



SURFACE ROUGHNESS PREDICTION IN MILLING USING OBLIQUE ANGLE WITH MILD STEEL AND HIGH SPEED STEEL (HSS)

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Research Article

Abstract

There is a need to improve the surface texture roughness in oblique metal cutting in milling operation in order to enhance the economic and technological life of the produced machine parts. Failures can occur due to craters, waviness, flay as well as lay. Many researchers have posited that the entirety of surface roughness cannot be measured with the value of the absolute surface roughness (Ra). The research work obtained models that can predict above the (Ra) and the results will serve as a guide to machinist whilst updating the machining database. The study developed a near sure-fire surface roughness result when machining mild steel with high speed steel while maximizing the tool life and minimizing the machining time.

The study has discovered a sure fire response surface roughness when applying high speed steel (HSS) as tool piece and mild steel as work piece. Furthermore, Ra, Rz, Rq, Rt, M/Ctime were minimized at runs 4, while the TL was optimized at values of 0.461, 01.304, 0.463, 1.317, 65.4 seconds and 91126275.2 seconds respectively. The Analysis of Variance (ANOVA) carried out has evidently showed that the null hypothesis should be accepted at significance a level of 0.05.

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Keywords

Oblique, Surface roughness, Box-behnken, process parameters, Machining, Tool life.

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1.0 INTRODUCTION

Mild Steel and High Speed Steel (HSS) combination has been utilized to mill a good number of machine parts. The oblique metal cutting process in milling operation involves multi-cutting tool and a work piece which are not perpendicular in operation. According to Alli (2014), “there can’t be any level of industrialization in any country if the machining process of that state is not optimized”. Practically all machining operations in modern manufacturing involves oblique cutting and many researchers have tried optimize the procedures in oblique metal cutting and as such many of the researchers have considered the economic effects of such optimization rather than the technological drawbacks in oblique metal cutting. Furthermore a lot of authors have worked on prediction of roughness with respect to only the absolute average value (Ra) and many experts in surface finishing department have posited that the (Ra) cannot describe the entire surface texture of a material whereas (Rz), Root mean squared (Rq), Maximum height of the profile (Rt), Machining time (M/Ctime) and tool life (TL) can describe such.

From these known facts the present research will obtain mathematical models that can predict surface roughness in oblique metal cutting with a view of optimizing the process and above absolute average (Ra). Oblique metal cutting procedure is a type of cutting where cutting tool is not at 90 - degree to the direction of the tool motion. In this cutting process, flow of chip is never perpendicular to cutting point of the tool piece. Nakhjavani et al. (2019) posited that in manufacturing industries, have utilize milling processes in removal of metal chips from blank materials, as it is easier to produce various sizes, shapes and features in record time. Hewidy et al. (2005), noted that to determine the quality and reliability of machined part to be produced the measure of surface roughness is cognisance, their study further stated that absolute average (Ra) is used to measure the topography of a produced part. When poor surface finish is introduced to the production process the resultant effect is increased friction and wear and the performance index of the machined part is significantly hampered while the time of production

is elongated Wang et al. (2002). Taylor (1907) was a pioneer author that worked on metal chip removal process; he developed a model for calculating the tool life of a metal cutting tool, which is of great significance to this current study. Oblique metal cutting as shown in Figure 1.6 is a method of cutting where the cutting where the angle of perpendicularity is not at 90 – degree in line with the cutting tool direction Anand et al, (2016). Also in oblique cutting the flow of chip removal is not perpendicular because, direction of action is not perpendicular (Awopetu and Ayodeji, 2008). Tool life does not fail easily as compared to orthogonal cutting where perpendicularity is visible (Bhuyan and Routara, 2016). Figure 1.6 shows Pictorial view of Oblique cutting. www.mech4study.com (2016)

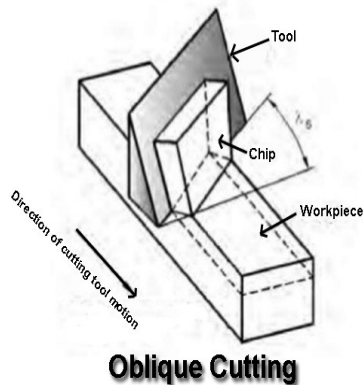


Figure 1.0 Pictorial view of Oblique cutting
(Mech4Study, 2016)

