ISSN 2229-5518

Analysis of corrosion characteristics in turning process of HSLA steel

Singaravel B[1], Marulaswami C[2], Selvaraj T[3]
Department of Production Engineering, National Institute of Technology, Tiruchirappalli, Tamil Nadu, India.

Abstract— Turning operation is one of the primary machining operations wherein enhanced machining performance is obtained by selection of suitable process parameters. High Strength Low Alloy (HSLA) medium carbon steels (EN25 steel) are considered to possess better mechanical properties than carbon steel. In this experimental study, the effects of machining parameters on corrosion characteristics (corrosion rate and current density) of the machined samples are evaluated in turning of EN25 steel. The machining parameters selected are cutting speed, feed rate and depth of cut in order to enhance corrosion characteristics of turned components. The result of the investigation revealed that the mentioned machining parameters are necessary and essential to evaluate the functional attributes of HSLA steel effectively.

Index Terms— Turning, cutting speed, feed rate, depth of cut, EN25 steel, corrosion rate, current density

---

1 Introduction

Turning is a primary and important machining process in engineering industries to obtain the desired shape and size. The achievement of high performance and selection of appropriate process parameters are significant tasks in turning operation. The proper selection of machining parameters leads to higher productivity and better output values in terms of low cutting force, minimum dimensional accuracy errors, better surface finish, long tool life and less power consumption [1, 2].

The quality of the machined component is assured by surface roughness measurement which is an important part of manufacturing. Surface roughness of the machined components influences the fatigue strength, wear resistance and corrosion resistance. Also, surface roughness measurement is an important performance characteristic in machinability study. Nowadays manufacturing industries give special attention to obtain good surface finish in machining operation [3]. In engineering systems, iron and steels are mostly used due to multipurpose applications and least expensiveness. The main disadvantages of iron and steels are poor corrosion resistance in mild service situations. This corrosion resistance may reduce the load carrying capacity of the material. Corrosion measurement and its control in machining operation is one of the ways to improve their efficiency. There will be different solutions to solve this corrosion and extend life of the components. This achievement of optimum process parameters for any machining operation is one such consideration [4].

In machinability investigation, a statistical design of experiments is used to estimate the appropriate experimental data. In order to achieve maximum efficiency of machined sample, it is highly essential to improve the functional attributes by selecting appropriate machining parameters. This study is used to enhance the efficiency of the system by improving functional attributes during service.

2 Literature Review

Horvath and Kiss [5] analyzed surface roughness parameters in turning of aluminum alloys. The result showed that cutting speed and feed rate had significant effect on surface roughness but the interactions of these factors also had much influence on surface roughness. Sharma et al. [6] investigated the coolant effect on surface quality of AISI D2 steel in turning process. The result indicated that surface finish increased due to the cutting fluid effect. Carou et al. [7] experimentally analyzed the influence of process parameters on surface quality of UNS M11917 magnesium alloy in turning process. The results revealed that surface finish was influenced by feed rate. De Oliveira Junior et al. [8] investigated corrosion analysis of machined component in turning of UNS32750 super stainless steel. In their work, the effects of coolant pressure, cutting speed and status (new and fresh) of cutting tools on corrosion resistance of the machined samples were investigated. The result revealed that coolant pressure, cutting speed and worn out tool were the most influenced parameters to ensure the maximum corrosion resistance of components. Hassiots and Petropoulos [9] investigated the relation between topographic parameters and corrosion resistance of turned components of St37 and Ck60 carbon steels. The results revealed that different corrosion behavior were obtained based on machining conditions and types of steel used. The minimum surface roughness provided maximum corrosion resistance and also proper machining parameters control the corrosion resistance of the machined sample. Hassiots et al. [10] analyzed the effects of surface roughness parameters on corrosion resistance in turning of AISI304 stainless steel. The result mentioned that lower surface roughness parameters influenced corrosion behavior of machined samples. Gravalos et al. [11] carried out pitting corrosion tests on turned super austenitic stainless steel surfaces, evaluating the influence of surface roughness and residual stress of these surfaces on pitting formation. They turned several work pieces using different values of feed, depth of cut and cutting speed and verified that no variable exerted a significant effect on residual stress, while feed exerted strong influence on surface roughness. After that, they subjected these turned surfaces with different values of roughness and residual stress to a pitting corrosion test and concluded that surface roughness is

ISSN 2229-5518

more important than residual stress in pitting formation. Low surface roughness contributed in reducing pitting, since the higher peaks of the surface roughness profile contributed in making the pitting formation easier. Moayed et al. [12] conducted a corrosion study on highly finished components. The result revealed that corrosion resistance increased when higher surface quality was considered. Gravier et al. [13] investigated corrosion behavior of copper by considering residual stress, surface roughness and crystallographic texture in turning process. The result indicated that residual stress and surface roughness were the most influencing and crystallographic texture provided minimum influence on corrosion resistance of the machined samples. Devi et al. [14] investigated corrosion study on EN24 and EN8 steel to enhance life of the steel. The result revealed that EN24 steel had better corrosion property than EN8 steel due to uniform distribution of carbide.

