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Evaluation of Process Influencing Parameters In Machining Of AISI 1040 Medium Carbon Steel Using Taguchi Based PCA Method

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Abstract

AISI 1040 equivalent to EN8/080M40. Unalloyed medium carbon steel. AISI 1040 is a medium strength steel with good tensile strength. Suitable for shafts, stressed pins, studs, keys etc. Tool wear and surface roughness are widely considered most challenging aspect causing poor quality in machining of the copper. Optimization of cutting parameters is essential for the achievement of high quality and high rate of mass production. In the present work, an attempt has been made to investigate the effect of process parameter performance characteristics in turning of AISI 1040 steel using carbide insert and there by optimizing the process parameter using Taguchi's DOE method. Three process parameters namely speed, feed and depth of cut are used to optimize multi quality characteristics namely surface roughness and tool wear. The results reveal that Taguchi's technique used for minimizing the surface roughness and tool wear using MINITAB 16 produce a favorable range of the machining parameter values is proposed for efficient machining. The ANOVA concept is employed to find out the relative significance of machining parameters. Finally predicted responses were compared with the respective measured values, the results shows that the good agreement in best optimal value for better surface roughness and tool wear.

Introduction

Introduction to Machining: Quality and productivity play significant role in today's manufacturing market. From customers' viewpoint quality is very important because the extent of quality of the procured item (or product) influences the degree of satisfaction of the consumers during usage of the procured goods. Therefore, every manufacturing or production unit should concern about the quality of the product. Apart from quality, there exists another criterion, called productivity which is directly related to the profit level and also goodwill of the organization. Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss.

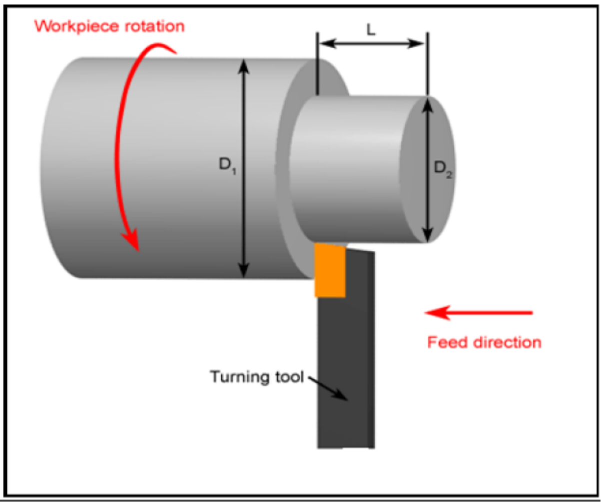

FIGURE 1. A typical turning operation

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine. Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same. Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev. Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work. The classes of cutting tool materials currently in use for machining operation are high- speed tool steel, cobalt-base alloys, cemented carbides, ceramic, and polycrystalline cubic boron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as cutting speed, feed, and depth of cut.

Machining Of Various Alloys: Rigidity of the entire system is consequently very important, as is the use of sharp, properly shaped cutting tools. The common practice in aerospace industry is the use of cutting fluids and lubricants when machining titanium alloys. Cemented carbide tools are the most frequently used when machining this kind of material at cutting speeds in the range of 45–60 m/min. Lubrication improves mach inability of the work piece material, increases productivity by reducing tool wear and extends the tool life. However, the toxicity of the cutting fluids seriously degrades the quality of the environment. Dry machining becomes then an ideal solution and introduces a greater challenge to manufacturing engineers due to the high temperatures generated during machining. This article focuses on mach inability of titanium alloys under various machining environments such as - LN2, elevated temperature and mist jet cooling. The main objective of the project is to understand the effect of change in machining environment on various aspects of machining of titanium alloys viz. tool wear, cutting forces, vibration and chatter, surface roughness and chip morphology. It is evident that the LN2 and mist jet environments effectively cool the cutting zone and reduce the tool wear. On the other hand, the elevated temperature environment reduces the cutting forces and thereby increases the material removal rate along and surface quality The materials having high tensile strength and wear resistance such as temperature resisting alloys, high manganese steel, Inconel, quenched steels, etc., which have wide applications in aerospace, nuclear industries, missile industries, etc., are usually difficult to machine. Machining of these high strength materials by conventional methods has to face many problems such as high tool wear, low surface finish, and high power consumption. As a result it increases the cost of manufacturing. To avoid mentioned problems, the costly cutting tools such as ceramic, cubic boron nitride, cermet, etc. are used. The cost of machining increases because of costly tools. Softening of work piece by heating the work piece is another alternative approach. The machining can be carried out using low costly cutting tools. The machining becomes economical. From industrial point of view, the most important aspect of metal cutting is mach inability and its influence on the economics of the manufacturing. There are many methods to enhance the mach inability of difficult to cut the materials by employing ramping technique, high pressure coolant supply technology, cryogenic machining, use of self- propelled rotary tooling and hot machining. Researchers focused on improved cutting tools for enhancing mach inability of such high strength materials, smoothness of the product, cost of operation and performances. Hot machining is a suitable method to machine hard work piece material with high surface quality and good mach inability. The main aim of hot machining is to facilitate an effective and easier machining method. The machining of work piece at elevated temperature using ordinary tool is more effective approach than machining with high strength cutting tools. The basic principle behind hot machining is the reduction in hardness of work piece material leading to reduction in the component force, with improvement in surface finish and tool life. In hot machining operation work piece has been heated above recrystallization temperature where the yields stress of 3materials decreased rapidly. The heating gas flame is used to raise the temperature of the work piece material. A schematic view of the turning operation was shown in figure 1. There are many heating techniques such as gas flame heating, arc heating, electric resistance heating, etc. for hot machining operation having their own importance for softening of work piece material. In different ways these heating techniques affect properties such as micro structure, micro hardness, etc. The use of heating techniques depends on the shape and size of the work piece materials, cost restriction and accuracy requirement.