Milling operations is a procedure of producing or machining flat, curve or irregular surfaces. (Khorasami et al, 2011) worked on tool life prediction analysis on face milling machine using 7075 Al material and they applied the artificial neural network and taguchi model to obtain and predict the best point of the tool life in applying 7075 Al. (Li et al, 2008; Lalwani et al, 2008 and; Lim and Meng, 2010). The main constituents of the milling machine include a motor driven spindle, which is mounting and rotates or revolves the milling cutting tool or cutter and a movable or adjustable work table which is used in feeding the work piece against the cutter Mankova, (2000). Milling machine are basically or primarily grouped or classified as vertical or horizontal types. According to Siddputa and paurobally (2013), the milling machine machines can then be sub grouped into (a) the knee – type (b) the ram – type (c) manufacturing or bed – type and lastly (d) the planer – type. Generally milling machines have a self-electric driven motor (Moon and Kalmar-Nagy, 2001), a coolant system is also stored in place with a variable spindle speed as regards different work piece and an automatic power operated feed

table (Lopez et al, 2002). Measure of tool life in metal cutting is very important and is one of the most critical aspects of manufacturing (Choudhury and El-Baradie, 1998). The study of tool life in metal cutting can provide us with some responses such as input work materials, machine parameters and surface finish (Depince and Hascoet 2006). Tool life is generally the performance of a new tool piece, if it works satisfactorily until it is declared failed (Dhar and Kamruzzaman 2006). Tool life is always expressed in machining time (T) in minutes or seconds, whereas in most machine tool industries or manufacturing industries tool life is usually the measure of number of jobs performed, the total value of chip removed and the total length of cut during active time (Galante et al, 1998). Cheng et al. (1993) designed a system for obtaining surface roughness for work in process, and they were able to state that roughness of a work piece is caused by the motion of tool piece and work piece. They used the cylindrical capacitive displacement sensor (CCDS) to obtain their result. Oktem et al. (2005) applied the genetic programming method to obtain their result and posited that the surface roughness causative factors are feed rate, spindle speed and depth of cut and they also observed that vibrations during machining also played a significant role in generation of the surface roughness. From their study and observations they were able to infer that vibration and process parameters generate the best efficient predictions of roughness of surface by method genetic programming. Hilmi and Ali (2021) studied the machinability of AISI430 stainless steel on lathe machine with different coated tool inserts with various cutting speed and feed rate and the Taguchi analysis was able to determine the ideal machining order to achieve the best surface roughness texture of the absolute average (Ra). Furthermore, Jahani (2021) has shown that an increase in surface roughness also increases the cell attachment on TiL3NbL3Zr implants while influencing it major functions such as wettability and mechanical properties negatively. This study is concerned mainly on the prediction of responses from surface roughness measurement whilst obtaining the best tool life geometry and the adequate machining time for a particular surface roughness using mild steel as work piece and high speed steel as tool piece.

2.0 Materials and Methods

This study was carried out in Prototype Engineering Development Institute (PEDI) Ilesha Osun State Nigeria, a subsidiary of National Agency for Science and Engineering Infrastructure (NASeni). The knowledge garnered in literature as well as machine

handbook's was significant in selection of the process and the process parameters necessary for cutting in oblique with a bias to milling machine. Box – Behnken (RSM) was adopted as the process parameters are already defined. The responses to be obtained from the design of the experiment (DOE) include the Ra, Rt, Rz, Rq, TL as well as the M/Ctime.

A. Description of Process Parameters for the Experiment

The oblique milling process parameters echelons are obtained at three (3) disparate values of best choice from parameters selection chart developed by Armarego et al. (1969). Igboanugo and Onifade (2012) and Born et al. (2001) as well as Cheng and Li. (1993) posited method for obtaining the necessary process parameters. The corresponding spindle speeds in rev/min was obtained by the equation (i) Jain (2009).

$$N = \frac{1000s}{\pi D} \quad (i)$$

N is the spindle speed, s is the cutting speed; and D is the diameter of work-piece.

The work piece diameter for this research is 80mm

B. Tester for Roughness and Accessories

The Landtek equipment for measuring the work piece roughness is compatible with required standards, DIN, JIS, ANSI and ISO This surface tester is robust and therefore it's applied in industrial environment and it can be used to ascertain surface roughness parameters in processed parts in relation to preselected conditions of measurements and also show all the measured parameters in the dashboard of the testing machine and also on personal computer (PC) through the RS232 connector cable .

