ISSN 2141-2987
Journal of NIMechE Vol. 7, No. 1 pp 23- 34
Printed in Nigeria

EVALUATION OF CUTTING VARIABLES ON SURFACE ROUGHNESS AND CHIP FORMATION IN TURNING AISI 304L STEEL WITH COATED CARBIDE INSERTS

[1]Lawal S.A., [2]Sule I.S., [3]Namessan N.O., [4]Ugheoke B.I. and [5]Abutu J.

[1,3,5]Department of Mechanical Engineering, Federal University of Technology, Minna-Nigeria.
[2]Department of Agricultural and Bio-Resources Engineering, Taraba State University, Jalingo - Nigeria
[4]Department of Mechanical Engineering, University of Abuja, Nigeria

Abstract
This study involved the use of full factorial method to evaluate the effect of cutting variables on surface roughness and types of chip formation in turning of AISI 304L alloy steel with coated carbide insert under dry condition. The input variables used were cutting speed, feed rate and depth of cut. Minitab 17 software was used to analyse the data. The analysis of variance shows that feed rate has the most significant effect on surface roughness with 79.86% and the relationship between feed rate and cutting speed at constant depth of cut shows that as feed rate increase for every cutting speed, the surface roughness increases. It was observed that the chips formed at different cutting conditions were continuous, helical, straight, and serrated types.

Keywords: Cutting speed, feed rate, depth of cut, surface finish and turning process

1.0 INTRODUCTION

Engineering products are produced from different materials and these products are manufactured into its usual form from processes such as turning and milling operations. Whereas others do not, but require further working to finish component of the desired shape and size (Rajender, 2006). In metal turning process, cutting tools remove a certain layer of material and impart the required shape, size and surface quality to the workpiece. Varieties of cutting tools have been developed to satisfy the requirements of production for its smooth running. In turning and facing operations an improper selection of cutting parameters will cause undesired surface roughness and high tooling cost. All dimensions and shapes are determined either analytically or graphically during design of cutting tools. For effective production, researches were carried out in the past and many are in progress for the purpose of reducing production cost and manufacturing parameters without compromise on product quality (Kapil *et al.*, 2013).

In any metal cutting operation the features of tools, input work materials and machine parameter settings will influence the process efficiency and output quality characteristics. A significant improvement in process efficiency may be obtained by process parameter optimization that identifies and determines the regions of critical process control factors leading to desired outputs or responses with acceptable variations ensuring a lower cost of manufacturing. For turning process, the cutting conditions that is, speed, feed and depth of cut plays an important role in the efficient use of a machine tool. In order to determine the optimum cutting conditions, there is the need to estimate the tool life and cutting forces with a reasonable degree of accuracy since many of the constraints on the process are influenced by these parameter (Raoa *et al.*, 2014). In metal cutting processes, the desired cutting parameters are determined either by experience or by using a handbook which does not ensure the selected parameters to be optimal. To determine the optimal cutting conditions, reliable mathematical models have to be formulated to associate the cutting parameters with cutting performance in terms of statistical approach. In literature, Response Surface Methodology (RSM) has been used by some researchers for the analysis and prediction of surface roughness (Lalwani *et al.*, 2008). Many works on machining of carbon or alloy steel have applied a full or partial factorial design (Abouelatta and Mádl, 2001, Lawal *et al*, 2014, Lawal *et al*, 2015).

Ilhan and Harun, (2011) optimized turning parameters based on the Taguchi method to minimize the surface roughness. They carried out dry turning tests on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. To ensure accurate readings of the surface roughness each experiment were repeated three times. Analysis of variance (ANOVA) was used to investigate the effects of cutting speed, feed rate and depth of cut on surface roughness. It was concluded that the feed rate has the most significant effect on surface roughness. Ali, (2010) investigated the surface roughness in the turning of AISI 8660 hardened alloy steels using ceramic based cutting tools studied in terms of cutting parameters such as cutting speed, feed rate, depth of cut as well as tool nose radius, by means of a statistical approach. Machining tests were carried out with physical vapour deposition (PVD) coated ceramic cutting tools under different conditions. An orthogonal design, signal-to-noise ratio and ANAOVA were employed to find out the effective cutting parameters and nose radius on the surface roughness. The results obtained showed that the feed rate was the most dominant factor among controllable factors on the surface roughness, followed by depth of cut and tool's nose radius. The interaction of feed rate and depth of cut was found to be significant on the surface finish due to surface hardening of steel. Lanjewar *et al.*, (2008) conducted experiments to evaluate the performance of AISI304 steel on auto sharpening machine by using Taguchi method. The results revealed that tools shape and feed are significant factors.

