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Study of Cutting Forces & Surface Finish in End Milling

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Abstract:- Faced with intense global competition and to enhance customer expectation in terms of accuracy and precision, various manufacturing firms are considering the adoption of automated systems in order to achieve manufacturing excellence. Automated systems are highly useful to maximize production and to achieve better safety and health requirements of the present day industry. Hence computer aided monitoring of various operations are essential which may be fed to a computer interfaced machine for getting the best results. The effect of various process parameters like speed, feed and depth of cut on the cutting forces and surface finish of Aluminum and Brass in End milling process on a Universal Milling Machine was investigated by using Factorial Technique. The coefficients were calculated by using regression analysis and the model is constructed. The model is tested for its adequacy by using Fisher's test at 95 % confidence level. By using the mathematical model the main and interaction effect of various process parameters on milling cutting forces and surface finish was studied.

Key words:- End Milling, Surface Finish, Factorial Technique.

I. INTRODUCTION

Surface finish produced on machined surface plays an important role in production. The surface roughness has a vital influence on most important functional properties such as wear resistance, fatigue strength, corrosion resistance and power losses due to friction. Poor surface roughness will lead to the rupture of oil films on the peaks of the micro irregularities which lead to a state approaching dry friction and results in decisive wear of rubbing surface. Therefore finishing processes are employed in machining the surface of many critical components to obtain a very high surface finish.

- **Process Variables**

  Surface roughness in End Milling depends on spindle rpm, feed, depth of cut, Helix angle. Mainly surface finish depends on spindle rpm, feed and depth of cut.

- **Factorial Technique**

Factorial technique is a combination of Mathematical and statistical techniques. It is useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize the response.

II. INTRODUCTION TO MILLING MACHINE

A milling machine is a machine tool that removes unwanted metal on the work piece as the work is fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can also hold one or more number of cutters at a time. This is why a milling machine finds wide application in production work. This is superior to other machines as regards accuracy and better surface finish, and is designed for machining a variety of tool room work.The first milling machine came into existence in about 1770 and was of French origin. The milling cutter was first developed by Jacques de Vasucanson in the year 1782. The first successful plain milling machine was designed by Eli Whitney in the year 1818. Joseph R Brown a member of Brown & Sharpe Company invented the first Universal milling machine in the year 1861.

III. CLASSIFICATION OF MILLING

- **Peripheral Milling**

In peripheral (or slab) milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter rotation is generally in a plane parallel to the work piece surface to be machined.

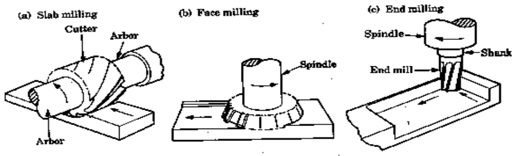


Fig.1 Classification of Milling

- **Face Milling**

In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the work piece surface. The milled surface results from the action of cutting edges located on the periphery and face other cutter.

- **End Milling**

The cutter in end milling generally rotates on an axis vertical to the work piece. It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body.Methods of milling

- **Up Milling**

Up milling is also referred to as conventional milling. The direction of the cutter rotation opposes the feed motion. For example, if the cutter rotates clockwise, the work piece is fed to the right in up milling.

- **Down Milling**

Down milling is also referred to as climb milling. The direction of cutter rotation is same as the feed motion. For example, if the cutter rotates counter clockwise, the work piece is fed to the right in down milling.