2.1 Tool Life Theory

Chen and Su (1998) reported an extended Taylor's equation developed by Armarego and Brown (1969) as obtained in equations (ii) and (iii) for rough and finish machining respectively.

$$T = \frac{C_o}{V_r^\alpha f_r^\beta d_r^\gamma} \quad (ii)$$

$$T = \frac{C_o}{V_s^\alpha f_s^\beta d_s^\gamma} \quad (iii)$$

Where α , β , γ and C_o are constants of the Taylor tool-life equation.

Shah and Gawande (2012) extended tool-life prediction model that took into consideration the depth of cut as expressed in equation (iv).

$$T = C \left(V^l f^m d^n \right) + e \quad (iv)$$

2.2 Model Development

The model developed in obtaining predictions for optimality for the oblique cutting process in milling while using the response surface methodology (RSM) in Box-Behnken has minimized the surface roughness textures and the time for milling while maximizing the tool life of the tool piece is depicted below.

$$R_a = -1.404277 + 0.4609697v + 204.21115f - 838.3885(ap) - 0.014552v^2 - 28731.72f^2 + 0(ap)^2 - 4.149109vf - 16.20073v(ap) + 185525.46f(ap) \quad (v)$$

$$R_z = -3.973589 + 1.304198v + 577.06366f - 2369.901(ap) - 0.041176v^2 - 81301.51f^2 + 0(ap)^2 - 11.68213vf - 46.03984v(ap) + 525042.52f(ap) \quad (vi)$$

$$R_q = -1.221915 + 0.3682406v + 285.51108f - 617.322(ap) - 0.006236v^2 - 24124.68f^2 + 0(ap)^2 - 17.1353vf - 42.52367v(ap) + 207813.46f(ap) \quad (vii)$$

$$R_t = -3.718812 + 1.246309v + 612.27968f - 2380.732(ap) - 0.03864v^2 - 81011.32f^2 + 0(ap)^2 - 13.93391vf - 41.66338v(ap) + 522314.61f(ap) \quad (viii)$$

$$TL = 38564839 + 2282144.5v + 0f - 6.14009(ap) + 0v^2 + 0f^2 - 4.130013(ap)^2 - 4398786vf + 5.7525009v(ap) + 0f(ap) \quad (ix)$$

$$\frac{M}{CTime} = 542.14407 - 28.37931v - 33861.51f - 157087.6(ap) + 0.7642434v^2 + 2834566.8f^2 + 0(ap)^2 - 1018.926vf + 10444.633v(ap) + 4525396.4f(ap) \quad (x)$$

2.3 Predictions Surface Response Model of Regression Analysis

The response obtained from the quadratic model is both polynomial and fractional regression contemplates. The response for Ra, Rz Rq and Rt, are in micrometer while the machining time and tool life are measured in seconds. The experimental responses have minimized residuals as provided from the error column. To boot the error squares have lager part to be unity, thereby supporting the claim of the research.

3.0 Results and Discussion

Table 1: The Process Parameters for Machining Mild Steel with High Speed Steel (HSS)

Runs	L (mm)	Process Parameters						
		v (mpm)	f (mm/rev)	ap (mm)	v (m/s)	f (mmPM)	f m/s)	ap (m)
1	50	503	1.5	1	8.3833	0.03292	0.00198	0.00
2	50	1005	1.5	1	16.7500	0.06578	0.00395	0.00
3	50	503	4.5	1	8.3833	0.09876	0.00593	0.00
4	50	1005	4.5	1	16.7500	0.19733	0.01184	0.00
5	50	503	3	0.5	8.3833	0.06584	0.00395	0.00
6	50	1005	3	0.5	16.7500	0.13155	0.00789	0.00
7	50	503	3	1.5	8.3833	0.06584	0.00395	0.00
8	50	1005	3	1.5	16.7500	0.13155	0.00789	0.00
9	50	754	1.5	0.5	12.5667	0.04935	0.00296	0.00
10	50	754	4.5	0.5	12.5667	0.14805	0.00888	0.00
11	50	754	1.5	1.5	12.5667	0.04935	0.00296	0.00
12	50	754	4.5	1.5	12.5667	0.14805	0.00888	0.00
13	50	754	1.5	1	12.5667	0.04935	0.00296	0.00
14	50	754	1.5	1	12.5667	0.04935	0.00296	0.00
15	50	754	1.5	1	12.5667	0.04935	0.00296	0.00

Table 2: Experimental responses Output for Mild Steel with High Speed Steel (HSS)