Ahmed, (2013) studied the effects of cutting speed, feed rate, tool path and depth of cut process parameters on the surface roughness in the pocket machining of AA5083 aluminium alloy materials using Taguchi method. It was found that surface roughness correlates positively with feed rate and depth of cut, but negatively with cutting speed while the tool path pattern factor is of less significance. In this study, the effect of cutting variables on surface roughness and chip formation during turning of the AISI 304L austenitic stainless steel using coated carbide inserts adopting design of experiment via full factorial design method would be investigated.

2.0 MATERIALS AND METHODS

2.1 Materials

The workpiece material employed in this investigation was AISI 304L alloy steel with the following chemical composition as shown in Table 1. The cutting tool used in the turning process was coated carbide inserts (CNMG 120408-DM).

Table 1: Chemical composition of AISI 304L (AK Steel, 2007)

	% C	% Si	% Mn	% Ni	% Cr	% N	% P	% S
Min.	0	0	0	8.000	18.000	0	0	0
Max.	0.030	0.750	2.000	12.000	20.000	0.100	0.045	0.030

2.2 Method

This design technique involves the combination of three factors at three levels necessary to study the combined effect of the experimental factors on a response. A complete trial or replications of all the possible combinations of the levels of the factors were investigated in this study.

The factors and their levels are shown in Table 2. Three factors at three levels experimental design layout as specified by full factorial design [$L_{27}(3^3)$] is shown in Table 3 using Minitab 17 software. The confidence level specified for this analysis is 95%.

Table 2: Factors and their levels

Parameter	L1	L2	L3
Cutting speed (m/min)	150	200	250
Depth of cut (mm)	0.1	0.2	0.3
Feed rate (min/rev)	0.5	0.6	0.7

Table 3: Experimental Design Layout

Runs	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	2	3	1
2	3	1	3
3	3	3	3
4	1	1	3
5	3	1	2
6	2	2	2
7	2	3	3
8	3	1	1
9	2	2	3
10	2	3	2
11	2	1	2
12	1	3	3
13	2	1	3
14	2	2	1
15	1	2	1
16	3	3	2
17	3	2	1
18	3	2	3
19	1	2	2
20	1	3	1
21	1	1	2
22	1	1	1
23	3	2	2
24	1	3	2
25	2	1	1
26	3	3	1
27	1	2	3

The turning process was conducted on a computer numerical control (CNC) lathe (model SPT-32) as shown in Figure 1 with the following configuration: - slant bed turning centre and maximum spindle speed of 4000 rpm, rapid traverse of 15,000 mm/min, spindle motor power of 28 KW motor drive, maximum work weight of 300 Kg and maximum swing diameter over bed of 490 mm. The workpiece was prepared to a diameter of 50 mm and length of 200 mm. This was necessary to maintain a ratio of 1: 4 (diameter to length) of workpiece so as to ensure the required stiffness of chuck/workpiece/cutting force (Lawal *et al.*, 2014).