Quality Characteristics: Surface roughness is a measure of the surface finish of a product and an index of the product quality. Surface roughness is a measurement of the small scale variations in the height of a physical surface. It is expressed in various ways and methods, like arithmetic mean or centre-line average (Ra), Root-mean square average (Rq), maximum peak (Ry), ten-point mean roughness (Rz), maximum valley depth (Rv), maximum height of profile (Rt = Rp) etc. Out of all these, the most commonly used indicator for surface roughness is Ra.Ra, or the arithmetic mean value, previously known as AA (Arithmetic Average) or CLA (Centre-Line Average) is the arithmetic mean of deviations of a series of points from the centre line or datum line. The datum line is such that sum of the areas under the profile above the datum will be equal to the sum of areas below the datum. Tool wear is an inherent occurrence in every conventional machining process. Bin Halim said that the tool wear is analogous to the gradual wear of the tip of a pencil. It is the gradual failure of cutting tools due to regular operation. The tool wear rate is dependent on the tool material itself, the tool shape and geometry, work piece material etc. The foremost important factors affecting the tool wear which can be easily controlled are process parameters. A key factor in the rate of tool wear of materials is the temperature achieved during machining. The general idea is that energy expended in cutting is converted into heat and that a large fraction of it is taken away in the chip. This results in about 20% of the heat generated going into the cutting tool.

Experimental Plan & Evaluation

Selection Of Machining Parameters: The turning operation is governed by geometry factors and machining factors. This study consists of the three primary adjustable machining parameters in a basic turning operation viz. speed, feed and depth of cut. Material removal is obtained by the combination of these three parameters. Other input factors influencing the output parameters such as surface roughness and tool wear also exist, but the latter are the ones that can be easily modified by the operator during the course of the operation.

Cutting Speed: Cutting speed may be defined as the rate at which the uncut surface of the work piece passes the cutting tool [1]. It is often referred to as surface speed and is ordinarily expressed in m/min, though ft. /min is also used as an acceptable unit. Cutting speed can be obtained from the spindle speed. The spindle speed is the speed at which the spindle, and hence, the work piece, rotates. It is given in terms of number of revolutions of the work piece per minute i.e. rpm. If the spindle speed is 'N' rpm, the cutting speed V c (in m/min) is given as

$$V_C = \frac{\pi d N}{1000} \quad (1)$$

Where, D = Diameter of the work piece in mm

Feed: Feed is the distance moved by the tool tip along its path of travel for every revolution of the work piece. It is denoted as 'f' and is expressed in mm/rev. Sometimes, it is also expressed in terms of the spindle speed in mm/min as

$Fm = f N$

Where, f = Feed in mm/rev N = Spindle speed in rpm

Depth of Cut: Depth of cut (d) is defined as the distance from the newly machined surface to the uncut surface. In other words, it is the thickness of material being removed from the work piece. It can also be defined as the depth of penetration of the tool into the work piece measured from the work piece surface before rotation of the work piece. The diameter after machining is reduced by twice of the depth of cut as this thickness is removed from both sides owing to the rotation of the work.