Runs	L(mm)	Experimental Responses					
		M/Ctime	Ra	Rz	Rq	Rt	TL(sec)
1	50	120	2.251	6.367	2.336	6.43	60791136
2	50	138	2.031	5.744	2.42	5.801	45608474
3	50	187	1.718	4.859	1.802	4.907	22804237
4	50	189	0.461	1.304	0.463	1.317	91126275
5	50	240	0.516	1.46	0.516	1.474	60791136
6	50	65.4	2.657	7.516	2.81	7.59	15202825
7	50	155.4	0.719	2.034	0.838	2.054	20263712
8	50	187	1.76	4.978	1.836	5.028	22804237
9	50	187.2	1.481	4.188	1.566	4.23	60791136
10	50	68.4	2.014	5.696	2.141	5.753	30375425
11	50	144	1.76	4.978	1.811	5.028	60791136
12	50	120	2.843	8.043	2.996	8.122	45563138
13	50	186	1.65	4.667	1.726	4.413	45563138
14	50	248	0.469	1.328	0.469	1.341	60791136
15	50	210	2.438	6.894	2.522	6.962	20263712

Table 3: Predicted Experimental responses for Mild Steel with High Speed Steel (HSS)

Runs	Predicted Responses					
	M/Ctime Hat	RaHat	RzHat	RqHat	RtHat	TLHat
1	224.6552	1.052432	2.976511	1.049664	2.978092	57623976
2	160.0835	1.941374	5.489222	2.305393	5.532221	76499973
3	163.4932	1.557868	4.405816	1.678047	4.470224	57478293
4	147.0192	0.888921	2.513151	0.927726	2.551035	75918399
5	208.8389	1.537891	4.349208	1.5344	4.37353	57551134
6	82.61022	1.685345	4.765916	1.836956	4.781366	76209186
7	157.19	1.296616	3.667553	1.381568	3.706956	57551134
8	136.1904	2.039997	5.76915	2.147691	5.825543	76209186
9	186.6593	2.042877	5.777537	2.148943	5.746405	67080112
10	122.5179	1.47757	4.177779	1.487794	4.199895	66752760
11	174.2254	1.550233	4.383698	1.612567	4.388655	67080112
12	136.8831	2.083591	5.893198	2.182072	5.935248	66752760
13	180.4424	1.796555	5.080617	1.880755	5.06753	67080112
14	180.4424	1.796555	5.080617	1.880755	5.06753	67080112
15	180.4424	1.796555	5.080617	1.880755	5.06753	67080112

Table 4: Actual and Predicted Error responses for Mild Steel with High Speed Steel (HSS)

Runs	Error Responses					
	M/Ctime/ M/Ctime Hat	Ra/RaHat	Rz/RzHat	Rq/RqHat	Rt/RtHat	TL/TLHa t
1	-104.6552	1.198568	2.976511	1.286336	3.451908	3167160
2	-22.08348	0.089626	5.489222	0.114607	0.268779	-30891499
3	23.50684	0.160132	4.405816	0.123953	0.436776	-34674056
4	41.98084	-0.427921	2.513151	-0.464726	-1.234035	15207876
5	31.16112	-1.021891	4.349208	-1.0184	-2.89953	3240002
6	-17.21022	0.971655	4.765916	0.973044	2.808634	-61006361
7	-1.789975	-0.577616	3.667553	-0.543568	-1.652956	-37287422
8	50.8096	-0.279997	5.76915	-0.311691	-0.797543	-53404949
9	0.540714	-0.561877	5.777537	-0.582943	-1.516405	-6288976
10	-54.11794	0.53643	4.177779	0.653206	1.553105	-36377335
11	-30.22542	0.209767	4.383698	0.198433	0.639345	-6288976
12	-16.88308	0.759409	5.893198	0.813928	2.186752	-21189623
13	5.557649	-0.146555	5.080617	-0.154755	-0.65453	-21516975
14	67.55765	-1.327555	5.080617	-1.411755	-3.72653	-6288976
15	29.55765	0.641445	5.080617	0.641245	1.89447	-46816400

