Recent Trends on Optimization Techniques, Cutting Parameters, surface integrity & Material Removal Rate in machining of AISI stainless steel: A review

N.A. Patel, P. D. Patil and H.G. Patil

Department of Mechanical Engineering, D. N. Patel College of Engineering, Shahada.

ABSTRACT

Surface finish is very important criteria in Industry for quality of the product. For obtaining the desired surface finish, process parameters of machining process turning, have to be optimized. Up to now industries are dependent on Handbook data, for determining the parameters, but using Taguchi method & Response surface method, optimized data can be obtained by preparing the model, and validation of that model is done by the experiments. In the present paper, review of such effort is taken into account. This is a short review of researchers work for optimizing the process parameters using speed, feed, depth of cut, nose radius, various coating on tool, and tool geometry as input parameters and output parameter as surface roughness, tool wear, Material removal rate etc.

Introduction

Surface finish has become the most significant technical requirement as it is an index of product quality. In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. Nowadays, manufacturing industries specially concerned to dimensional accuracy and surface finish. In order to obtain optimal cutting parameters, manufacturing to obtain optimal cutting parameters, manufacturing industries have depended on the use of handbook based information which leads to decrease in productivity due to sub-optimal use of machining capability this causes high manufacturing cost and low product quality[2]

Many industrial parts are produced by various machining operations, among which turning is one of the important operation used in wide variety of industrial application. This method relies on cutting action of a tool to remove material from the surface of the work piece. As in the case of all machining processes, the quality of turning operation is significantly affected by the process tuning parameters. There are several process parameters in turning. The most important ones include cutting speed, feed rate, rake angle, clearance angle, end cutting edge angle and side cutting edge angle. In terms of machined product, the main quality measure is the attainable surface quality. Therefore, it is of great interest to study the effects of tuning parameters on the process response characteristic. Many attempts have been made to determine the optimum values of the process parameters in turning operation. Several research have been focused on study the effects of tool geometry specifications on quality characteristics and determined their optimum values.[11]

In the past two decades, the applications of stainless steel materials have increased enormously in various fields. The attractive combination of excellent corrosion resistance, a wide range of strength levels including strength retention at cryogenic and elevated temperatures, good formability, and an aesthetically pleasing appearance have made stainless steel materials of choice for a diverse range of applications, from critical piping components in boiling water nuclear reactors to the ubiquitous kitchen sink. Stainless steels are known for their corrosion resistance along with better mechanical properties. At the same time, machinability is one cumbersome issue which is being discussed by the fabricators for a quite long period. [16]

Considerable efforts are still in progress on the use of hand book based conservative cutting conditions and cutting tool selection at the process planning level. The need for selecting and implementing optimal machining conditions and most suitable cutting tool has been felt over the last few decades. Despite Taylor's early work on establishing optimum cutting speeds in machining, progress has been slow since all the process parameters need to be optimized. Furthermore, for realistic solutions, the many constraints met in practice, such as low machine tool power, torque, force limits and component surface roughness must be overcome.[1]

Review on Optimization Technique:

A review of literature shows that various traditional machining optimization techniques like Lagrange's method, geometric programming, goal programming, dynamic programming etc. have been successfully applied in the past for optimizing the various machining process variables. Fuzzy logic, genetic algorithm, scatter search, Taguchi technique and response surface methodology are the latest optimization techniques that are being applied successfully in industrial applications for optimal selection of process variables in the area of machining. In the recent optimization technique Taguchi methods is latest design techniques widely used in industries for making the product/process insensitive to any uncontrollable factors such as environmental variables. Taguchi approach has

potential for savings in experimental time and cost on product or process development and quality improvement. From the above discussion one can use the Taguchi method for optimizing the turning process parameters like speed, feed, and depth of cut, nose radius, and type of tool, materials of tool and work piece and cutting fluids etc. for minimizing the surface roughness and maximize the tool life by experimental setup. Orthogonal array in the Taguchi technique will help to finalize the number of levels and thus finalize the number of experiments. Also the signal to noise ratio will help to observe the behavior of quality characteristics of work piece.[1]

