International Journal of Engineering and Advance Technology Studies
Vol.1, Issue 2, pp. 23-33, September 2013
Published by European Centre for Research Training and Development UK www.ea-journals.org)

INVESTIGATION OF THE CHARACTERISTIC BEHAVIORS OF CAST IRON, ALUMINUM AND BRASS UNDER THE EFFECTS OF CUTTING SPEEDS AND FEED RATES IN CYLINDRICAL MACHINING OPERATION

M. C. Nwosu and E.C. Chinwuko
Department of Industrial and Production Engineering, Nnamdi Azikiwe University Awka, Nigeria.

ABSTRACT: *In order to establish, the pattern of surface characteristics against some input machining variables: this study was carried out on the effects of cutting speed and feed rate during turning process on the surface characteristic of three different metals – Cast iron, aluminum and Brass. The cutting force decreased from 6700N to 5900N when the cutting speed increased from 3.20-m/s to 7.50m/s. Correspondingly the surface friction co-efficient decreased from 0.358 to 0.236. The cutting force increased with increase in feed rate with corresponding increase in co-efficient of friction. The increase in cutting force with increased feed rate simply implies that the machine ability decreases with feed rate in the order aluminum, brass and cast Iron. The corresponding increase in co-efficient of friction with increasing feed rate implies that surface roughness increased with feed rate. Co-efficient of friction and cutting force both decreased when cutting speed is increased leading to decrease in surface roughness. It is concluded that a high cutting speed combined with lower feed rate will produce a smooth surface finish. Also physical property of material such as hardness affects the response of material to machining operation.*

KEYWORDS: Cylindrical machining, cutting speed, feed rate, surface characteristic and cutting force

INTRODUCTION

Machined components are expected to meet certain degree of surface finish in order to effectively fit and perform reliably in service. The service life of mechanical components is strongly influenced by their surface integrity. The required degree of surface finish is specified to guarantee smooth surface, great accuracy to tolerance level and a good aesthetic value. The profiles created during machining operation are critical in determining the nature and event of residual stresses and metallurgical change/damage that accompanied the process. The generation of good surface finish in machine component is not only process determined but is also affected by the process variables [Anstead et al, and Serender K]. For instance, the character of surface finish produced in milling, grinding, and turning operations are not the same. The choice of a particular process is dictated majorly by the intended service conditions [Adeyemi]. The development of good surface character in a chosen machining operation is greatly influenced by the interplay of the process variables. Some of these variables are cutting speed, feed rate, depth of cut, the cutting angles, tool materials and geometry, types of material being machined and lubrication [Oxley], these parameters affect surface characteristics in terms of surface friction co-efficient, surface roughness value, and the surface smoothness and waviness profiles developed during machining operation. These effects are developed by the combination of the cutting force and the progressive increase in temperature generated in both the tool and work piece as machining operation progresses. For instance, cutting force has a significant influence on the dimensional accuracy.

Liu et al [Liu, X. et al, 2002], investigated the cutting force distribution in cutting tests of titanium alloy in terms of the size effects of un-deformed chip thickness, the influence of effective rake angle and the chips flow angle. Their result indicated that the cutting force distribution in the cutting process has a significant effect on the dimensional accuracy of the finished part. That is, the cutting force generated during machining operation is a critical parameter in ensuring dimensional accuracy.

Several research works had been carried out on the interrelationship of the process variables and the surface characteristic developed in material during machining operations. [Saglam et al] measured the cutting force and temperature variation developed as an effect of the change in rake angle and approaching angle of the cutting tool in machining an AISI 1040 steel hardened at $40HR_c$. They posited that a small rake angle generated a high cutting force and attendant increase in temperature with the possibility of inducing metallurgical change in the work piece. Reddy and Rao studied the effect of solid lubricants on cutting force and surface quality in end milling. The kernel of their work was the substitution of the conventional cutting fluid with solid lubricant for desirable control of cutting temperature. Their work investigated the effect of graphite and molybdenum disulphide as solid lubricants on surface quality, cutting forces and specific energy while machining 1045 steel using cutting tools of different geometry in comparison with wet machining. The result of their study indicated that there was a considerable improvement in the process performance with solid lubricant assisted machining as compared to that of machining with cutting fluids.