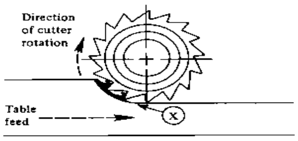


Fig.2 Up Milling

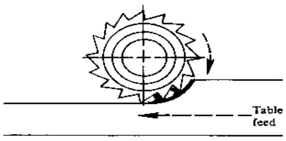


Fig.3 Down Milling

IV. EXPREIMENTAL SETUP

- **Description of Universal Milling Machine**

A universal milling machine is so named because it may be adapted to a very wide range of milling operations. A universal milling machine can be distinguished from a plain milling machine in that the table of a universal milling machine is mounted on a circular swiveling base which has degree graduations, and the table can be swiveled to any angle upto 45° on either side of the normal position. The table can be swiveled about a vertical axis and set at an angle other than right angles to the spindle. Thus in a universal milling machine, in addition to three movements as incorporated in a plain milling machine, the table may have a fourth movement when it is fed at an angle to the milling cutter. This additional feature enables it to perform helical milling operation which cannot be done on a plain milling machine unless a spiral milling attachment is used. The capacity of a universal milling machine is considerably increased by the use of special attachments such as dividing head or index head, vertical milling attachment. Rotary attachment, slotting attachment, etc. The machine can produce spur, spiral, bevel gears, twist drills, reamers, milling cutters, etc.

- **Universal Milling Machine Specifications**

Table Size	300 x 1330mm
Number of Spindles	8

Fig.4 Universal Milling Machine Front View and Right side View

V. SURFACE FINISH INDICATOR

The instrument used for measuring surface finish was surface indicator. This device consists of tracer head and an amplifier. The head housed a diamond stylus, having a point radius of 0.03 mm, which been against the surface of the work and may be moved by hand or it may be another driven. Any movement of the stylus covered by surface irregularities is converted into electric fluctuations by the tracer head. These signals are magnified by the amplifier and registered on the digital display. The reading shown on the display indicator the average height of the surface roughness or the depth of the surface from the reference line. For accurate determination of the surface finish the indicator must first be calibrated by setting it to a precision reference surface on a block calibrated to ASA standards.

- **Principle of Talysurf**

The Talysurf is all electronics instrument working on carrier modulating principle. This instrument gives the information more rapidly and accurately. This instrument records the static displacement of the stylus. The measuring head of this instrument record the static displacement of the stylus. The measuring head of this instrument record consists of a diamond stylus of about 0.002 mm tip radius and which is drawn across the surface by means of motorized driving unit, which provides the motorized speed giving reading. The arm carrying the stylus forms an armature which pivots about the centre piece of e-shaped stamping on two coils with other two resistances's from an oscillator. As the armature is pivoted about the central leg, any movement if the stylus covers the air gap to vary and this the amplitude of the original A.C. current flowing in the coils is modulated. This is further demodulated so that the current flow in directly proportional to the vertical displacement of the stylus only.

Fig.5 Surface Finish Indicator (Talysurfe)

- **Procedure for to measure the surface finish with a surface Finish Indicator**
  - Turn the switch on and allow the instrument to warm for approximately 3 minutes.
  - Check the machine calibration by moving the stylus over the test block.
  - If necessary, adjust the calibration control so that the instrument registers the range as the test book.
  - Thoroughly clean the surface to be measured to ensure accurate readings and reduce wear on the rider cap protecting the stylus.
  - Now the stylus moves on the work piece smoothly to the specified cut off length and the value is displayed in micrometers.

VI. TOOL MATERIAL

- **High Speed Tool Steel**

High speed steels (HSS) are carbon steels with alloying elements such as Tungsten (W), Chromium (cr), Vanadium (V), Molybdenum (Mo) and Cobalt (Co).

- These are normally grouped into three classes:
  - Class – I: 18-4-1 HSS: 18% W, 4% Cr, 1%V.
    This type is called Tungsten type HSS and is well known for air and heat resistance.
  - Class – II: 6-6-4-2: 6%W, 6%Mo, 4%Cr, 2%V. This type is called Molybdenum type HSS and is well known for wear and impact resistance.
  - Class – III: Super HSS: 2 to 15% Co additionally to increase cutting efficiency for heavier cut imparting higher temperatures.