$$d = \frac{D2 - D1}{2}$$

Where, D1 = Initial diameter of job D2 = Final diameter of job

Surface Roughness: Surface roughness is a measure of the surface finish of a product and an index of the product quality. Surface roughness is a measurement of the small scale variations in the height of a physical surface. It is expressed in various ways and methods, like arithmetic mean or centre-line average (Ra), Root-mean square average (Rq), maximum peak (Ry), ten-point mean roughness (Rz), maximum valley depth (Rv), maximum height of profile (Rt = Rp) etc. Out of all these, the most commonly used indicator for surface roughness is Ra.Ra, or the arithmetic mean value, previously known as AA (Arithmetic Average) or CLA (Centre-Line Average) is the arithmetic mean of deviations of a series of points from the centre line or datum line. The datum line is such that sum of the areas under the profile above the datum will be equal to the sum of areas below the datum. Generally, surface roughness is expressed in microns (µm).Studies by Sahin Y. and Motorcu A.R., have shown that surface roughness is mostly dependent on feed rate which is the dominating factor. The surface roughness is usually measured in a direct way by the use of devices called Profilometer. The Profilometer is a stylus probe instrument in which the stylus mounted in the pick-up unit traverses across the machined surface by means of a motor drive. The pick-up receives ad rectifies the output which is further amplified and the average height of the roughness is reported digitally. One of the common types of Profilometer available is the Taylor Hobson Talysurf. It works on the principle of carrier modulation.

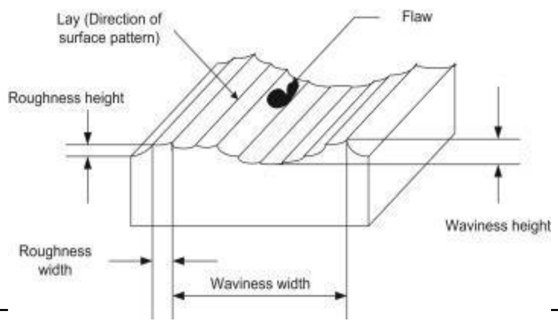

FIGURE 2. Measure of Roughness

Tool Wear: Tool wear is an inherent occurrence in every conventional machining process. Bin Halim said that the tool wear is analogous to the gradual wear of the tip of a pencil. It is the gradual failure of cutting tools due to regular operation. The tool wear rate is dependent on the tool material itself, the tool shape and geometry, work piece material etc. The foremost important factors affecting the tool wear which can be easily controlled are process parameters. A key factor in the rate of tool wear of materials is the temperature achieved during machining. The general idea is that energy expended in cutting is converted into heat and that a large fraction of it is taken away in the chip. This results in about 20% of the heat generated going into the cutting tool. The following types of tool wear modes can be observed. They are

a) Flank
b) Notch
c) Crater
d) Edge rounding
e) Edge Chipping
f) Edge Cracking

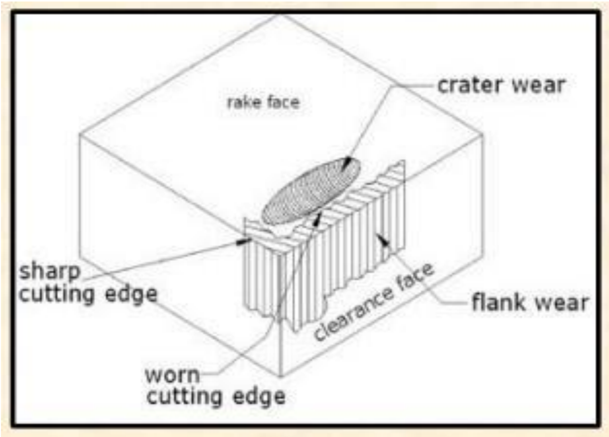

FIGURE 3. Different types of tool wear

Flank Wear: Flank wear is the wear that occurs on the flank surface or flank faces of the cutting tool. This occurs due to direct mechanical abrasion and friction between the flank surface and the work piece during the operation. The width of the wear land is a straightforward measure of the flank wear. The width is denoted as VB. The tool life is conventionally considered to be over when the average flank wear land VB reaches 300 µm or the maximum flank wear land VB max becomes 600 µm and found that cutting speed and diffusion coefficient index have the most notable effect on the flank wear, followed by feed and depth of cut.