The influence of feed rate in providing high precision and efficient machining in terms of surface roughness and dimensional accuracy was demonstrated in the work of [Baek et al, 2001]. Their work sought to optimize the feed rate in a face milling operation using a surface roughness model. The developed model was validated through cutting experiments; and it was used to predict the machined surface roughness from the information on the insert run-outs and the cutting parameters. They inferred that from the estimated surface roughness value, the optimal feed rate that gave a maximum material removal rate under the given surface roughness constraint could be selected by a bisection method. All these described past works were centrally concerned with the generation of good surface finish and maintenance of dimensional accuracy in work piece during machining operation.

The ability to produce a surface finish on a particular manufactured component in machining operations depends on understanding how the various contending process variables play on one another to affect, ultimately, the character of the surface of a machined component. The objective of this work is to investigate the effects of cutting speed and feed rate on surface characteristics of some metals during cylindrical turning operation.

MATERIALS AND METHODS

2.1 **Typical Forms of Selected Metallic Material**

Material	Composition	Code	U.T$_s$ MPa	Y$_s$ MPa
Cast Iron	60 – 40 - 18	60	448	324
Brass	Cu 61.5%, Zn 35.5% and Pb 3.0%	C36000	360	220
Aluminum	1100(A9110)	A91100	90	35

Source: Metals Handbook, **ASM materials Park Ohio**

Experimental Apparatus

The specimens used for this study were normalized Cast Iron, Brass and aluminum tubes. The cutting tool used was carbide tool-brazed-on Tungsten carbide (Seco-S4) Material whose geometry is given in Table 1. A centre lathe machine with all the necessary attachments (dynamometer, and Tachometer) were used for measurements of the necessary parameters in turning operation.

Table I: Geometry of experimental cutting tool [Serope et al, 2006]

Clearance Angle	12^o
Side Clearance Angle	8^o
Approach Angle	90^o
Plan Angle	10^o
Side Rake Angle	5^o
Back Rake Angle	5^o

Experimental Procedure

The experimental set-up consisted of a centre lathe machine on to which the cylindrical specimen, the cutting force dynamometer, tachometer and the work piece were firmly attached.
The metallic tubes were individually rigidly positioned on the lathe machine before turning operation was commenced. Three samples 200mm long of each of the specimen were used for the study. Four lathe machine speeds of 245 rpm, 330 rpm, 450rpm and 575rpm were used for the turning operation.

Turning operations were carried out on the three different metallic specimens – cast Iron, brass and aluminum tubes respectively using a brazed on-Tungsten carbide cutting tool. The specimens were marked into four different portions with a partitioning tool before each portion was machined at the four selected lathe speeds.

The values of horizontal [F_h] cutting force and vertical [F_v] cutting forces were obtained with the aid of the lathe dynamometer using equations (1) and (2) respectively while machining the specimens at varying cutting speeds and feed rates. These values were used to obtain the resultant cutting force by applying equation (3). The friction co-efficient [μ], was evaluated using equation (4).

F_h = horizontal reading x 25900 N/m (1)
F_v = vertical reading x 25900 N/m (2)
Where:
F_h = horizontal force, F_v = Vertical cutting force
$R = [F_h^2 + F_v^2]^{1/2}$ (3)
The friction co-efficient μ is given as
$\mu = (F_t + F_c \tan(x)) / (F_c - F_t \tan(x))$ (4)
Where x = tool rake angle

RESULTS AND DISCUSSIONS

The results of the study were obtained through equations 1- 4 and are shown in tables 2 and 3 (appendix- 1), and are illustrated in the plots as in figures 1-5 (appendix- 2). The equations of the Curves are shown as 1- 4 of appendix- 3. The Coefficients of the R^2 indicates how far the experimental results deviate from the theoretical Values. R^2 is between 0 and1; and is of highest value at 1.

