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Influence of Cutting Parameters on Thrust Force, Torque and Temperature in Milling of E-Glass and Polyester Composites

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Abstract:
This paper discusses the influence of cutting parameters in milling of M.S, Alluminium, Epoxy-E-Glass and Polyester composites and also studies the effect of spindle speed and feed rate on thrust force and torque using carbide milling cutter. This paper presents a mathematical model for correlating the interactions of milling parameters and their effects on thrust force and torque. The optimum value of cutting parameters is also determined to get minimum value of thrust force and torque.

Keywords*: Milling, cutting speed, cutting angle, wear resistance, thrust force, torque, shear lane temperature, finite element analysis*

1. Introduction

Milling is a forming operation whereby chips are removed using a cutting tool known as a "milling cutter". This has several cutting edges laid out around its axis of rotation, and is subjected both to a rotational movement and a feed motion. This type of operation is carried out on what is called a milling machine.

A milling operation is characterized by the following parameters:
a_p: Axial engagement of the tool, also known as the axial pass depth in mm.
a_e: Radial engagement of the tool in mm.
N:Rotationalspeedinrev min^{-1}.
v_c: Cutting speed in m min^{-1}
f_z: Feed per tooth in mm $tooth^{-1}$.
v_f: Feed rate in mm min^{-1}.
Q: Material removal rate in cm^3 min^{-1}

The choice of tool for a milling operation is dependent on several criteria:

- The shape of the part to be produced
- The type of alloy
- The range: Rough, finish
- The characteristics of the machine
- The quantity of parts (price)

Aluminum alloy milling operations can be classified into two categories of application

- Polycrystalline diamond insert milling cutters with a diameter of 80 mm allow surfacing operations to be conducted at very high cutting speeds.
- The monolithic design (the milling cutter body and attachment are coupled) of the tool creates greater rigidity, thus allowing high material removal rates when producing aeronautical parts. The number of teeth is limited on this type of tool to favor the evacuation of chips.
- Similarly, the solid carbide milling cutter has just two teeth, to favor the evacuation of chips. In general, these milling cutters are used with diameters of less than 20 mm (cost/removal rate/tool life economic criterion)

As well as overall geometry, other criteria must be taken into consideration for the milling of aluminum alloys:

- Cutting angles
- The geometry of inserts
- Tool materials

2. Model of Cutting Tool

The main modules of the proposed work are:

- Part Design
- Assembly
- Drawing
- Sheet Metal

3. Finite Element Analysis

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems.

4. Calculations

4.1. Thrust Force and Torque Calculations

Materials: - Aluminum Alloy, Mild Steel, E – glass, Polyester Composite
Cutter diameter = 25R5
Width of Work piece = 75mm
No of Teeth on cutter = 4 = n_o
Depth of Cut = d = 0.2
Width of Cut = b = 5mm
Width of chip = b_c = 5mm
r_t = Chip Thickness Ratio (PG 117)
$r_t = \frac{t}{tc} = \frac{vc}{v} = \frac{lc}{l}$
L_C = Length of Chip = 7mm
L = Uncut Chip Length = 75mm
$\propto$ = Rake Angle = 20°
β = Friction Angle = 40
$\emptyset$ = Shear Angle

S. no	Speed (RPM)	Feed (mm/min)
1	3000	200
2	2500	300
3	2000	400

Chip Thickness Ratio
$r_t = \frac{t}{tc} = \frac{vc}{v} = \frac{L_C}{L}$
$r_t = \frac{L_c}{L} = \frac{7}{75} = 0.093$
Shear Angle ($\emptyset$).
$\text{Tan } \emptyset = \frac{r_t cos\propto}{1-r_t\, sin\propto}$
$\text{Tan } \emptyset = \frac{0.093\, cos20}{1-0.093\, sin20}$
$\emptyset = 5.781$
To Calculate Thrust Force

$$Ft = \mu\, [\, \frac{HA_c}{3}\, (\frac{Cot\emptyset}{\sqrt{3}} + 1)] + A_F(0.62H\sqrt{\frac{43H}{E}})$$