VII. WORK PIECE MATERIAL

- **Aluminum**

The best known characteristic of aluminum is its light weight, the density being about one third that of steel or copper alloy. Aluminum has good malleability and formability, high corrosion resistance and high electrical and thermal conductivity. Aluminum in nontoxic, nonmagnetic, and no sparking. Pure aluminum has a tensile strength of about 13000 PSI. However, substantial increases in strength are obtained by sold working or allying some alloys, properly heat – treated, approach tensile strength of 100,000 PSI.One of the most important characteristics of aluminum in its mach inability and workability commercially pure aluminum, 11000 alloy (99.0 +%Al) is suitable for applications where good formability or very good resistance corrosion are revised and where high strength is not necessary.

- **BRASS**

Brass is any alloy of copper and zinc. The proportions of zinc and copper can be varied to create a range of brasses with varying properties. In comparison, In organ pipes designed as "reed" pipes, brass strips are used as the "reeds”. Brass has higher malleability than copper or zinc. The relatively low melting point of brass (900 to 940°C, depending on composition) and its flow characteristics make it a relatively easy material to cast. By varying the proportions of copper and zinc, the properties of the brass can be changed, allowing hard and soft brasses. The density of brass is approximately 8400 to 8730 kilograms per cubic meter (equivalent to 8.4 to 8.73 grams per cubic centimeter).

Fig.6 Work Piece Material-Aluminum

Fig.7 Work Piece Material-Brass

VIII. EXPERIMENTAL DETAILS OF ALUMINIUM FOR SURFACE FINISH

2)	3) Speed 4) (N)	5) Feed (F)	6) Depth of Cut (d)	Surface Finish (Y)	Y^2
7) Y_1	8) +	9) +	10) +	1.33	1.76
11) Y_2	12) +	13) +	14) -	1.85	3.42
15) Y_3	16) +	17) -	18) +	1.50	2.25
19) Y_4	20) -	21) +	22) +	2.97	8.82
23) Y_5	24) -	25) -	26) -	2.65	7.02
27) Y_6	28) -	29) -	30) +	1.49	2.22
31) Y_7	32) -	33) +	34) -	2.15	4.62
35) Y_8	36) +	37) -	38) -	1.35	1.82

Table.1 Experimental values of surface finish for Aluminum

K	1.9113	SS	DOF	F value
A	0.013	0.000006	1	0.00000424
B	-0.0813	0.02641	1	0.01866
C	-0.0038	0.000056	1	0.00000396
AB	-0.2413	0.2328	1	0.1644
BC	0.1638	0.1073	1	0.0758
CA	-0.475	0.9025	1	0.6377
ABC	0.0738	0.0218	1	0.0154
SSR		1.2908	7	
SST		2.706	15	
SSE		1.415	8	

Table.2 Calculated Fisher’s values of surface finish for Aluminum

- Multiple Linear Regression Equation:

Y_1= 1.9113-0.013X_1-0.0813X_2-0.0038X_3

- Product of Multiple Linear Regression Equation:

Y_1= 1.9113-0.013X_1-0.0813X_2-0.0038X_3-0.2413X_1X_2+0.1638X_2X_3-0.475X_1X_3 – 0.0738$X_1X_2X_3$

- **Checking the adequacy using Fishers Table**

The F values obtained for Aluminum are tabulated in the above table and the values are cross checking in the Fishers table and found within the limit.

IX. EXPERIMENTAL DETAILS OF ALUMINUM FOR CUTTING FORCES

	40) 41) SPEED rpm	42) FEED mm/sec	43) DEPTH OF CUT mm	Resultant Force (KgF)	
	N	44) f	45) D	F_A	F_A^2
Y1	47) -	48) -	49) -	4	16
Y2	51) +	52) -	53) -	8	64
Y3	55) -	56) +	57) -	12	144
Y4	59) -	60) -	61) +	10	100
Y5	63) +	64) +	65) -	4	16
Y6	67) +	68) -	69) +	6	36
Y7	71) -	72) +	73) +	3	4
Y8	75) +	76) +	77) +	2	4