DISCUSSION OF RESULTS

Figure 1 is the graph of co-efficient Friction (μ) against feed at constant speed (chosen speed). The graph shows that friction increases with feed. The higher the co-efficient of friction, the higher the degree of surface roughness, and the increase in co-efficient of friction decreases as cutting speed increases. Figure 1 revealed also that at a particular feed rate level of approximately 0.1mm the co-efficient of friction of cast Iron and brass are almost equal. At this level it is expected that the s cast Iron and brass would have the same surface characteristic. This indeed was the reality. At this level of feed however, aluminum retains it low value of frictional co-efficient. At feed levels less than 0.1mm the frictional response of Cast Iron is higher than that of brass. The brass momentarily at feed levels greater than0.1mm but less than 0.12mm has a higher frictional co-efficient. The surface characteristic of the brass at this situation was higher compared to the cast Iron. The surface roughness decreases to obtain a smoother surface finish and continuous chips corresponding progressive decrease in co-efficient of friction. The surface roughness increases from aluminum, brass to mild steel. This scenario of the co-efficient of friction is related to the hardness of the material in reference to the machinability of the materials [Callister Jr.]. The higher the hardness of the material, the higher the cutting force and the higher the friction co-efficient produced hence, poor surface is produced. In terms of structural mechanics, increased cutting force leading to higher frictional force is generated as a consequence of strain hardening. This implies that higher shear stress will be required to initiate slip and material cleavage which eventually causes the chips removal. This apparently leads to increased temperature in both the specimen and the tool material. If the temperature is high enough, it may lead to metallurgical transformation in the various work pieces. The dimensional accuracy and the quality of machining are affected in the process. The energy consumption is equally high.

Figure 2 involved the direct variation of resultant cutting force with feed rate for the three different materials at constant cutting speed of 330rpm (4.32m/s). The generated cutting force given by equation 3, increases with increasing feed rate for all the three different test materials. Cast Iron developed the highest stream of result for cutting forces while aluminum had the least spectrum. This is due to the differential response of these materials to plastic deformation. The different test samples have different yield strength (Y_s) – aluminum (35MPa), brass (21MPa) and cast Iron (346MPa) respectively [Calliser Jr.]. The implication of this is that plastic deformation will occur readily in aluminum and least in Cast Iron due to the amount of force required to initiate plastic deformation. It is apparent from Figure 2 that the effect of feed on resultant cutting force is most prominent in cast steel. At lower feed rate of less than 0.09mm, the differential resultant cutting forces associated with three different materials are very marginal. However, at feed levels greater than 0.09mm, the response of resultant cutting force to change in feed was very strong in Cast Iron. The Cast Iron had a very wide margin of differentials compared to both brass and aluminum. This is best explained in terms of the strain hardening tendency of the materials. Strain hardening effect is most significant in mild steel and thus Cast Iron delivers great plastic deformation resistance to chips formation. Hence, the very high value recorded in the resultant cutting force for the Cast Iron specimen. The surface characteristic of the Cast Iron specimen at this level of feed is very rough with heavy intensity of burrs. The cutting forces for brass and aluminum were however approaching a convergence. The surface characteristic of brass and aluminum at these conditions had a smooth texture.

Figure 3 displayed the frictional force response to changes in cutting speed at constant feed. The figure revealed that frictional force decreases with increase in cutting speed across the three test specimens investigated. A critical analysis of, Figure 3 revealed that the fall in frictional force with increase in cutting speed is most pronounced in aluminum and least in Cast Iron. Machining at higher cutting speed leads to high friction between tool and work piece. This can result in high temperature which tends to structurally anneal the specimens and makes material removal in form of chips quite easy rather than the strain hardening that takes place at lower cutting speed. This definitely requires less cutting force and low energy cost in terms of power consumption. When the temperature generated due to frictional force rather high very close to or at the softening temperature of the material, the material softens and the surface characteristic of the finished component becomes poor due to the formation of severe contours and burrs. In the present study, the progressive decrease in co-efficient of friction as cutting speed increases implies that more material will easily be removed. The significance of this is that machine ability increases with increase in cutting speed while cutting forces reduces. The increase in machinability is in the order Cast Iron, Brass and aluminum. This is because the tendency for structural annealing at high temperature is higher in non-ferrous materials compared to ferrous materials.