A_C = Cross – Section of Chip
A_f = Area of Tool Flank Face
$\emptyset$ = Shear Angle in w/p
μ = Friction Coefficient on Rake Face
H = Hardness of w/p
E = Young's Modulus of w/p

4.2 Aluminium Alloy with Speed 3000 Rpm, FEED 200mm/Min

THRUST FORCE

$$F_t = \mu[\, \frac{HAc}{3}\left(\frac{Cot\emptyset}{\sqrt{3}} + 1\right)] + A_f\, (0.62H\sqrt{\frac{43H}{E}}$$

E = 78Gpa, H =150

$F_t = 0.8\ [\frac{150\times15}{3}\ (\ \frac{cot5.781}{\sqrt{3}} + 1)] + 2.227\ [0.62\times150\sqrt{\frac{43\times150}{78\times10^3}}$

= 5027.037 + 59.557

= 5086.594N

SHEAR PLANE TEMPERATURE

θi = initial temp = 33°c

λ = 1(assume) = factor representing the fraction of heat retained by chip

J = heat equivalent of mechanical energy = 4200j

ρ_w = density = 2840 kg/m^3 = 0.000002840kg/mm^3

C_w = Sp.heat = 0.926 × 10^3 J/kg°c

$E_s = \frac{Kcos\propto}{sin\emptyset\cos\ (\emptyset-\propto)}$

K = yield stress = 520Mpa

$\propto$ = rake angle = 20°

$\emptyset$ = shear angle = 5.781

$E_s = \frac{520\ cos20}{\sin 5.781\cos\ (5.781-20)}$

E_s = 5004.481

$\theta s = \frac{(1)(5004.481)}{(4200)(0.000002840)(0.926\times10^3)} + 33$

θs = 486.085°c

TORQUE

Torque = $F_t \times \frac{D}{2}$

D = cutter diameter in mm

Tangential force

$F_t = Z_s.K_s.F_c.W$

Z_s = No.of teeth simultaneously engaged with w/p

$Z_s = \frac{z}{360} \times \theta_3 = \frac{4}{360}$ (5.781+ 40 – 20)

Z_s = 0.2864

$F_c = \frac{57.3}{\theta 3} \times ft\ \times \sin A(\cos\theta_1 - \cos\theta_2)$

A = Approach angle = 20°

$F_c = \frac{57.3}{25.781} \times 0.016 \times \sin 20\ (\cos 40 - \cos 65.781)$

$F_c = 4.322196 \times 10^{-3}$

Specific cutting force

$K_s = \frac{T_C\ cos\propto A_C}{\cos\ (\emptyset-\propto)} + \frac{T_F\ cos\propto sin\beta A_F}{\cos(\emptyset+\beta-\propto)\cos\ (\emptyset-\propto)}$

$T_c = \frac{thrust\ force}{Area} = \frac{5086.594}{15}$ = 339.106n/mm^2

$T_f = \frac{5086.594}{2.227}$ = 2284.056n/mm^2

$K_s = \frac{339.106cos20\times15}{\cos\ (5.781-20)} + \frac{2284.056cos20sin40\times2.227}{\cos(5.781+40-20)\cos\ (5.781-20)}$

K_s = 4930.894 + 3307.510 = 8238.404N

Tangential force

$F_t = 0.2864 \times 8238.404 \times 4.322 \times 10^{-3} \times 5$

F_t = 50.98N

Torque = $F_t \times \frac{D}{2} = 50.98 \times \frac{25}{2}$

Torque = 637.354N-mm

4.3. E-Glass with Speed Of 3000rpm FEED Of 200mm/Min

THRUST FORCE

$$F_t = \mu\left[\frac{HA_c}{3}\left(\frac{\cot\emptyset}{\sqrt{3}} + 1\right)\right] + A_f\left(0.62H\sqrt{\frac{43H}{E}}\right)$$

E = 50000N/mm^2

H = 38

$Ft = 0.8\left[\frac{38\times15}{3}\left(\frac{Cot5.781}{\sqrt{3}} + 1\right)\right] + 2.227\left(0.62 \times 38\sqrt{\frac{43\times38}{50\times10^3}}\right)$

= 1273.516+6.4860.