Beside this, Regression Analysis has drawback like, it did not apply factorial experimentation to design of experiment and having limitation for application to few no. of parameters.[10] Taguchi is good optimization techniques because it gives systematic planning of experiments , has relatively low cost, most widely used from last 2 decades and it saves time & cost[5], it reduces system performance to variable sources, it makes selection of parameter combination by orthogonal array & less number of trials [8]. While Response surface Methodology RSM includes all parameters and their interaction and is used when there is suspecting curvature in response. [10] RSM is practical, Economical and easy for use[13]. RSM Reduces cost of expensive analysis methods like FEA, CFD. RSM has less no. of runs than Taguchi full factorial design & also Taguchi ignores parameter interaction [22] In RSM, CCD (Central Composite Design) is used for accurate prediction of all response variables while BBD (Box-Behnken Design) is used for performing non sequential operations, it involves fewer points as it do not have axial points and has less expensive runs than CCD. BBD design of experiments are better than CCD design of experiment.[17]

Review on Cutting parameters & Surface Integrity & Material Removal Rate:

M. Kaladhar et al , have made 16 trials for turning AISI202 on CNC lathe using CVD coated cemented carbide tools with input variables speed(111-200 m/min), Feed(0.15-0.25 mm/rev), Depth of cut (0.25-0.75 mm), and nose radius (0.4 & 0.8 mm) , and there effects on output variables Surface roughness were explored. They observed from ANOVA analysis that Feed 57.59% and nose radius 24.82% are the contributions on surface roughness & most significant factors. They had also prepared the correlation models and validation is obtained very closely and concluded that in order to obtain a good surface finish on AISI 202 steel, optimal machining conditions were achieved as speed 200m/min, feed 0.15mm/rev, depth of cut 0.25mm and nose radius 0.8mm. [2]

P. Marimuthu & K. Chandrasekharan, have made 27 trials on Fanuc controlled CNC lathe using CVD coated cemented carbide cutting tool, with input parameters, speed (110,160,210m/min), feed 0.1,0.2,0.3mm/rev), depth of cut (0.7,1.4,2.1) mm and their effects on output variables Surface Roughness and Tool Wear were explored. With the help of Taguchi method, ANOVA and Artificial Neural Network (ANN) , they found optimum parameters for Surface roughness were speed 110 m/min, feed 0.1mm/rev, depth of cut 2.1mm, while that for minimum tool wear speed 110m/min, feed 0.1 mm/rev, depth of cut 1.4 mm from ANOVA results, feed rate and depth of cut are the significant cutting parameters for affecting SR and that for TW speed & feed are the most significant parameters. They also prepared model using ANN and they are well validated with experimental and expected

values and concluded that ANN are suitable to model SR and TW.[3]

S. Ranganathan et al carried out 8 trials on AISI 316 SS using WC insert tool with input parameter speed (24.75-94.24m/min), feed (0.25-0.381 mm/rev), Depth of cut (0.1-1.0 mm) and their effect on Surface roughness (SR) & Tool wear (TW) were studied and experimental values were validated with the expected values using ANOVA and regression models, and concluded that models developed from ANOVA predicts closure vales to experimented one and models can be used for predicting values of output parameters.[4]

M. Kaladhar et al. were applied Taguchi method and utility concept's model to predict the Surface roughness and Metal removal rate simultaneously i. e. multi response optimization during turning AISI 202 with input parameters speed (111-200m/min), depth of cut (0.25-0.75mm), feed (0.15-0.25 mm/rev), node radius (0.4 & 0.8) using CVD coated tool on CNC late. In first stage – single response problem optimum values for SR and MRR are obtained, and then in second stage ie multiple response problem establishes that combination of higher level of speed depth of cut nose radius & lower level of feed is necessary. Based on ANOVA & F-test analysis most statistical significant & contributing parameters for multiple performance are depth of cut & speed, whereas feed, nose radius are less effective. It is also found that proposed model based on Taguchi approach & utility concept is simple useful & provides an appropriate solution for multi-response optimization problem.[5]