Table.3 Experimental values of Resultant force for Aluminum

K	6.125	SS	DOF	F value
A	0.375	0.0625	1	0.00143
B	0.625	1.5625	1	0.03596
C	-2.37	22.5625	1	0.5793
AB	-1.12	5.0625	1	0.1165
BC	-1.87	14.0625	1	0.3237
CA	-0.62	1.5625	1	0.0359
ABC	0.375	0.5625	1	0.0129
SSR		45.43		
SST		88.87		
SSE		43.44		

Table.4 Calculated Fisher’s values of Resultant force for Aluminum

- Multiple Linear Regression Equation:

F_A = 6.125+0.375X_1+0.625X_2-2.37X_3

- Product of Multiple Linear Regression Equation:

$F_A = 6.125+0.375X_1+0.625X_2-2.37X_3-1.12X_1X_2-1.87X_2X_3-0.62X_1X_3+0.375X_1X_2X_3$

- **Checking the adequacy using Fishers Table**

The F values obtained for Aluminum are tabulated in the above table and the values are cross checking in the Fishers table and found within the limit.

X. EXPERIMENTAL DETAILS OF BRASS

78)	79) Speed 80) (N)	81) Feed (F)	82) Depth of Cut (D)	Surface Finish (Y)	Y^2
83) Y_1	84) +	85) +	86) +	0.90	0.81
87) Y_2	88) +	89) +	90) -	1.43	2.04
91) Y_3	92) +	93) -	94) +	0.67	0.44
95) Y_4	96) -	97) +	98) +	2.38	5.66
99) Y_5	100) -	101) -	102) -	1.18	1.39
103) Y_6	104) -	105) -	106) +	0.9	0.98
107) Y_7	108) -	109) +	110) -	1.36	1.84
111) Y_8	112) +	113) -	114) -	0.82	0.67

Table.5 Experimental values of surface finish for Brass

K	1.205	SS	DOF	F value
A	0.1775	0.1260	1	0.099
B	0.1025	0.0420	1	0.033
C	-0.1425	0.0812	1	0.0638
AB	-0.0775	0.024	1	0.0188
BC	0.1925	0.1482	1	0.1165
CA	-0.3125	0.3906	1	0.3070
ABC	-0.18	0.1296	1	0.1018
SSR		0.9416	7	
SST		2.213	15	
SSE		1.272	8	

Table.6 Calculated Fisher's values of surface finish for Brass

- Multiple Linear Regression Equation:

$Y_2=1.205+0.1775X_1+0.1025X_2-0.14255X_3$

- Product of Multiple Linear Regression Equation:

$Y_2=1.205+0.1775X_1+0.1025X_2-0.14255X_3-0.0775X_1X_2-0.1925X_2X_3-0.3125X_1X_3-0.18X_1X_2X_3$

- **Checking the adequacy using Fishers Table**

The F values obtained for Brass are tabulated in the above table and the values are cross checking in the Fishers table and found within the limit.

XI. EXPERIMENTAL DETAILS OF BRASS FOR CUTTING FORCES

	116) SPEED rpm	117) FEED mm/sec	118) DEPTH OF CUT mm	Resultant Force (KgF)	
	N	119) f	120) D	F_B	F_B^2
Y1	122) -	123) -	124) -	8	64
Y2	126) +	127) -	128) -	5	25
Y3	130) -	131) +	132) -	4	16
Y4	134) -	135) -	136) +	7	49
Y5	138) +	139) +	140) -	3	9
Y6	142) +	143) -	144) +	3	9
Y7	146) -	147) +	148) +	1	1
Y8	150) +	151) +	152) +	2	4

Table.7 Experimental values of Resultant force for Brass

K	4.125	SS	DOF	F value
A	0.125	0.0625	1	0.0028
B	-0.62	1.562	1	0.0701
C	-1.75	12.25	1	0.5504
AB	0.875	3.06	1	0.1375
BC	-0.12	0.0625	1	0.00280
CA	0.12	0.0625	1	0.00280
ABC	-0.62	1.562	1	0.0701
SSR		18.62	7	
SST		40.87	15	
SSE		22.25	8	