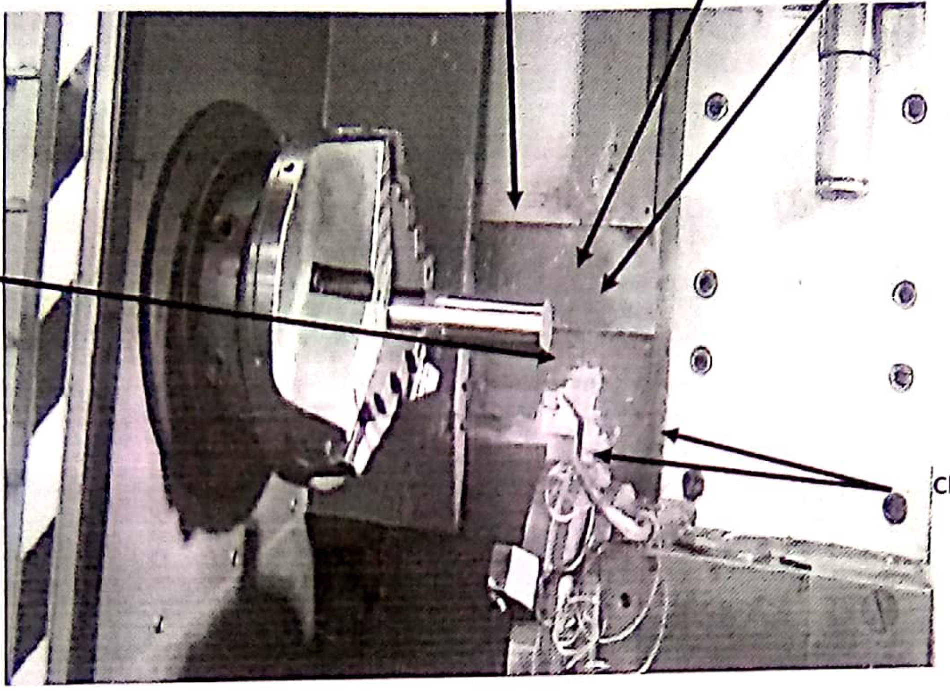

Figure 1: Experimental set up for turning operation

Each turning experiment was conducted for ten minutes and a new cutting tool was used for each run. After each turning operation, the surface roughness of the machined surface was measured using Surface Roughness Tester (SRT-6210S) having a diamond stylus tip of radius 5 µm. The experimental set up for surface roughness measurement is shown in Figure 2. A cut-off length (or sampling length) of 0.8 mm was used for surface roughness measurements between 0.36 and 2.5 µm, while 2.5 mm cut-off length was used for surface roughness measurements above 2.5 µm. The roughness surface (R_a) was measured at three positions along the machined surface, that is, at the middle and 10 mm from the two ends of the machined surface. The average of the three R_a values measured was calculated and recorded for each experimental run.