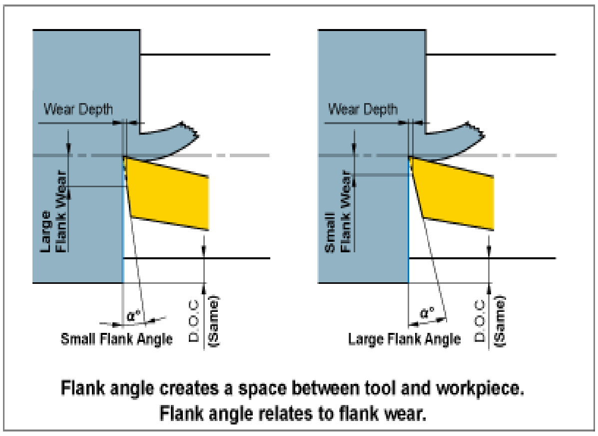

FIGURE 4. Flank Angles

Crater wear: Crater wear is the wear that takes place on the rake face or the top face of the cutting tool. It occurs parallel to the principal cutting edge. This type of erosion occurs due to the rubbing of the chip on the rake face during machining. According to a study, the most notable factors that affect the crater wear phenomena are temperature occurring at the chip-tool interference and the chemical affinity between the tool and work materials at the elevated temperatures encountered during machining. Factors affecting flank wear also influence crater wear and found out during the dry machining of boiler steel using TiCN-Ni-WC cermet inserts that crater wear increases significantly with cutting speed and feed.

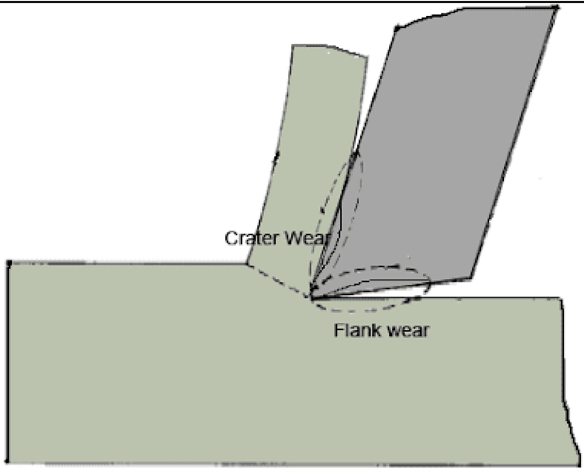

FIGURE 5. Representation of crater and flank wear

Experimental Plan: The aim of the experiments was to analyze the effect of cutting parameters on the tool wear and work piece surface temperature of AISI 1040 MC Steel. The experiments were planned using Taguchi's orthogonal array in the design of experiments which help in reducing the number of experiments. The experiments were conducted according to a three level, L9 (34) orthogonal array. The cutting parameters identified were cutting speed, depth of cut and feed. The control parameters and the levels used in experiment are given in the Tables 2. The table 3 represents the experimental results.

FIGURE 6. Machined AISI 1040 Medium Carbon steel

TABLE 1. Parameter selection

Parameter	Symbols	Level 1	Level 1	Level 1
Cutting Speed	rpm	600	700	800
Feed Rate	mm/rev	0.10	0.15	0.20
Depth of cut	mm	0.25	0.50	0.75

TABLE 2. Orthogonal array L9 of Taguchi experiment design and experimental results

Trial No.	Speed (rpm)	Feed(mm/rev)	Depth (mm)	Ra (Microns)	Tool wear(mm)
1	600	0.1	0.2	1.56	0.2
2	600	0.15	0.5	2.63	0.24
3	600	0.2	0.75	2.98	0.31
4	700	0.1	0.5	1.38	0.35
5	700	0.15	0.75	2.54	0.39
6	700	0.2	0.2	2.83	0.43
7	800	0.1	0.75	1.62	0.21
8	800	0.15	0.2	1.35	0.22
9	800	0.2	0.5	2.25	0.26

Analysis of variance (ANOVA): The experimental results from Table 3 were analysed with analysis of variance (ANOVA), which used for identifying the factors significantly affecting the performance measures. The results of the ANOVA with the tool wear and work-piece surface temperature are shown in Tables 5 and 6 respectively. This analysis was carried out for significance level of α=0.1 i.e. for a confidence level of 90%. The sources with a P-value less than 0.1 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source of the total variation and indicating the degree of influence on the result.

TABLE 3. Analysis of variance for tool wear

Source	DOF	SS	MS	F	P	C (%)
S	2	330.9654	0.017544	36.72	0.027	23.21
F	2	387.0967	0.031744	66.44	0.015	42.17
D	2	260.5432	0.003011	6.30	0.137	9.35
Error	2	102.9763	0.000478			0.91
Total	8	1153.902				98.53
S = 2.98345			R-sq = 90.39%			R- sq(adj) = 93.49