Table.8 Fisher's values of Resultant force for Brass

- Multiple Linear Regression Equation:

$F_B= 4.125+0.125X_1-0.62X_2-1.75X_3$

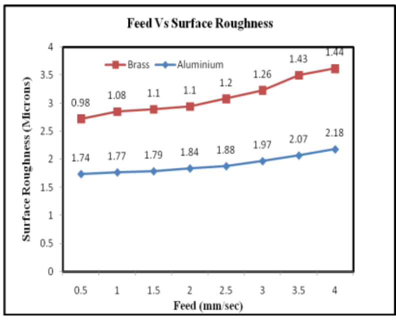
- Product of Multiple Linear Regression Equation:

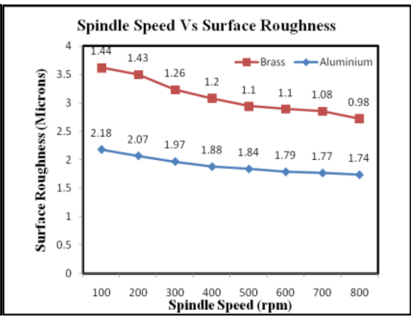
$$F_B = 4.125+0.125X_1-0.62X_2-1.75X_3+0.875X_1X_2-0.125X_2X_3+0.125X_1X_3-0.625X_1X_2X_3$$

XII. VARIATION OF MILLING PARAMETERS ON SURFACE FINISH

The effect of milling parameters (speed, feed and depth of cut) on surface roughness is presented in Fig.8,Fig.9,Fig.10. It is understood that surface roughness increases with feed keeping other parameters constant, Surface roughness decreases with spindle speed keeping other parameters constant , Surface roughness increases with spindle speed keeping other parameters constant.

From the comparison table(table.3,table 4) of experimental, multi linear and product of multi linear, it is understood that the values obtained experimentally are close to the predicted values.





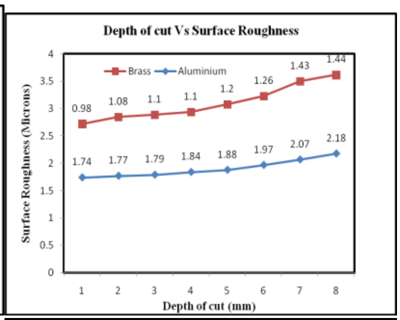
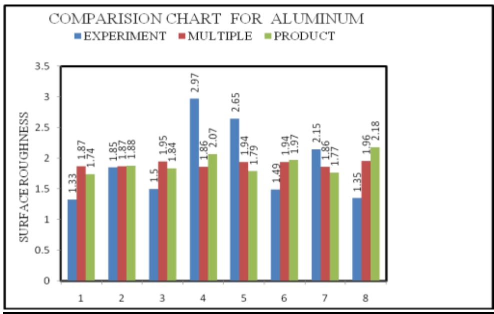


Fig.8 Feed Vs Surface Roughness **Fig.9** Spindle Speed Vs Surface Roughness **Fig.10** Depth of cut Vs Surface Roughness