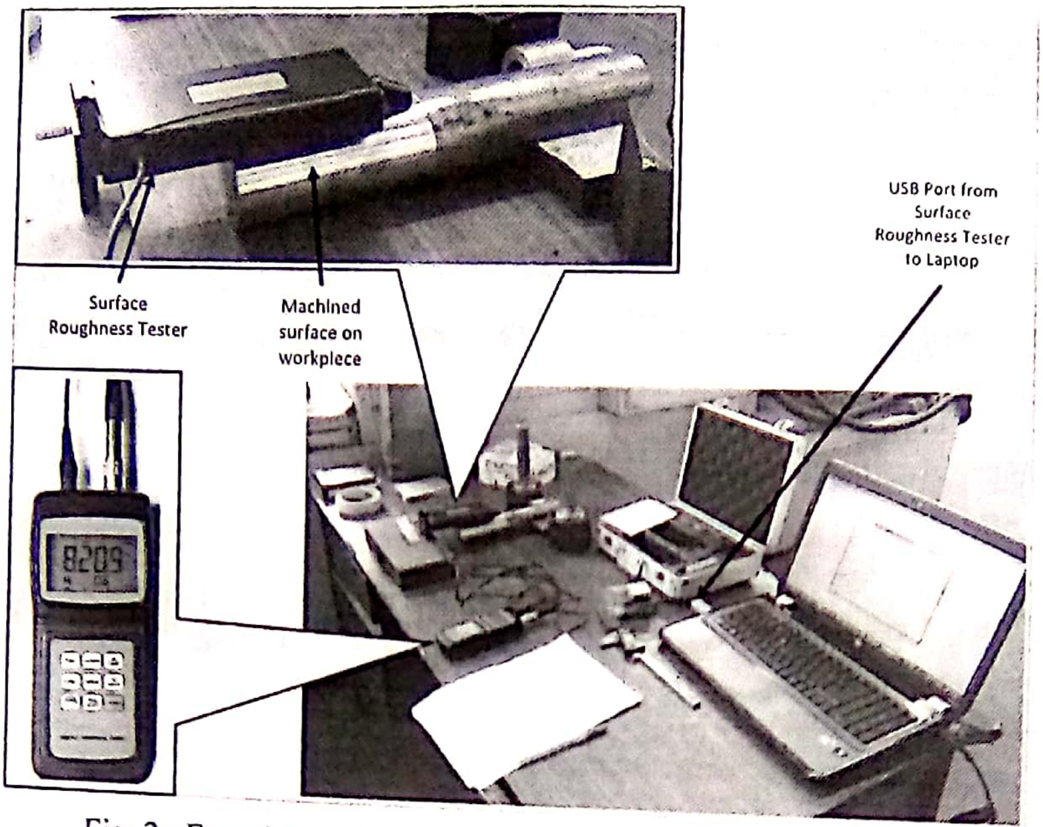

Fig. 2: Experimental set up for surface roughness measurement

After the completion of each experimental run, sample of the chips formed were collected and labelled. The surface morphology of the samples of chips formed during each of the experimental runs was investigated at 100 x magnification under the Nikon Eclipse – ME600 optical metallurgical microscope.

3.0 RESULTS AND DISCUSSION

3.1 Surface Roughness

The results of the effect of machining parameters (cutting speed, feed rate and depth of cut) on the response (surface roughness) during the machining of AISI 304L steel when using coated carbide tools are presented in Table 4. Signal-to-noise ratio analysis of the surface roughness values were determined using the smaller the better characteristic quality as shown in equation 1 and presented in Table 4.

$$S/N = -10\log\frac{1}{n}\left(\sum_{i-1}^{n} y_i^{\,2}\right) \quad (1)$$

where n = number of outputs in the combination of factor level, y = the outputs for the specified combination of factor level.

Table 4: Experimental Results of Surface Roughness and S/N ratio

Runs	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness, Ra (µmm)	S/N ratio (dB) for Surface Roughness
1	200	0.3	0.5	1.53	-3.693
2	250	0.1	0.7	0.52	5.646
3	250	0.3	0.7	0.82	1.712
4	150	0.1	0.7	0.77	2.270
5	250	0.1	0.6	0.97	0.265
6	200	0.2	0.6	1.53	-3.694
7	200	0.3	0.7	3.26	-10.264
8	250	0.1	0.5	0.95	0.491
9	200	0.2	0.7	1.87	-5.437
10	200	0.3	0.6	4.04	-12.128
11	200	0.1	0.6	1.13	-1.062
12	150	0.3	0.7	4.46	-12.987
13	200	0.1	0.7	1.26	-2.007
14	200	0.2	0.5	2.60	-8.299
15	150	0.2	0.5	2.12	-6.527
16	250	0.3	0.6	2.58	-8.232
17	250	0.2	0.5	1.22	-1.763
18	250	0.2	0.7	1.43	-3.107
19	150	0.2	0.6	2.56	-8.165
20	150	0.3	0.5	3.06	-9.714
21	150	0.1	0.6	0.93	0.630
22	150	0.1	0.5	1.64	-4.297
23	250	0.2	0.6	1.72	-4.711
24	150	0.3	0.6	4.26	-12.588
25	200	0.1	0.5	1.11	-0.867
26	250	0.3	0.5	2.46	-7.819
27	150	0.2	0.7	3.16	-9.994

2.2 Analysis of Variance and Main Effect Plot of Surface Roughness

Analysis of variance (ANOVA) was conducted to identify the significance effect of machining parameters on the surface roughness of the workpiece. The relative importance for each parameter is given by the order of their percentage contribution (p-value) during the machining process. Table 5 shows the results of the analysis as well as the p-value of each parameter.