Figure 4 displayed the cutting force response to changes in cutting speed at constant feed. In the figure, the cutting force decreases with increasing cutting speed across all the three materials investigated as in Figure 3.

The resultant cutting force or what is generally referred to as machining force is one of the important criteria by which the performance of any machining process can be evaluated. The cutting force determines the power requirement the process [Bhattacharyya]. The intensity of heat generated depends on this force and it is very crucial as far as the machining temperature and surface quality of machined materials are concerned.

Figure 4 revealed that as cutting speed increases the cutting force decreases. This trend is expected because as cutting speed increases, machining becomes adiabatic and the heat generated with increased cutting speed in the shear zone cannot be conducted away during the very short time in which the metal passes through this zone. Therefore, the temperature rise softens the material aiding grain boundary dislocation thereby reducing cutting forces across the three materials as apparent in Figure 4.

The grain boundary dislocation which enhances material removal in the form of chips at high cutting speed is highest in aluminum and least in Cast Iron. This implies that increase in cutting speed enhances ease of machining. The increase in machine ability is in the descending order of cast steel, brass and aluminum. Cast Iron had the highest hardness followed by brass and then aluminum. Thus the increase in surface roughness from aluminum through brass to Cast Iron

CONCLUSION

The work has revealed that cutting forces and co-efficient of friction generated in a typical machining process are affected by machining parameters such as feed rate and cutting speed. The cutting force increased with increase in feed rate with corresponding increase in co-efficient of friction. The cutting force and co-efficient of friction both decreased with increasing speed. The increase in co-efficient of friction with corresponding increase in cutting force implies that machine ability decreases in the ascending order of aluminum, brass and Cast Iron. At feed level of approximately 0.1mm, the frictional co-efficient of Cast Iron and brass had the same surface characteristics. At feed rate lower than 0.09mm, the differential resultant cutting force associated with the three metals is marginal. However, at feed levels greater than 0.09mm, Cast Iron had wide margin of differentials. The work has revealed that machining different metals at federate of less than 0.09mm requires minimal cutting force and thus minimum energy is consumed. But at feed rate greater than 0.09mm, machining of Cast Iron consumes more energy than either brass or aluminum. Knowing this behaviour will assist manufacturing industries in optimizing the feed rate in order to conserve energy consumption.

It is concluded that higher cutting speed combined with lower feed rate produces a smooth surface finish. Also, physical property of materials such as hardness affects the response of material to machining operation.

REFERENCES

Anstead, B. H. Philip F.O and Nylon L.B.(1987), Manufacturing Process John Wiley. New York, Pp 87-125

Serender, K. (1987), Principles of Metal Working 2nd Edition, Addison Wesley Publishing Company, California (1987).

Adeyemi, M.B. (1998), Effects of Heat Treatment on the Quality of Surface Finish of Turned Steel Rods. Journal of Engineering Research, Vol 6 No. 1, pp. 27-35

Oxley, P.L.B.(1989) Analytical Approach to Assessing Machine ability. *Journal of Mechanics of Machining,* Part B Vol. 2, pp 458-510

Liu, X. –W. Cheng. K. Webb, D. and Luo, X – C, (2002) Prediction of Cutting Force Distribution and its Influence on Dimensional Accuracy in Peripheral Milling. International Journal of Machine Tools & Manufacture. Vol. 42. No 7, pp. 761-875.