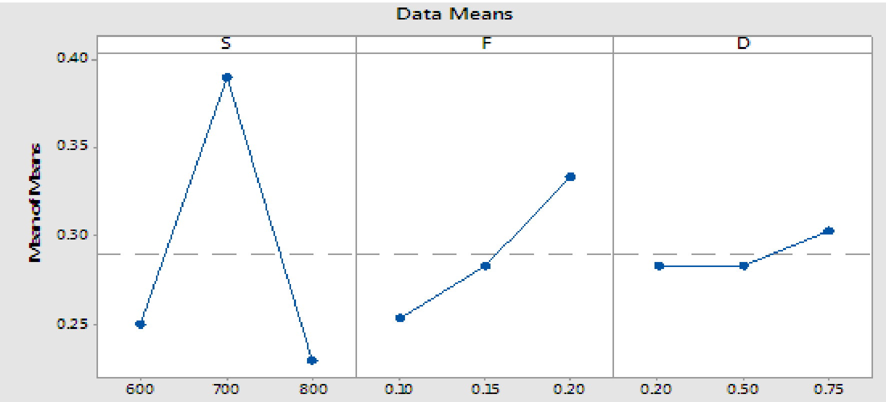

FIGURE 7. Mean plot of tool wear

TABLE 4. Analysis of variance for Ra

Source	DOF	SS	MS	F	P	C (%)
S	2	0.035089	0.017544	36.72	0.027	33.24
F	2	0.063489	0.031744	66.44	0.015	60.15
D	2	0.006022	0.003011	6.30	0.137	5.70
Error	2	0.000956	0.000478			0.91
Total	8	0.105556				100
S = 0.021567			R-sq = 99.09			R- sq(adj) = 96.38

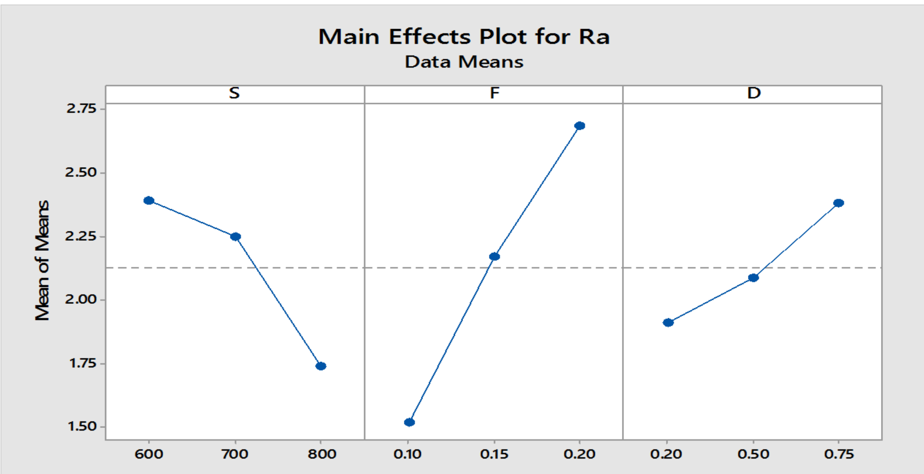

FIGURE 8. Mean plot for Ra

Principal Component Analysis

Principal Component Analysis is a dimension reduction tool that can be used in multi variable analysis problem. Principal Component Analysis aims at reducing a large set of variables to a small set that still contains most of the information contained in the large set. It is a method to identify patterns in a data in such a way as to highlight their similarities and differences. So the data can be compressed without losing any information. It is the most meaningful basis to re-express a noisy and grabled data set. We often do not know what measurements best reflect the dynamics of our system in question. Sometimes we record more dimensions than we really need PCA alleviates this problem by mapping the original predictors into a set of principal components that is lesser in dimension than the number of the original variables. Such a transformation will usually be accompanied by a loss of information. The goal of PCA is, therefore, to preserve as much information contained in the data as possible. The optimal number of principal components (PCs) needed to achieve this task is not known a priori. The task is to find a set of principal components with eigen values that have a significantly larger value than the remaining components. The results of the PCA method compared to the traditional Taguchi’s Technique shows a closeness in target values.

Conclusion

The experimental results showed that the Taguchi parameter design is an effective way of determining the optimal cutting parameters for achieving tool wear and low work-piece surface finish. The percent contributions of depth of cut (23.85%) and cutting speed (9.24%) in affecting the variation of tool wear are significantly larger as compared to the contribution of the feed (42.70%). The significant parameters for work-piece surface roughness were cutting speed and depth of cut with contribution of 41.17% and 34.45% respectively. Although not statistically significant, the feed has a physical influence explaining 21.58% of the total variation. The relationship between cutting parameters (cutting speed, depth of cut, feed) and the performance measures (Tool wear and work-piece surface roughness) are expressed by multiple regression equation which can be used to estimate the expressed values of the performance level for any parameter levels.

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