Table 5: ANOVA for Surface Roughness

Variables	DOF	SS	MS	F	p-value (%)
Cutting speed (rpm)	2	5.935	2.967	441.59	18.14
Feed rate (mm/rev)	2	26.13	13.065	1944.19	79.86
Depth of cut (mm)	2	0.5179	0.259	38.53	1.58
Error	20	0.1344	0.007		0.41
Total	26	32.7173	1.258		100

It can be observed that cutting speed, feed rate and depth of cut have percentage contribution of 18.14, 79.86 and 1.58 % respectively. This indicates that the feed rate (79.86%) has the most significant effect on the surface roughness during the turning process.

The main effect plot for the surface roughness is shown in Figure 3. It was observed from the main effect plot that the optimal values of the cutting speed, feed rate and depth of cut are at level 3 (250 rpm), level 1 (0.1 mm/rev) and level 3 (0.7 mm) respectively. A model equation 2 for the output parameter (surface roughness) was obtained using Minitab 17 software.

When the optimal values of the input variables were substituted in the model equation, the predicted optimum surface roughness value of 0.515 μm was obtained. However when confirmation test was conducted, the value of surface roughness obtained was 0.522 μm. The percentage error in this experiment is 1.44% which is acceptable.

$$R_a = 2.08 - 0.01143cs + 9.56fr + 0.48doc \quad (2)$$

where *cs* is cutting speed, *fr* is feed rate and *doc* is depth of cut

The values of R^2 and adjusted R^2 are 68.33 % and 64.20 % respectively. These values are lower than accepted values which may be due to experimental uncertainty.

Figure 5 shows the interaction plot for surface roughness. When the effect of one variable depends on the level of the other variable interactions plot can be used to visualize the possible interactions of the variables. Parallel lines in an interaction plot indicate no interaction while two independent variables interact if the effect of one of the variables differs depending on the level of the other variable. It was observed that cutting speed has the most significant influence at 150 rpm of cutting speed and 0.3 mm/rev of the feed rate. The effect of feed rate was noticed at 0.3 mm/rev when the depth of cut was 0.6 mm.

