the Surface Roughness and the Formation of Built Up Edge (BUE) in the Drilling of Al 5005, Tribology in Engineering, Dr. Hasim Pihtili (Ed.), ISBN: 978-953-51-1126-9, InTech, DOI: 10.5772/56027.

[17] F. Lachaud, R. Piquet, F. Collombet, L. Surcin,Drilling of Composite Structures, 52 (3–4) (2001), pp.511–516 GU J Sci,25(2):533-540 (2012)

[18] H. Hocheng, C.C. Tsao, Comprehensive analysis of delamination in drilling of composite materials with various drill bits, Journal of Materials Processing Technology 140 (2003) 335–339

[19] Irfan Khan, Dheeraj Luthra, Mukesh Verma, Sarabjot Singh, Selection of optimum Drilling Parameter in Drilling of commercial Acrylic sheet to achieve minimum Hole Expansion by using Taguchi Approach, International Journal of Engineering Science and Technology (IJEST), ISSN : 0975-5462,Vol. 4 No.04 April 2012/1256-1261

[20] J.P. Davim and P. Reis, Drilling carbon fiber reinforced plastic manufactured by auto clave experimental and statistical study, Materials and Design, Vol. 24, No. 5, 2003, pp. 315-324

[21] J.Z. Zhang, J.C. Chen and E.D. Kirby, Surface roughness optimization in an end-milling operation using the Taguchi design method, Journal of Materials Processing Technology, Vol. 184, No. 2007, 1-3, pp. 233-39.

[22] Jose Mathew, N Ramakrishnan, N K Naik, Investigations into the Effect of Geometry of a Trepanning Tool on Thrust and Torque During Drilling of GFRP Composites, Vol 91, Issues 1-3, 1999,pp1-11

[23] Jadoun R S, Pradeep Kumar, Mishra B K, Mehta R C S ,Parametric optimization for out-of-roundness of holes in ultrasonic drilling of engineering ceramics using the Taguchi method, INCARF 2003, IIT Delhi

[24] Kurt M., Kaynak Y. , Bakır B., Köklü U., Atakök G., Kutlu L., 2009,’’Experimental Investigation And Taguchi Optımızatıon For The Effect Of Cuttıng Parameters On The Drilling Of Al 2024-T4 Alloy With Diamond Like Carbon (DLC) Coated Drills’’, 5. Sixth International Advanced Technologies Symposium (IATS’09), Karabük, Turkey

[25] Kanai, M. and Kanda, Y. 1978. Statistical Charasteristics of Drill Wear and Drill Life for the Standardized Performance Tests. Annals of the CIRP, Vol. 27, No. 1,pp. 61.66.

[26] Karnik, S.R., V.N. Gaitonde, J.C. Rubio, A.E. Correia, A.M. Abrao and J.P. Davim, 2008. Delamination analysis in high speed drilling of carbon fiber reinforced plastics (CFRP) using artificial neural network model. Mater. Des., 29: 1768-1776. DOI: 10.1016/j.matdes.2008.03.014.

[27] Khashaba, U.A. ,2004. Delamination in Drilling GFR-Thermoset Composites, Composite Structures, 63, 313–327.

[28] L. M. P. Durão, J. M. R. S. Tavares, A. T. Marques, A. M. Baptista, A. G. Magalhães, Int. Journal of Materials and Product Technology, v. 32, (2008), p. 226.

[29] L.B. Zhang, L.J. Wang, X.Y. Liu, H.W. Zhao, X. Wang, H.Y. Luo,Mechanical Model for Predicting Thrust and Torque in Vibration Drilling Fibre-Reinforced Composite Materials, International Journal of Machine Tools & Manufacture, 41 (2001), pp. 641–657

[30] M. Nouari, G. List, F. Girot, D. Coupard, Experimental analysis and optimisation of tool wear in dry machining of aluminium alloys, Wear 255 (2003) 1359–1368

[31] M. Pirtini, I. Lazoglu, Forces and hole quality in drilling, International Journal of Machine Tools & Manufacture 45 (2005) 1271–1281

[32] Mohan, N.S., S.M. Kulkarni and A. Ramachandra, 2007. Delamination analysis in drilling process of GFRP composite materials. J. Mater. Process. Technol., 186: 265-271. DOI: 10.1016/j.jmatprotec.2006.12.043

[33] Ranganath M S, Vipin, Nand Kumar and R. Srivastava "Surface Finish Monitoring in CNC Turning Using RSM and Taguchi Techniques" International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 4 (9), 2014, pp 171-179