Based on literature review, it has been found that few research works are carried out on analysis of corrosion rate and current density of the machined sample. Hence an effort has been made to investigate the effect of process parameters on functional attributes of the machined components using statistical technique in the turning of EN25 steel with CVD coated carbide tool.

3 Experimental Setup

EN25 steel [BS-970-1955-EN25 steel and DIN standard of 32NiCrMo10-4] is used as work material, which possesses high mechanical strength than carbon steel. This steel is used for heavy duty drive shafts [15, 16]. Table 1 shows the chemical compositions of EN25 steel. The turning operations are conducted on CNC turning center with 7.5 KW spindle power in coolant environment.

Table 1 Chemical compositions (wt %) of EN25 steel

Element	wt %
Carbon	0.293
Silicon	0.185
Manganese	0.629
Nickel	2.49
Chromium	0.577
Molybdenum	0.51
Sulphur	0.02
Phosphorous	0.02

The cutting tool material used is Chemical Vapor Deposition (CVD) multi layer coating ($TiN/TiCN/AL_2O_3$) of fine grained tungsten carbide 6% cobalt substrate with ISO geometry of CNMG 120404. In the coated element, TiN provides better heat resistance and lower coefficient of friction; TiCN provides wear resistance and thermal stability and Al_2O_3 provides crater wear resistance due to high-temperature conditions and hardness.

Taguchi orthogonal array is used to study the effect of process parameters on performance characteristics with minimum number of experiments [17]. In this work, L_{18} orthogonal array is applied to conduct turning operations with different combinations of input parameters. Table 2 shows the levels of selected machining parameters and their values.

Table 2 Machining parameters and their levels

Factors	Levels		
	Level 1	Level 2	Level 3
Cutting speed (m/min)	95	155	215
Feed rate (mm/rev)	0.07	0.15	0.23
Depth of cut (mm)	0.5	1.0	1.5

The surface roughness of the machined components is determined by Mitutoyo surftest SJ 301 roughness testing machine. The surface roughness is measured thrice for the machined sample and average value is considered for investigation. The corrosion rate and its current density are measured by potential dynamic polarization technique at room temperature and 0.5 mV/s scan rate, using electrochemical cell which contains three cells. These three-electrode cell consists of steel (working electrode), saturated calomel (reference electrode) and graphite (counter electrode), which are used to conduct polarization experiments. The machined samples are cleaned with the help of distilled water and acetone. Specimens are attached to a holder and kept exposed to the testing environment as to achieve maximum exposure of 1 cm^2 surface area, followed by dipping in 3.5% NaCl solution. This process is maintained an hour to measure the corrosion potential. Fig.1 shows the experimental set up for corrosion test to find the corrosion rate and current density of machined samples. The experimental results are presented in Table 3.

Fig.1 Corrosion test equipment

Table 3 Experimental results

Sl.no	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (µm)	Corrosion current density (mA/ cm^2)	Corrosion rate (mm/ year)
1	95	0.07	0.5	1.121	0.00258	0.1229
2	95	0.15	1.0	1.620	0.0622	0.1742
3	95	0.23	1.5	2.073	0.0956	0.2795
4	155	0.07	0.5	1.043	0.00167	0.1024
5	155	0.15	1.0	1.452	0.0204	0.1821
6	155	0.23	1.5	1.965	0.0621	0.2364
7	215	0.07	1.0	0.986	0.00107	0.0711
8	215	0.15	1.5	1.347	0.0239	0.1473
9	215	0.23	0.5	1.850	0.0506	0.1961
10	95	0.07	1.5	1.027	0.00352	0.1158
11	95	0.15	0.5	1.278	0.0421	0.2142
12	95	0.23	1.0	2.121	0.0894	0.2953
13	155	0.07	1.0	1.004	0.00129	0.0932
14	155	0.15	1.5	1.674	0.0296	0.1648
15	155	0.23	0.5	1.941	0.0456	0.2201
16	215	0.07	1.5	0.994	0.00101	0.0842
17	215	0.15	0.5	1.437	0.0231	0.1376
18	215	0.23	1.0	1.864	0.0309	0.1861

4 Results And Conclusions

In this investigation, objective parameters considered are corrosion rate and corrosion indensity of the machined samples. The experiments are carried out using L_{18} orthogonal array and results are displayed in Table 3. Generally, smaller-the-best characteristic for objective parameters are considered to obtain the effects and significance of process parameters.