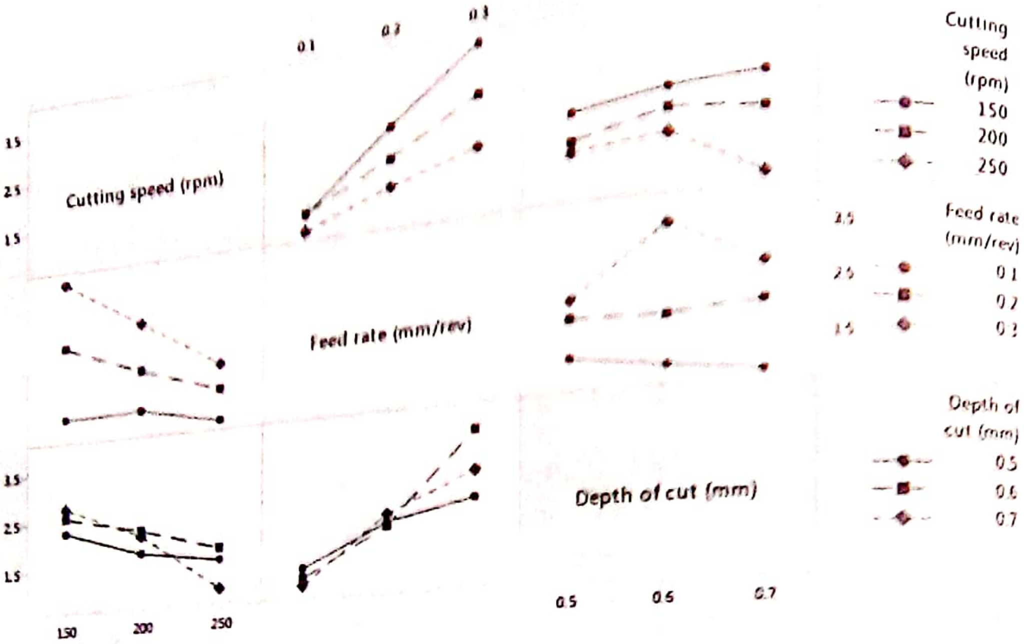

Figure 5: Interaction plots for surface roughness

3.2 Chip Formation

The types of chip formed at different cutting conditions are shown in Figure 6 during turning of AISI 304L alloy steel with coated carbide insert. The chips are observed to be continuous, helical, straight, and serrated. Figure 6 (a, b) shows the chips generated at constant cutting speed of 150 rpm, feed rate 0.10 mm/rev and with different depths of cut of 0.5 and 0.6 mm, respectively. It was noticed that with the increase in the depth of cut, the chip transforms from wavy to the saw toothed type. With the decrease of chip curvature, the chip thickness, and the contact length are increased. Figure 6 (c–e) shows the chips formed at constant cutting speed 200 rpm, depth of cut 0.5 mm, and with three different feed rates of 0.10, 0.20, and 0.30 mm/rev. respectively for c, d and e. With the increase of the feed rate, the chips are transformed gradually from wavy to serrated, the chip curvature was changed, and at the highest feed rate (0.30 mm/rev), the chip breakage occurs. Figures 6 (d) and 6 (f) show the chips formed at constant feed rate of 0.2 mm/rev and depth of cut of 0.5 mm with two different cutting speeds of 200 and 250 rpm respectively. The chips are continuous at all cutting speed; however, at cutting speed 200 rpm, the chips are segmented and a reduction in chip curvature was observed. As the speed increased from 200 to 250 rpm, the chip thickness decreases while the radius of curvature increases.