[34] Ranganath M S, Vipin, "Surface Finish Monitoring in CNC Turning Using DOE Techniques" International Journal of Modern Engineering Research Website: www.ijmer.com (ISSN 2249-6645, Vol 4 (9), 2014,

[35] R. Riza Motorcu, , The Optimization of Machining Parameters Using the Taguchi Method for Surface Roughness of AISI 8660 Hardened Alloy Steel. Journal of Mechanical Engineering, Vol.56, No. 6, 2010, pp. 391-401

[36] R. Stone and K. Krishnamurthy, Int. J. Machine Tools & Manufacture, v. 36 (1996), p. 985.

[37] Redouane Zitoune, Vijayan Krishnaraj and Francis Collombet, Study of drilling of composite material and aluminium stack, Composite Structures, 2010, Vol. 92, No. 5, pp. 1246-1255.

[38] Redouane Zitoune, Vijayan Krishnaraj, Belkacem Sofiane Almabouacif, Francis Collombet, Michal Sima, Alain Jolin "Influence of machining parameters and new nano-coated tool on drilling performance of CFRP/Aluminium sandwich", Composites: Part B 43 (2012) pp.1480–1488

[39] Rubioa,J. Campos, Abrao, A.M., Faria, P.E., Correia A. Esteves, DavimJ.Paulo, 2008. Effects of High Speed in the Drilling of Glass Fibre Reinforced Plastic: Evaluation of the Delamination Factor, International Journal of Machine Tools & Manufacture, 48, 715–720.

[40] S.C. Lin and I.K. Chen, Drilling of carbon fiber-reinforced composite material at high speed, Wear, 1999, Vol. 194, No. 1-2, pp. 156–162.

[41] Sharad Kumar Shukla and Akhilesh Lodwal ,Experimental Analysis Of Vibration On Radial Drilling Machine Using Piezoelectric Sensor, Bookman International Journal of Mechanical and Civil Engineering, Vol. 2 No. 1 Jan-Feb-Mar 2013/7-10

[42] Show-Shyan Lin, Ming-Tsan Chuang, Jeong-Lian Wen, and Yung-Kuang Yang., "Optimization of 6061T6 CNC Boring Process Using the Taguchi Method and Grey Relational Analysis", The Open Industrial and Manufacturing Engineering Journal, 2009, 2, 14-20.

[43] Singh and N. Bhatnagar ,Drilling of uni-directional glass fiber reinforced plastic (UD-GFRP) composite laminates, The International Journal of Advanced Manufacturing Technology, Volume 27, Issue 9-10 (2006), pp 870-876

[44] Shravan Kumar Singh, Beant Singh, Rashpal Singh, Optimization Of Axial Force In Drilling Process On Mild Steel By Taguchi's Approach , International Ejournal Of Mathematics And Engineering 162 (2012) 1502 – 1508.

[45] Turgay KIVAK1, Kasım HABALI , Ulvi SEKER, The Effect of Cutting Paramaters on The Hole Quality and,Tool Wear During The Drilling of Inconel 718, Gazi University Journal of Science, 25(2):533-540 (2012)

[46] U.A. Khashaba, M.A. Seif and M.A. Elhamid, Drilling analysis of chopped composites, Composites Part A, Applied Science and Manufacturing, 2007, Vol. 38, No. 1, pp. 61-70.

[47] V. Krishnaraj, S. Vijayarangan and A. Ramesh Kumar, Effect of drilling parameters on mechanical strength in drilling glass fiber reinforced plastic, International Journal of Computer Applications in Technology, 2007, Vol. 28, No. 1, pp. 87-93.

[48] Velayudham and R. Krishnamurthy, Effect of point geometry and their influence on thrust and delamination in drilling of polymeric composites, Journal of Materials Processing Technology, 2007, Vol. 185, No. 1-3, pp. 204–209.

[49] Wen-chou Chen, Some Experimental Investigations in the Drilling of Carbon Fibre-Reinforced Plastic (CFRP) Composite Laminates, International Journal of Machine Tools and Manufacture, 01/1997

[50] Y. Tyagi, V. Chaturvedi, and J. Vimal, Parametric Optimization of Drilling Machining Process using Taguchi Design and ANOVA Approach, Journal of Emerging Technology and Advanced Engineering, Vol. 2, No. 7, 2012, pp. 339-347.