Saglam, H.: Unsacar, F. and Yaldiz, S. *(2006)*, Investigation of the Effect of Rake Angle and Approaching Angle on Main Cutting Force and Tool Tip Temperature. *International Journal of Machine Tools and Manufacture Vol. 46, No 2, pp. 189-198.*

Reddy, N.S.K and Rao, P.V. (*2006),* Experimental Investigation to Study the Effect of Sol Lubricants on Cutting Forces and Surface Quality in End Milling. *Internal journal Machine Tools and Manufacture No 2. pp. 185-189.*

Back, D.K.: Ko T. J. and Kim, H.S: (2001), *Optimization of Feed rate in a Face Milling Operation Using a Surface Roughness. Model, International Journal of Machine Tools and Manufacture* Vol. 41 No. 3, Pp 451-462.

Callister Jr. W.D. (1997), *Materials Science and Engineering: An Introduction.* 4th Edition, John –Wiley & Sons Inc, New York pp 145 -260

Bhattacharya, A; ‘Metal Cutting Theory and Practice’, Central Book Publishers, Calcutta.

Serope Kalpakjian, Steven R. S., (2006), Manufacturing Engineering and Technology Fifth Edition, Pearson Education, USA, pp 608-642

APPENDIX 1

Table 2: Effects of feed rate on surface smoothness at constant cutting speed of 330 rpm (4.32m/s)

Material	**Feed Rate** (mm)	**Cutting forces**		**(N)**	**Friction Co-efficient μ**
	t_o	F_v	F_h	R	
Brass	0.06	2952	536	3000	0.273
	0.08	3446	804	3500	0.327
	0.10	3750	1072	3900	0.383
	0.12	3864	1608	4010	0.387
Aluminum	0.06	32.35	650	3300	0.264
	0.08	3108	804	3499	0.294
	0.10	3626	938	3781	0.354
	0.12	3844	1072	3991	0.376
Cast Iron	0.06	2590	536	2545	0.300
	0.08	3108	804	3210	0.354
	0.10	5180	1472	5290	0.381
	0.12	6470	1897	7885	0.391

Table 3: Effects of cutting speed on surface smoothness at constant feed 0.15mm

Material	**Cutting speed**		**Cutting forces (N)**			**Friction Co-efficient μ**
	Rpm	**m/s**	**F_v**	**F_h**	**R**	
Brass	245	321	6481	1700	6700	0.358
	330	4.32	6245	1400	6400	0.318
	450	5.89	6164	1300	6300	0.287
	575	7.53	5838	850	5900	0.236
Aluminum	245	3.21	6676	2830	7010	0.402
	330	4.32	6465	1660	6675	0.352
	450	5.89	6273	1500	6400	0.334
	575	7.53	6185	1400	6300	0.286
Cast Iron	245	3.21	6245	1400	6400	0.317
	330	4.32	6165	1250	6290	0.295
	450	5.89	5926	1000	6070	0.260
	575	7.53	5608	645	5645	0.205