Table 2, show the process parameters obtained from machining handbook while table 2 shows the experimental data obtained from the milling machine when cutting the mild steel with the high speed steel. Table 3 shows the predicted responses from equation (v) to (x) and table 4 show the difference in value between the actual measured and the predicted from equations (v) to (x), in the same vein figures 1 to 6 is also showing the graph of actual measured as against the predicted. The response surface optimisation carried out on Ra, Rz, Rq, Rt as well as M/Ctime and TL. The experimental and test data provided a general solution for the process parameters as observed from the P-values, Determination (R^2) Coefficient as well as the Root Mean Square Error (RMSE), has shown that the predicted and actual for Ra, shows a heteroskedasticity meaning that the spread along the horizontal and diagonal line of action is fairly not constant as also evident in the graphs of Rz, Rq and Rt. There is a clear homoskedasticity in the graph of TL and M/Ctime of actual and predicted values thereby showing that the spread is fairly constant therefore, this connotes that the parameters for the process in oblique metal cutting such as feed rate, depth of cut and cutting speed plays a significant role on the amount of process time for particular process parameter settings. To boot the process time can be greatly reduce if the necessary correct process parameter interactions are observed as this will in turn extend the tool life of the cutting material.

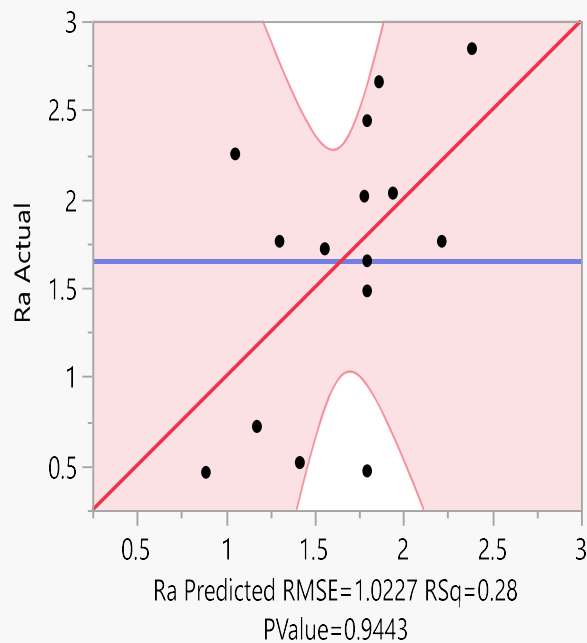


Figure. 1: Plot of Ra Actual and Ra Predicted for Mild Steel and HSS Tool Combination

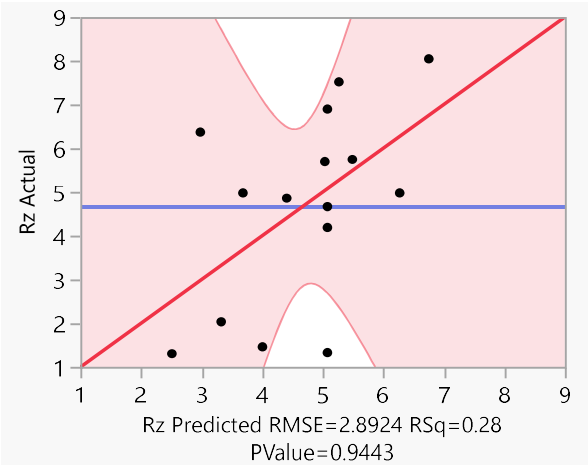


Figure. 2: Plot of Rz Actual and Rz Predicted for Mild Steel and HSS Tool Combination

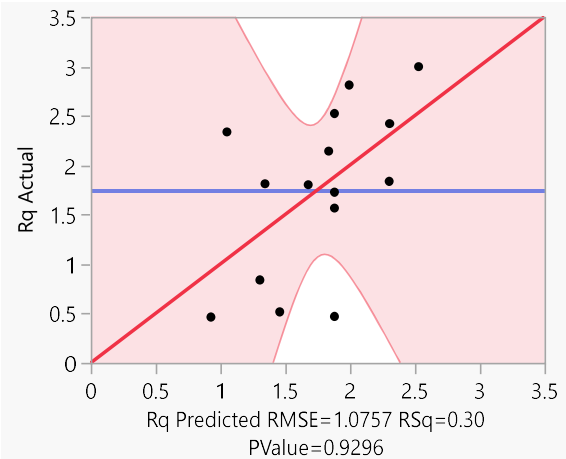


Figure. 3: Plot of Rq Actual and Rq Predicted for Mild Steel and HSS Tool Combination