According to Dr. Shather, increasing nose radius increases surface roughness, maximum run out occurs at high nose radius. And 0.4 mm nose radius is suitable for good value of surface roughness and run out.[6]

Dr. Daniel Kirby as carried out experiment on Fanuc controlled CNC lathe on 6061-T6511 Aluminum alloy 8 trials decided using orthogonal array of Taguchi method, with varying speed, feed, depth of cut and considering noise factor from conditions of jaws on chuck for optimum surface finish and came to conclusion that feed rate has highest significant effect on SR, Spindle speed has moderate effect, depth of cut has insignificant effect, The noise factor was not found to have statistically significant effect.[7]

Lan, using Taguchi and TOPSIS (Technique for order preference by similarity to Ideal Solutions), for to achieve optimum process parameters under consideration of multiple objectives were studied. Experimental results showed that SR & TW ratio are improved by 27.80& 16.21% resp. MRR under optimum parameter is increased by 212.5%.[8]

Ozek et al experimentally investigated parameters like speed(100-200 m/min), feed(0.1-0.4mm/rev), depth of cut(0.5-2mm) to explore their effect on surface roughness, tool flank wear, tool chip interface temperature and found that increasing cutting speed interface temperature, tool flank wear decreases and surface roughness got better with decreasing feed rate and depth of cut.[9]

Ahmari developed empirical models for tool life, surface roughness, and cutting force for turning operation and also the machinability model using process parameters speed (25-144 m/min), feed (0.1-0.7mm/rev), depth of cut(0.25-1.6mm), nose radius (0.4-1.6mm). And using two important data mining techniques Response surface methodology and neural networks with 28 experiments turning austenitic stainless steel AISI 302 to generate, compare and evaluate the proposed model of tool

life cutting force, SR. And found that CNN models are better than RA and RSM models, also RSM models are better than Ra models for predicting tool life, cutting force models. The developed machinability models can be utilized to formulate an optimization model for machining economic problem to determine the optimum values of process parameter of selected material.[10]

Farhad kolahan et al has carried out an experimental investigation to optimize the machining parameter and tool geometry simultaneously, for this they carried 25 turning trials on AISI 1045 SS, input parameters for 5 level were speed (18-104m/min), feed (0.05-0.65mm/rev), rake angle (2-20 deg), side cutting edge angle(0-40), end cutting edge angle (4-20) and output parameter surface roughness, and optimum parameters were determined, concluded that feed rate has slightly more effect on surface roughness than cutting speed.[11]

Nikunj Patel et al, turned AISI1030 for optimum surface roughness with different tool geometries and from them selected the best one using MADM (Multiple Attribute decision making), Simple Additive Weighted (SAW) method, Weighted Product (WPM) Method. The ranking of tool insert based on its performance score for SAW mwtod is 3-4-1-2-5, whereas by WPM method was 3-4-1-5-2.   [12]

Poornima and Sukumar had carried out experimental investigation by turning SS40 to find optimum parameters. Input parameters were speed (80-120 m/min), feed (0.15-0.22 m/min), depth of cut (0.5-1.5 mm), response parameter was surface roughness. Using RSM & GA optimum values obtained and validated with experimented one and found as speed 119 m/min, feed 0.15 m/min, depth of cut 0.5mm and optimum surface roughness as 0.74 microns.[13]

R. A. Mahadavinejad and Reddy experimented on AISI 304 and found the cutting speed has the main influence on flank wear as it increases to 175 m/min, flank wear decreases, feed decreases surface roughness decreases.