APPENDIX –2: Graphical Illustrations of Machining Characteristics

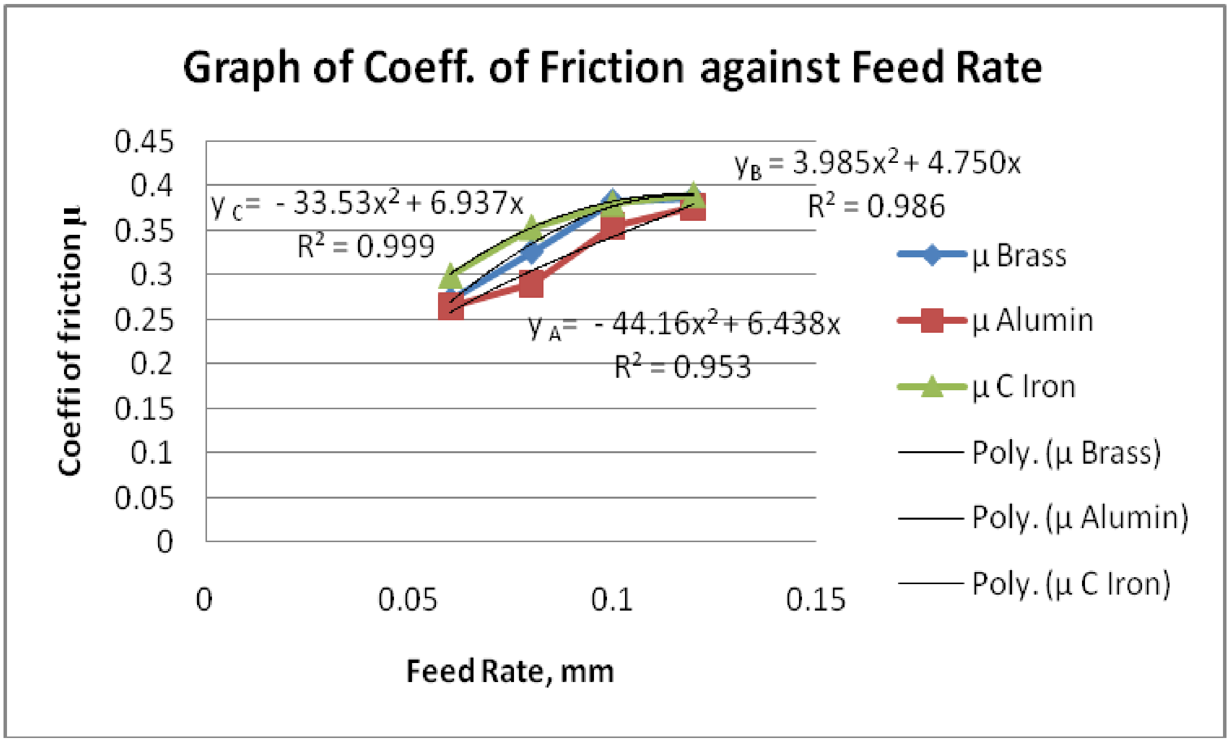

Figure 1: Graph of co-efficient Friction (µ) against feed at constant speed (chosen speed)