Fig. 2 shows the effects of machining parameters on surface roughness during turning of EN25 steel. The turning is performed at different combinations of machining conditions and the surface roughness value increases with increase of feed. This is mainly due to increased friction between work piece and cutting tool. Also, the application of cutting fluid is used to reduce the friction and improve the surface finish.

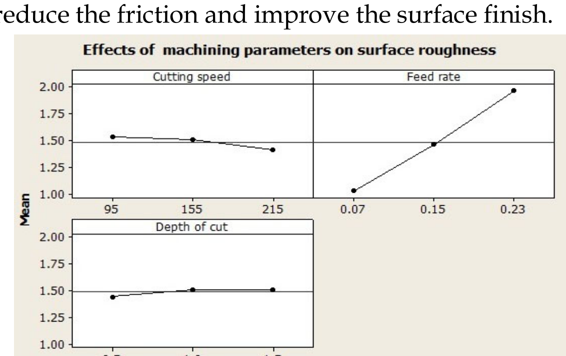

Fig.2 Effects of machining parameter surface roughness

The cutting process may influence the corrosion rate and current density (I_{corr}) of a machined surface because it causes plastic deformation of the machined surface. Moreover, the cutting fluid lowers the temperature of the material in the cutting region; hence temperature of the machined surface influences corrosion resistance. This result indicates that lower temperatures in the cutting region are beneficial for surface corrosion resistance. Figure 3 and 4 show the main effect of the factors that influence the corrosion rate and current deensity (I_{corr}) of turned surfaces. These figures indicate that the use of higher level of cutting speed (215 m/min) and lower level of feed rate (0.07 mm/rev) generated lower corrosion. When the cutting speed increased from 95 to 215 m/min, the corrosion rate also decreased. Increasing the cutting speed caused the cutting temperature to increase and is expected to weaken the material's corrosion rate. Surface finish is high at low feed condition, which is another parameter to be considered when analyzing the influence of the machining operation on the corrosion rate of the work piece. Therefore higher corrosion rate and minimum current density are obtained at higher level of cutting speed in wet turning operation. The potentio dynamic curves of machined samples at higher level of cutting speed and lower level of feed rate are compared with base material (Fig.5). From Fig 4, it can be noticed that current density (I_{corr}) values of machined samples are lower when compared to base material. This is due to moving of curves towards right, indicating minimum current density (I_{corr}) values. Thus higher corrosion rate is obtained at higher level of current density (I_{corr}) values.

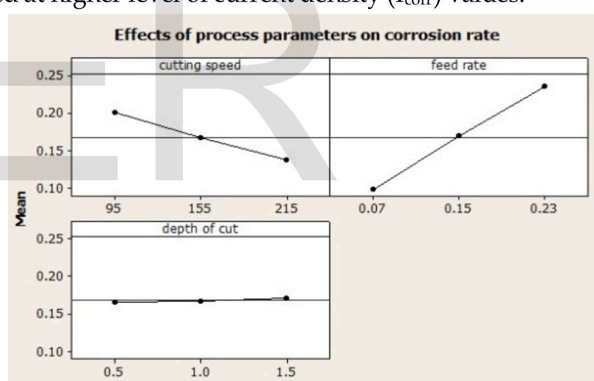

Fig.3 Effects of machining parameter corrosion rate

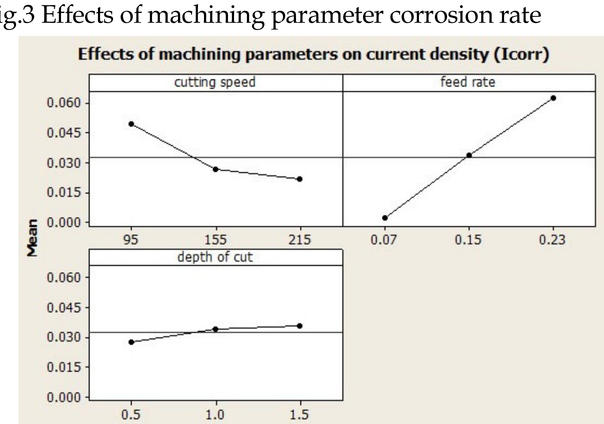

Fig.4 Effects of machining parameter on current density (Icorr)