= 1280.002N.

SHEAR PLANE TEMPERATURE

$\theta_S = \frac{\lambda E_S}{J\rho_W C_W} + \theta i$

$\theta i = Initial\ Temp = 33℃$

$\lambda = 1$

J = 4200 J

ρ_w = 2.58gm/cc = 0.00000258kg/mm^3

C_w = 900 J/kg°c

$E_s = \frac{k cos\propto}{sin\emptyset cos\,(\emptyset - \propto)}$

K = 1250Mpa

$\propto = 20°$

$\emptyset = 5.781$

$E_s = \frac{490cos20}{\substack{sin \\ 5.781cos\,(5.781-20)}}$

E_s = 4715.761Mpa

$\theta s = \frac{(1)(4715.761)\times 1}{(4200)(0.00000258)(1.03\times 10^3)} + 33$

θs = 455.518°c

TORQUE

Torque = $F_t \times \frac{D}{2}$

D = cutter dia in mm

Tangential Force

$F_t = z_s.k_s.f_c.w$

$Z_s = \frac{z}{360} \times \theta_3 = \frac{4}{360}(5.781 + 40 - 20)$

$Z_s = 0.2864$

$F_c = 4.322196 \times 10^{-3}$

Specific cutting Force

$K_s = \frac{T_C Cos\alpha Ac}{Cos(\emptyset-\alpha)} + \frac{T_F Cos\alpha Sin\beta Af}{Cos(\emptyset+\beta-\alpha)Cos(\emptyset-\alpha)}$

$T_c = \frac{1280.002}{15} = 85.333 N/mm^2$

$T_f = \frac{1280.002}{2.227} = 574.765 N/mm^2$

$K_s = \frac{85.333\ cos20\times 15}{(5.781-20)} + \frac{574.765cos20sin40\times 2.227}{cos(5.781+40-20)cos\,(5.781-20)}$

K_s = 885.749N

TANGENTIAL FORCE

$F_t = 0.2864 \times 885.749 \times 4.322196 \times 10^{-3} \times 5$

F_t = 5.474N

Torque = $F_t \times \frac{D}{2} = 5.474 \times \frac{25}{2}$ = 68.425 N-mm

4.4. For Speed 2000 Rpm, FEED 400mm/Min for All Materials

V = cutting speed = $\frac{\pi DN}{1000} m/\min = \frac{\pi \times 25 \times 2000}{1000}$ = 157.079m/min

Feed per tooth of cutter

$F_t = \frac{F}{n_c.N} = \frac{400}{4\times 2000} = 0.05$

TORQUE

Torque = $F_t \times \frac{D}{2}$

Tangential Force (Ft)

$F_t = Z_s.K_s.F_c.W$

$Z_s = \frac{z}{360} \times \theta_3 = 0.2864$

$f_c = \frac{57.3}{\theta 3} \times f_t \times$ sinA $(cos\theta_1 - cos\theta_2)$

A = Approach angle = 20°

$F_c = \frac{57.3}{25.781} \times 0.05 \times$ sin20 (cos40 –cos65.781) = 0.013

Specific cutting force

K_s = 8238.404N

Tangential force (F_t) = 0.2864 × 8238.404 × 0.013 × 5 = 153.366N

Torque = $F_t \times \frac{D}{2} = 153.366 \times \frac{25}{2}$ = 1917.075N-mm

4.5. For Speed 2500 Rpm, Feed = 300mm/Min for All Materials

V = cutting speed = $\frac{\pi DN}{1000} m/\min = \frac{\pi \times 25 \times 2500}{1000} = 196.349$