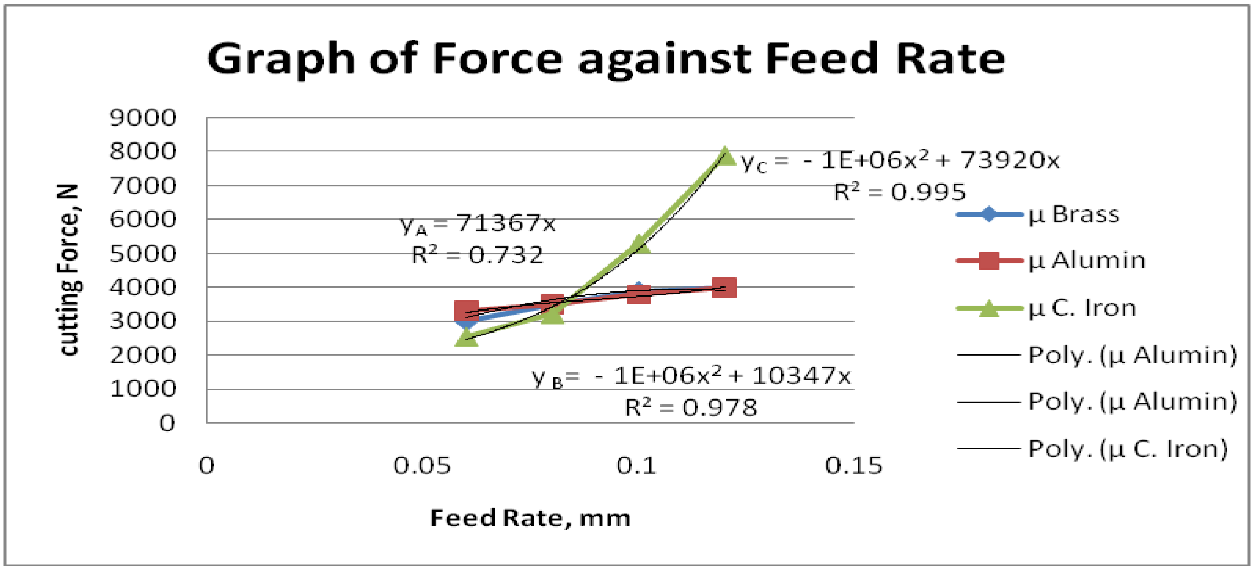

Figure 2: Variation of resultant cutting force with feed rate for the three different materials at constant cutting speed of 330rpm