Hari Singh and Pradeep Kumar had done experimentation with 27 trails on EN24 with Tic-Coated tungsten carbide inserts, models are prepared and validated with the following conclusions-The percent contributions of depth of cut (55.15 %) and feed rate (23.33 %) in affecting the variation of feed force are significantly larger (95 % confidence level) as compared to the contribution of the cutting speed (2.63 %). Optimal settings of various process parameters for turned parts to yield optimal feed force are: cutting speed = 310 m/min; feed rate = 0.14 mm/rev; depth of cut = 0.70 mm. The predicted range of the optimal feed force is: $149.55 < \mu FF$ (N) < 189.09[15]

D. Philip Selvarajana and P. Chandramohan also optimized the process parameters using Taguchi method 9 trial , 3 level, 3 input parameters and surface roughness as output parameter and concluded that, ANOVA results shows that feed rate, cutting speed and depth of cut affects the surface roughness by 51.84%, 41.99% and 1.66% respectively. A confirmation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.[16]

V. Suresh babu et al, optimized and validated the models ,In this work the effects of the depth of cut, spindle speed, and feed rate on surface roughness were quantified using the Box-Behnken design, which is one of the most commonly used RSM techniques. A empirical second order model predicting equations for surface roughness have been developed using response surface methodology for machining EN24 with standard high speed tools. The established equations clearly show that the cutting speed is main influencing factor on the surface roughness. Based on the designed experiments from RSM and further experimental machining carried out for EN24 material, and measured from Surftest, it is concluded that the Factor B, the feed rate is the significant model term followed by cutting speed and depth of cut. The probability value that is associated with the F value for this term is 0.0014. Since this factor has a probability value less than 0.05 it is considered to have a significant effect on the response, hence when it is maintained at the upper limit produces the better surface finish. It is concluded that the feed rate is the predominant contributor to the better surface finish followed by the spindle speed and depth of cut. The present study reflects that when the feed rate is 0.1mm/rev and cutting speed 111.5 m/min and depth of cut of 0.2 mm the lowest surface finish is attained. The model validation proves that the empirical model developed is accurate and has the capability to predict the value of the response within the limits of the factors investigated. The quadratic models developed using RSM noticed to be reasonably accurate and can be used for predicting within the bounds of the factors investigated. [17]

Ahmet Akdemir et al in their study, specimens were first prepared by austenitizing DI at 900 _C for 90 min and were then quenched in a 50% NaNO3þ50% KNO3 salt bath at 380 _C for 90 min. Then, the effects of cutting parameters on the machinability of ADI were investigated, and the measured outputs, such as cutting forces, surface roughness, and tool wear, were analyzed. By selecting convenient tool material, geometry, and machining conditions, ADI specimens were machined using a cutting speed in the range of 50–250 m/min, depth of cut in the range of 1–3 mm, and a constant feed rate of 0.12 mm/rev for a machining length of 1200 mm. The following conclusions have been drawn from the present study:

1. The cutting forces were measured along three directions. When the variation of the cutting forces with cutting speed was investigated, it was seen that the maximum cutting force was measured at lower cutting speed (50 m/min), whereas minimum force was obtained at the 200 m/min cutting speed. The observed increase in the cutting forces with increasing cutting speed from 200 m/min to 250 m/min can be attributed to the probable increase in tool wear at high cutting speeds, and consequently, this leads to an increase in the cutting forces due to the wearing away of the cutting tool.

2. The cutting force components increased proportionally with increasing rate at depths of cuts. When the depth of cut was increased from 1 mm to 1.5 mm, Ft and Ff increase by 73% and 89%, respectively.

3. Cutting speed has a major effect on tool wear; thus, excessive tool wear occurred at the cutting speed of 200 m/min, while less tool wear occurred at low cutting speed, namely 50 m/min and 100 m/min. The tool wear increases with increasing depth of cut, but this effect is not as significant as compared with the effect of cutting speed on tool wear.

4. In the experiments performed, it was observed that spheroidal graphite overlap by breaking off in the processing of austempered ductile iron, and they make the chip to emerge unstably by displaying a solid lubricant feature.