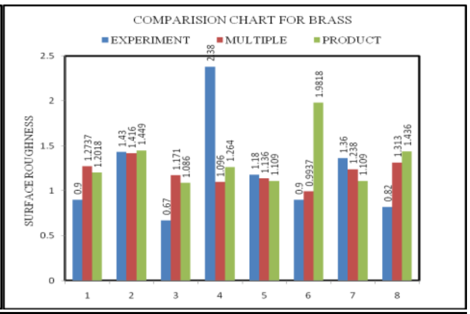
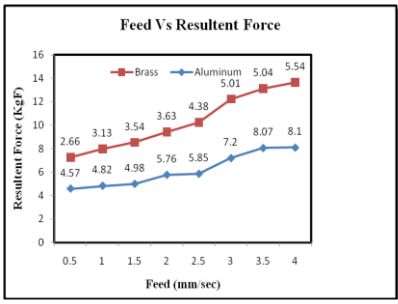
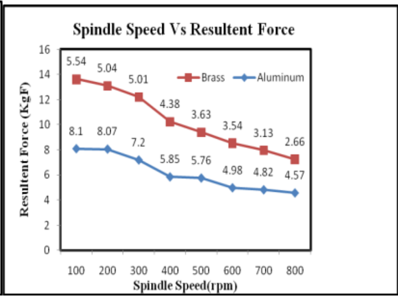


Fig.11 Comparision Chart For Aluminum **Fig.12** Comparision Chart For Aluminum

XIII. VARIATION OF MILLING PARAMETERS ON CUTTING FORCES

The effect of milling parameters (speed, feed and depth of cut) on cutting forces is presented in Fig.13 ,Fig.14,Fig.15.It is understood that Cutting forces increases with feed keeping other parameters constant,Cutting forces decreases with spindle speed keeping other parameters constant,Cutting forces increases with spindle speed keeping other parameters constant.From the comparison table(table.7,table 8) of experimental, multi linear and product of multi linear, it is understood that the values obtained experimentally are close to the predicted values.





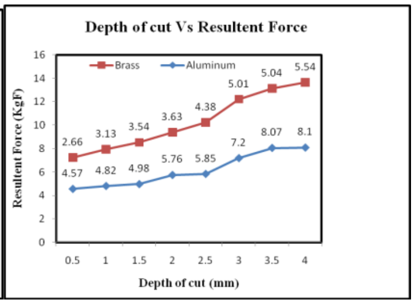
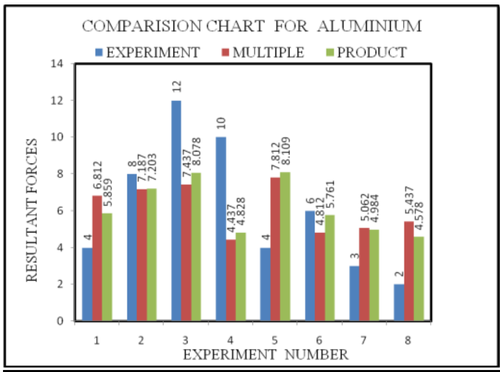


Fig.13 Feed Vs Resultent Force **Fig.14** Spindle Speed Vs Resultent Force **Fig.15** Depth of cut Vs Resultent Force



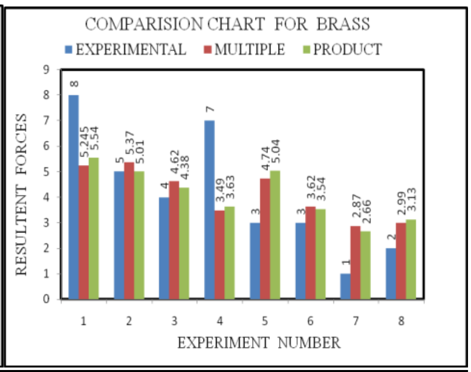


Fig.16 Comparision Chart For Aluminum **Fig.17** Comparision Chart For Brass

XIV. CONCLUSION

- Factorial Method is convenient to predict the main effects and the interaction effects of different influential combination of End Milling process parameters within the range of investigations on surface finish.
- The developed model can be used to predict the surface finish and cutting forces in terms of machining process parameters within the range of variables studied. Alternately it also helps to choose the influential process parameters so that desired value of surface finish and cutting forces can be obtained.
- Factorial Method is easy and accurate method for developing mathematical models for predicting the surface finish and cutting forces within the working region of the process variables. The developed model can be used in automatic and semi-automatic Milling machines in the form of a program for obtaining the desired quality.

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