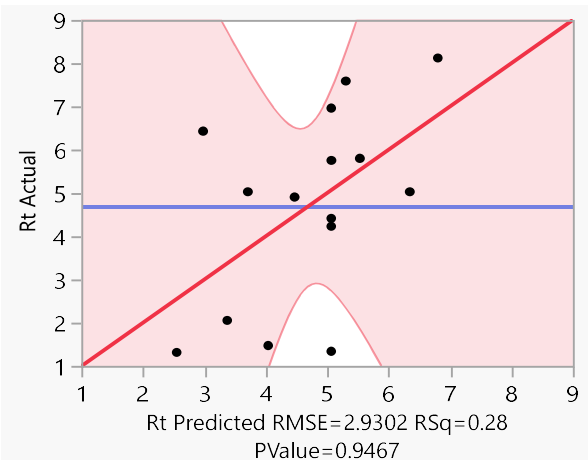


Figure. 4: Plot of Rt Actual and Rt Predicted for Mild Steel and HSS Tool Combination

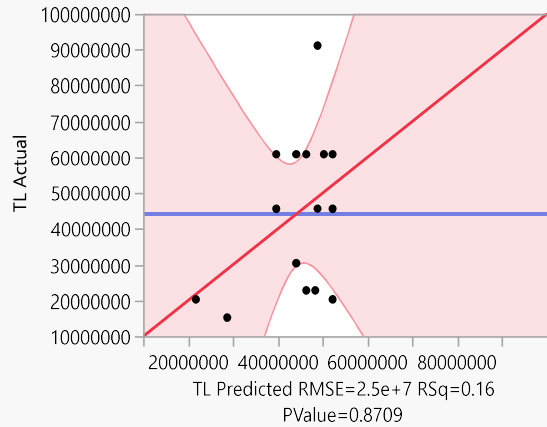


Figure. 5: Plot of TL Actual and TL Predicted for Mild Steel and HSS Tool Combination

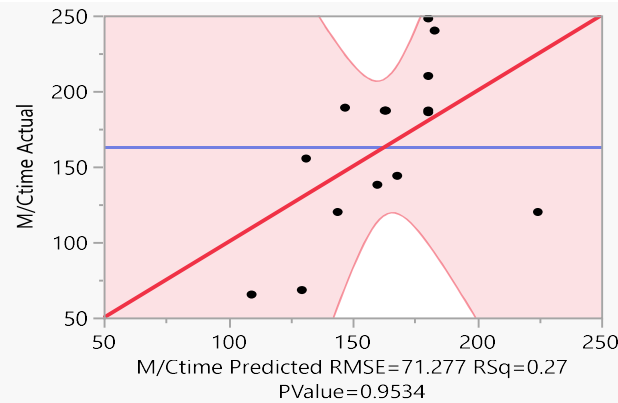


Figure 6: Plot of M/Ctime Actual and M/Ctime Predicted for Mild Steel and HSS Tool Combination.

Table 5. Summary of lack-of-fit

Response	Models	Source	p-value	Decision
Ra	RaHat	Lack-of-fit	0.944 3	Evidence not Enough
Rz	RzHat	Lack-of-fit	0.944 3	Evidence not Enough
Rq	RqHat	Lack-of-fit	0.929 6	Evidence not Enough
Rt	RtHat	Lack-of-fit	0.946 2	Evidence not Enough
TL	TLHat	Lack-of-fit	0.870 9	Evidence not Enough
M/Ctime	M/CtimeHat	Lack-of-fit	0.953 4	Evidence not Enough

4.0 Conclusion

Our study was able to determine the adequate values of process parameters needed in order to machine a particular texture of produced material while determining the tool life and machining time. The test and experimental data that is able to provide by this study can improve and nudge our machine tool industry into a decent economy. To boot the study was able to provide result of surface roughness texture of above the absolute average value (Ra), more so, values for Average distance between highest peak and lowest valley in each length (Rz), Root mean squared (Rq), Maximum height of the profile (Rt), Machining time (M/Ctime) and tool life (TL) has been provided when machining with mild steel and high speed steel. ANOVA was applied to determine the lack of fit while taking significance α interval level at 0.05, and the result suggested that the null hypothesis should be accepted as there is no enough evidence to accept the alternative hypothesis. Furthermore, our study was able to minimize the surface roughness Ra, Rz, Rq and Rt as well as the Machining time M/Ctime, while maximizing the tool life TL. The obtained results are 0.461micron for Ra, 1.304 micron for Rz, 0.463 micron for Rq, and 1.317 micron for Rt at run four (4) there we can infer that machining with low depth of cut, high for feed rate and medium speed of cut is critical in the positive direction for mild steel and high speed steel (HSS) combination. The maximized tool life (TL) is at run (4) in 91126275.2 seconds and the minimized machining time (M/Ctime) is at run six (6) with 65.4 seconds.

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