Feed per tooth of cutter

$F_t = \frac{F}{n_c.N} = \frac{300}{4 \times 2500} = 0.03$

$A_c = w \times d = 15$

$A = A_f = \sqrt{(D-d).d} = \sqrt{(25-0.2)\,0.2} = 2.227$mm

TORQUE

Torque = $F_t \times \frac{D}{2}$

Tangential force (F_t)

$F_t = Z_s.K_s.F_c.W$

$Z_s = \frac{z}{360} \times \theta_3 = 0.2864$

$F_c = \frac{57.3}{\theta 3} \times ft \times \sin A(\cos\theta_1 - \cos\theta_2)$

A = Approach angle = 20°

$F_c = \frac{57.3}{25.781} \times 0.016 \times \sin 20\,(\cos 40 - \cos 65.781)$

$= 8.114 \times 10^{-3}$

$F_t = 0.2864$

Specific cutting force

$K_s = 8238.404$N

Tangential force $F_t = 0.2864 \times 8238.404 \times 8.114 \times 10^{-3} \times 5$

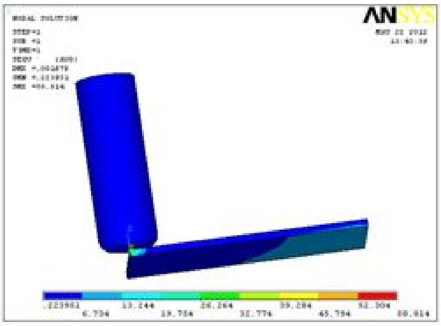
$F_t = 95.724$N

Torque= $F_t \times \frac{D}{2} = 95.724 \times \frac{25}{2} = 1196.55$N-mm.

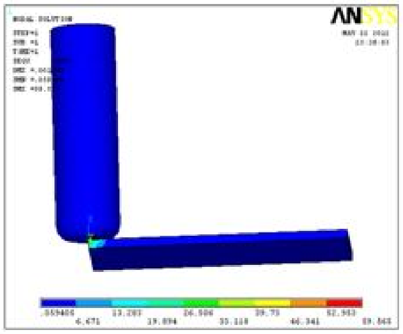
5. Analysis

5.1. Structural Analysis

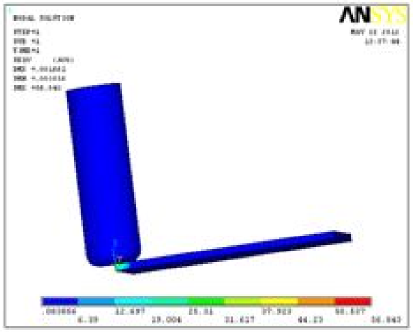
5.1.1. THRUST FORCE – 5086.594 N, TORQUE – 637.354 N mm