5. Optimum cutting parameter values are obtained by utilizing RSM. They are found to be the cut of depth (a) of 1 mm and the cutting speed (v) of 185.35 m/min for surface roughness (Ra). They are realized for the tangential force (Ft) and flank wear

(VB) as 1 mm, 167.17 m/min and 1 mm, 50.00 m/min, respectively.[18]

Maan Aabid Tawfiq performed test on AISI1045SS in order to examine the influence for type and no. of coatings on surface roughness, with cutting tool TiN, Tin/TiC, TiN/Al$_2$O$_3$/TiC multi layered coated cemeneted carbide inserts at 5 levels with input parameter speed , feed and coatings. And found that According to the coating types, the best surface roughness obtained by means of coated cutting tools with TiN/TiC double layer coats. The next best cutting tool was TiN/Al2O3/TiC, then TiN, then uncoated one respectively. For double layer coated insert tool (TiN/TiC), the considerable improvement is (41%) by increasing the cutting speed to. by about (275%). The surface roughness values obtained by using (TiN/TiC) coated tools are lower than those obtained by using (TiN/Al2O3/TiC), (TiN) coated, and uncoated cutting tools by about (10%). • when increasing the cutting speed from (80-300m)/min and reducing feed rate by (250%), the values of surface roughness is decreased (20%) for uncoated tool insert, (27%) for TiN coated layer insert, (55%) for (TiN/TiC) coated layer insert, and (49%) for (TiN/Al2O3/TiC) coated layer insert. A good correlation of cutting speeds and feed rates can result in better surface finish.[20]

A. Kacal & M. Gulesin used L18 orthogonal array and ANOVA was performed to identify the significant factors affecting surface roughness and primary cutting force, optimum process parameter condition were acquired using analysis of signal to noise ratio. For R$_a$ & F$_c$ values, prediction error was found to be within confidence limit at 95% confidence level.[21]

Hassan GOKKAYA & Muammer NALBANT, investigated the effects of a number of cutting tool coating materials on the surface quality of workpieces, depending on various cutting parameters. AISI 1015 steel was processed without cooling on a lathe using 4 different cemented carbide cutting tools, i.e. uncoated, coated with AlTiN and coated withTiAlN using the PVD technique, and one with 3-layer coatings (outermost being TiN) applied by the CVD technique. Among the cutting parameters, the depth of cut was kept constant (2.5 mm) while the cutting speed and feed rate were changed. Five cutting speeds (50, 73, 102, 145, 205 m/min) and 2 feed rates (0.24 and 0.32 mm/rev) were used during the machining process. Coating type, feed rate and cutting speed have different effects on surface roughness. In the experiments, less average surface roughness was obtained by using a 3-layer coated tool coated outermost with TiN. The lessening of cutting speed by about 33% improves the surface roughness by about 26%, and increasing the cutting speed by about 310% resulted in an improvement of about 69%. And following conclusion are obtained According to the coating types, the best surface roughness is obtained by means of cutting tools coated with TiN using the CVD technique. The next best cutting tools were ones that were TiAlN and AlTiN coated with the PVD technique and uncoated cemented carbide, respectively. The relationship between cutting speed and surface roughness is inversely proportional. Increasing the cutting speed decreases the surface roughness. The relationship between feed rate and surface roughness is proportional. Increasing the feed rate increases the surface roughness. On surface roughness, the effect of feed rate is more considerable than cutting speed. Decreasing the feed rate by 33% improves the surface roughness by about 26%, while increasing the cutting speed by about 310% improves the surface roughness by 69%. A good combination of cutting speed and feed rate can provide better surface qualities. The average friction coefficient of coating material affects the surface roughness. Low cutting speeds of uncoated and AlTiN coated tools cause a BUE. Formation of a BUE affects the surface roughness negatively.[22]

Conclusion:

Taguchi method can be used efficiently for process parameter optimization, Optimum process parameter were identified and feed & nose radius are most contributing factors respectively.

Model prepared from Artificial neural network are better than Response surface methodology models which are better than Regression Analysis models. In RSM BBD designs are better than CCD Designs. The best surface roughness obtained by means of coated cutting tools with TiN/TiC double layer coats. Many researchers had worked on optimizing process parameters and tool geometry, for surface roughness, Tool wear, Cutting forces, Material Removal rate etc but there is scope on working for hardness, micro-hardness.

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