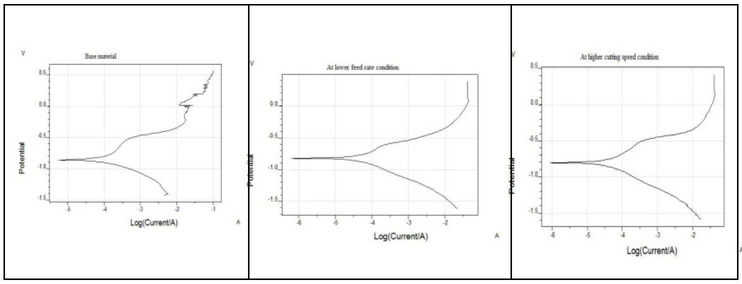

Fig.5 Potentio dynamic curves of base material and machined samples

7 Conclusions

This experimental study analyzed the effects of machining parameters for functional attributes in turning of EN25 steel using coated carbide tools. The following conclusions are derived from this analysis:

- The effects of machining parameters are analyzed for corrosion characteristics for the enhancement of functional life of the machined components.
- The maximum corrosion resistance and minimum current density values are obtained at higher level of cutting speed and lower level of feed rate.
- Surface roughness and cutting fluid of the machining condition influences the corrosion characteristics.

References

[1] M. Nalbant, H. Gökkaya and G. Sur, "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning," Mater & Des, vol. 28, pp. 193-218, 2007.

[2] D. G. Thakur, B. Ramamoorthy and L. Vijayaraghavan, "Study on the machinability characteristics of superalloy Inconel 718 during high speed turning," Mater & Des, vol.30, pp.1718-1725, 2009

[3] I. Asiltürk and M. ÇUnkaş, "Modeling and prediction of surface roughness in turning operations using artificial neural network and multiple regression method," Expert Sys App, vol.38, pp.5826-5832, 2011.

[4] I. Gurrappa and G. Malakondaiah, "Corrosion characteristics of DMR-1700 steel and comparison with different steels in marine environment," Mater Sci Eng A, vol.391, pp.235-242, 2005.

[5] R. Horváth, and A. Drégelyi-Kiss "Analysis of surface roughness of aluminum alloys fine turned: United phenomenological models and multi-performance optimization," Measurement, vol.65, pp.181-192, 2015.

[6] P. Sharma, B. S. Sidhu, and J. Sharma, "Investigation of effects of nanofluids on turning of AISI D2 steel using minimum quantity lubrication," Journal of Cleaner Production, vol.108, pp.72-79, 2015.

[7] D. Carou, E. M. Rubio, C. H. Lauro, and J. P. Davim "Experimental investigation on surface finish during intermittent turning of UNS M11917 magnesium alloy under dry and near dry machining conditions," Measurement, vol.56, pp.136-154, 2014.

[8] C. A. De Oliveira Junior, A. E. Diniz and R. Bertazzoli "Correlating tool wear, surface roughness and corrosion resistance in the turning process of super duplex stainless steel,"J Braz Soc Mech Sci, 36, 775-785.

[9] N. D. Hassiotis and G. P. Petropoulos, "Influence of surface roughness on corrosion resistance of turned carbon steel parts," IJMMM, vol.1, pp.202-212, 2006.

[10] N. Hassiotis, G. Petropoulos, C. Hatzopoulos and N. Vaxevanidis, "Influence of surface topography on corrosion of stainless steel AISI 304 turned surfaces with different cutting conditions," Adv Mater Res, vol.18, pp.399-405, 2007.

[11] M. T. Gravalos, M. Martins, A. E. Diniz, and P.R. Mei PR. "Influence of roughness on the pitting corrosion resistance of turned superaustenitic stainless steel," *Rem: Revista Escola de Minas*, vol.63, pp.77-82, 2010.

[12] M. H. Moayed, N. J. Laycock and R.C Newman "Dependence of the Critical Pitting Temperature on surface roughness,"Corros Sci, vol.45, pp.1203-1216, 2003.

[13] J. Gravier, V. Vignal and S. Bissey-Breton"Influence of residual stress, surface roughness and crystallographic texture induced by machining on the corrosion behaviour of copper in salt-fog atmosphere," Corros Sci, vol.61, 162-170, 2012.

[14] A. Devi, I. Sudhakar and V. V. Ramana, "An Experimental Study on Corrosion Behavior of En8 and En24 Grade Steels,"*Materials Today: Proceedings,* vol.2, 1251-1256, 2015.

[15] B. Singaravel and T. Selvaraj "Optimization of machining parameters in turning operation using combined TOPSIS and AHP method," *Tehn vjesn*, vol.22, pp.1475-1480, 2015.

[16] P. Dinesh Babu, G. Buvanashekaran and K. R. Balasubramanian, "The Elevated Temperature Wear Analysis of Laser Surface–Hardened EN25 Steel Using Response Surface Methodology,"Tribo Trans,vol.58, pp.602-615.

[17] B. Singaravel and T. Selvaraj "Application of Desirability Function Analysis and Utility Concept for Selection of Optimum Cutting Parameters in Turning Operation," JAMS, vol.15, pp.1-11.