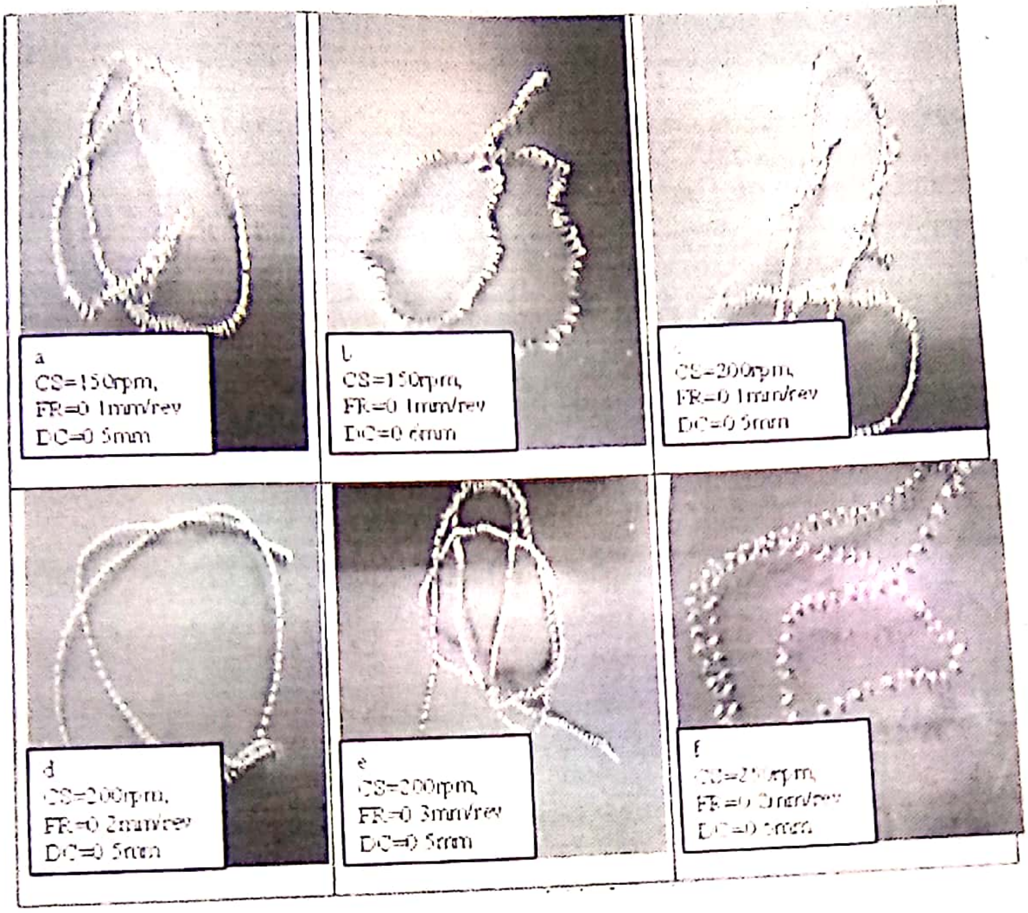

Figure 6: Types of Chip

4. CONCLUSION

The analysis of variance shows that feed rate has the most significant effect on surface roughness with 79.86%, while cutting speed has 18.14% significant and the least effect is depth of cut with 1.58% significant. The relationship between feed rate and cutting speed at constant depth of cut as depicted in the contour plots show that as feed rate increases for every cutting speed, the surface roughness increases. It was observed that the chips formed at different cutting conditions were continuous, helical, straight, and serrated type. It was noticed that with the increase in the depth of cut, the chip transforms from wavy to saw toothed type. With the decrease of chip curvature, the chip thickness, and the contact length are increased.

REFERENCES

Abouelatta, O.B and Mádl. J (2001). Surface roughness prediction based on cutting parameters and vibrations in turning operations. Journal of Material Processing Technology, 118, 269-277.

Ahmed, M. (2013). Optimization of Process Parameters with Minimum Surface Roughness in the Pocket Machining of AA5083 Aluminum Alloy via Taguchi Method. Arab Journal of Science and Engineering. 38: pp. 705–714.

AK Steel (2007). Product Data Sheet: 304/304L Stainless Steels - UNS S30400/UNS S30403. AK Steel Corporation. http://www.aksteel.com/pdf/markets_products/stainless/austenitic/304

3041 data sheet.pdf (@ 2.15 pm on 4th September. 2016)

Ali, R. M. (2010). The optimization of machining parameters using the Taguchi Method for surface roughness of AISI 8660 hardened Alloy Steel. Journal of Mechanical Engineering. 56. 6, 391-401.

Ilhan, A. and Harun, A. (2011). Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method. *Measurement* 44, pp. 1697– 1704.

Kapil, S., Dalgobird. M. and Sen, S. S. (2013). In metal turning, effect of various parameters on cutting tool: A review. Green Hills Engineering, Solan India. International Journal of Application or Innovation in Engineering & Management *(IJAIEM)* Volume 2, Issue 8.

Lalwani, D. I., Mehta, N.K. and Jain, P.K. (2008). Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel. Journal of Materials Processing Technology, 206, 167-179.

Lawal, S. A., Choudhury, I. A. and Nukman, Y. (2014). Evaluation of vegetable and mineral oil-in water emulsion cutting fluids in turning AISI 4340 steel with coated carbide tools. Journal of Cleaner Production, 66. 610-618.

Lawal, S. A., Choudhury, I. A. and Nukman, Y (2015), Experimental Evaluation and Optimization of Flank Wear During Turning of AISI 4340 Steel with Coated Carbide Inserts Using Different Cutting Fluids" Journal of Institution of Engineers, India (Series. C) 96 (1), 21 -28.

Lanjewar. R.W., Saha, P., Datta. U., Bemire. A.J., Jian. S. and Sen. S. (2008). Evaluation of machining parameters of AISI304 austenitic stainless steel on auto sharpening machine. Journal of Scientific Industrial and Research. 67: 282-287.

Rajender, S. (2006). *Introduction to basic manufacturing processes and workshop technology*, New age international (P) limited, publishers. 4-5.

Raoa, C. J., Sreeamulua, D. and Arun, T. M. (2014). Analysis of Tool Life during Turning Operation by Determining Optimal Process Parameters. *Procedia Engineering* 97, 241 – 250.