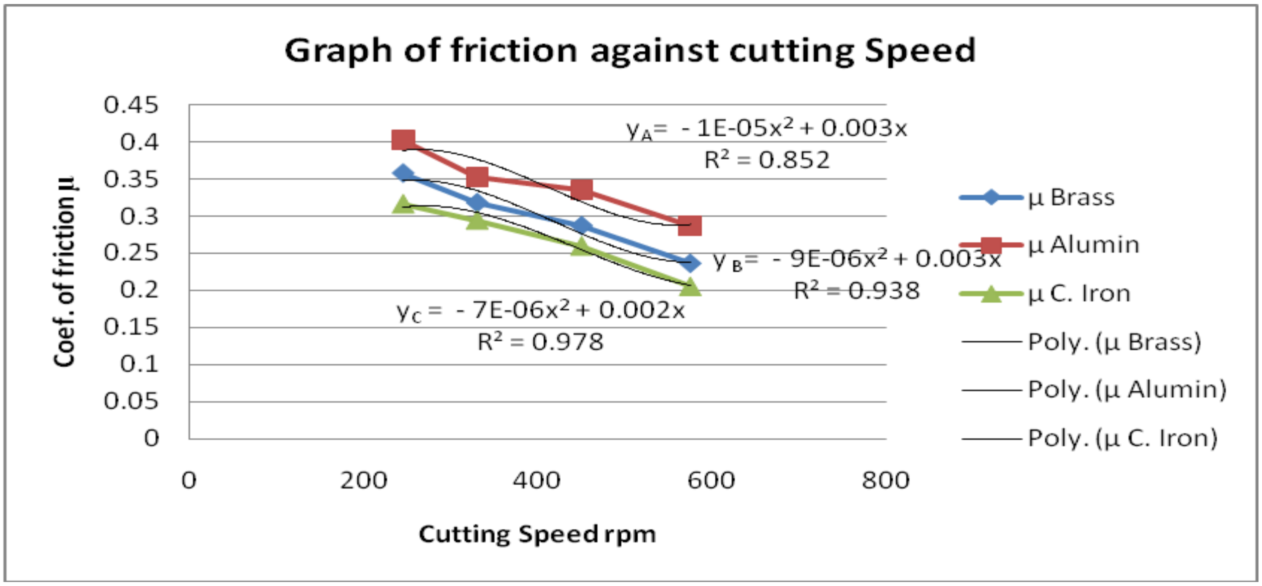

Figure 3: Frictional force response to changes in cutting speed at constant feed

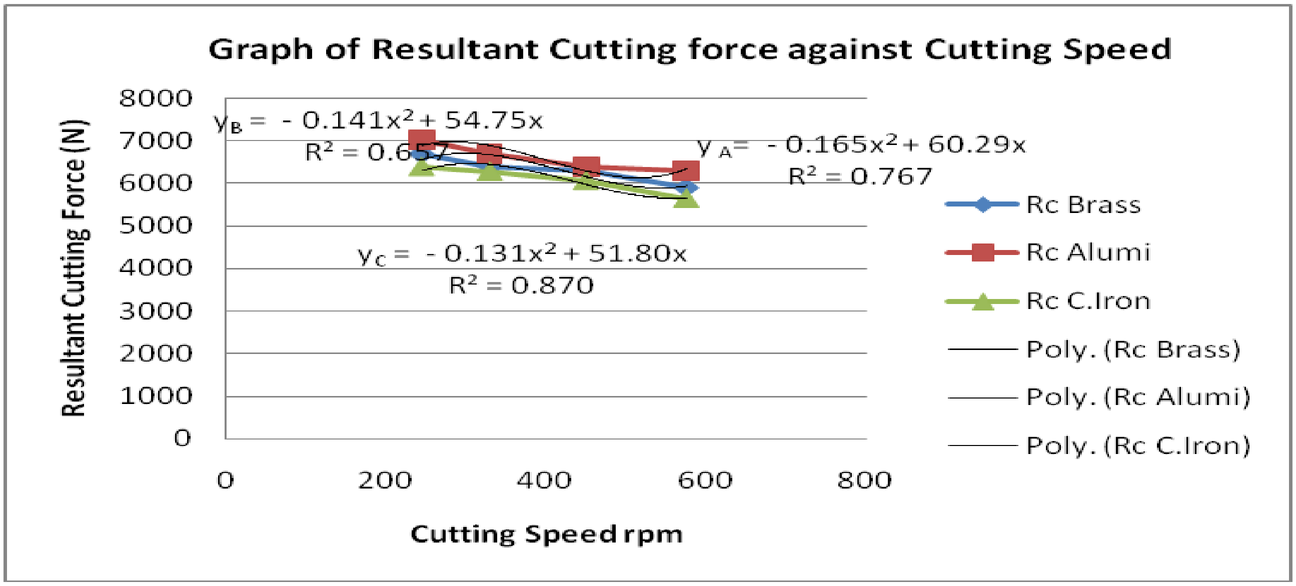

Figure 4: Cutting force response to changes in cutting speed at constant feed.

APPENDIX -3

The Experimental Curves Equations of the different Functional Graphs are:

1 Graph of Co-efficient of Friction (μ) against feed at Constant Speed (chosen speed)

$Y_A = -44.16X^2 + 6.438X$, $R^2 = 0.953$;
$Y_B = 3.985X^2 + 4.750X$, $R^2 = 0.986$;
$Y_C = -33.53X^2 + 6.937X$, $R^2 = 0.999$

Y_A – Co-eff. of Friction force for Aluminum, Y_B - Co-eff. of Friction force for Brass and Y_C - Co-eff. of Friction force for Cast Iron

2. Variation of resultant cutting force with feed rate for the Three different materials at constant cutting speed of 330rpm

$Y_A = 71367X$, $R^2 = 0.732$;
$Y_B = -1E^{06}X^2 + 10347X$, $R^2 = 0.978$;
$Y_C = -1E^{06}X^2 + 73920X$, $R^2 = 0.995$

Y_A – resultant cutting force for Aluminum, Y_B - resultant cutting force for Brass and Y_C - resultant cutting force for Cast Iron

~~3~~ Frictional Force responses to changes in Cutting speed at Constant feed

$Y_A = -1E^{-05}X^2 + 3E^{-03}X$, $R^2 = 0.852$;
$Y_B = -9E^{-6}X^2 + 3E^{-03}X$, $R^2 = 0.938$;
$Y_C = -7E^{-06}X^2 + 2E^{-03}X$, $R^2 = 0.978$

Y_A – Frictional force for Aluminum, Y_B - Frictional force for Brass and Y_C - Frictional force for Cast Iron

4 Cutting force responses to changes in cutting speed at Constant feed

$Y_A = -1.65X^2 - 60.29X$, $R^2 = 0.767$;
$Y_B = -0.141X^2 + 54.75X$, $R^2 = 0.657$;
$Y_C = -0.131X^2 + 51.8X$, $R^2 = 0.870$.

The negative (-) sign indicates a decrease of dependent variables (Y_A, Y_B and Y_C) with rise in the independent variables (X_{feed} and X_{speed}).

Y_A – Cutting force for Aluminum, Y_B - Cutting force for Brass and Y_C - Cutting force of Cast Iron