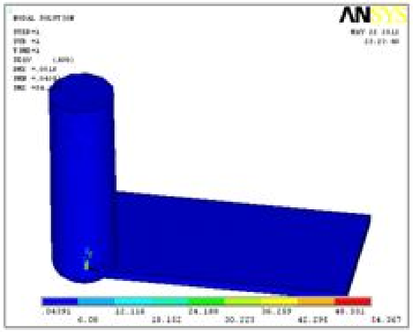
For Mild Steel



For E-Glass Epoxy

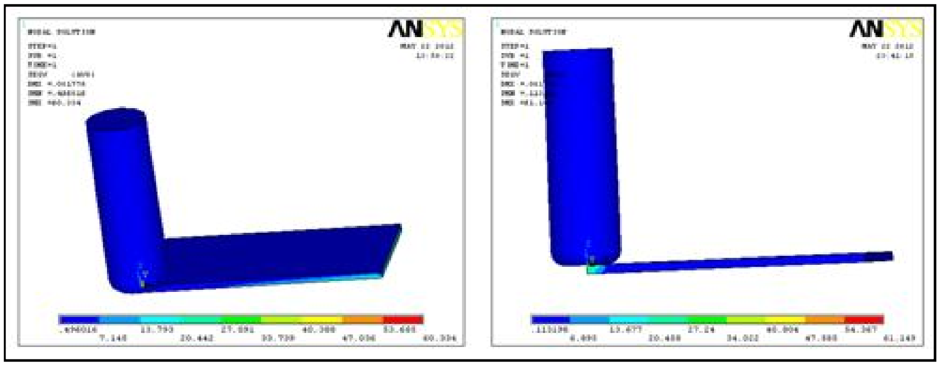


For Alluminium

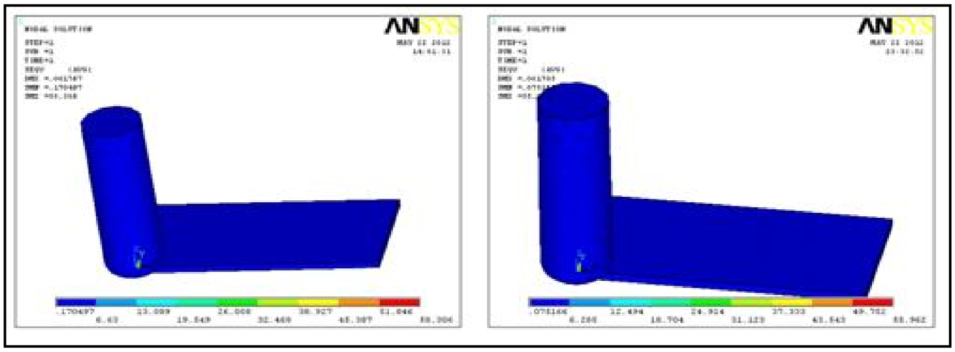


For Polyster

5.1.2. THRUST FORCE – 5086.594 N, TORQUE – 1196.55 N mm

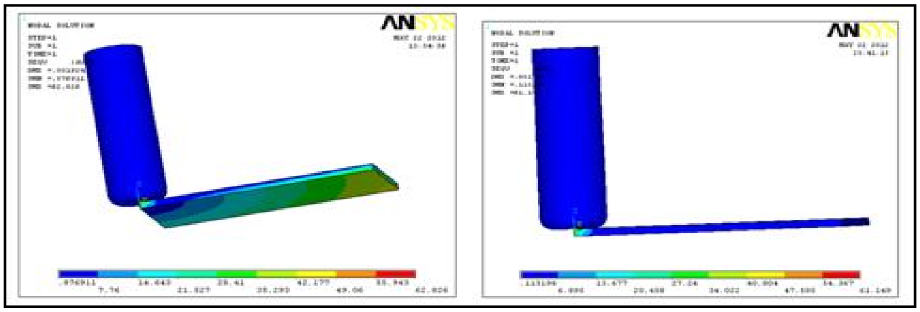


For Mild Steel *For E-Glass*

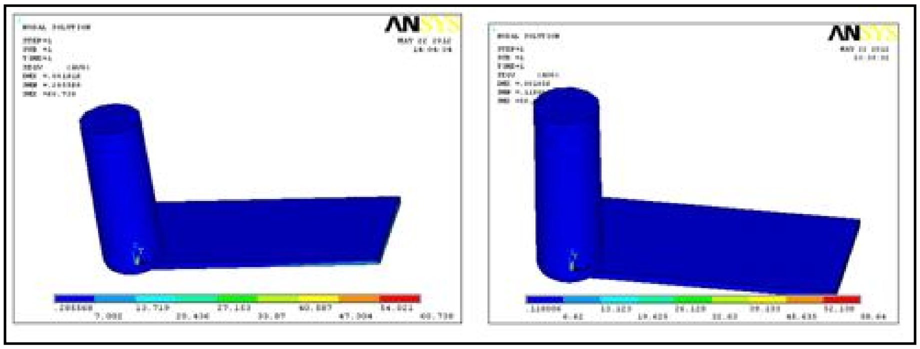


For Alluminium *For Polyster*

5.1.3THRUST FORCE – 5086.594 N, TORQUE – 1917.075 N mm

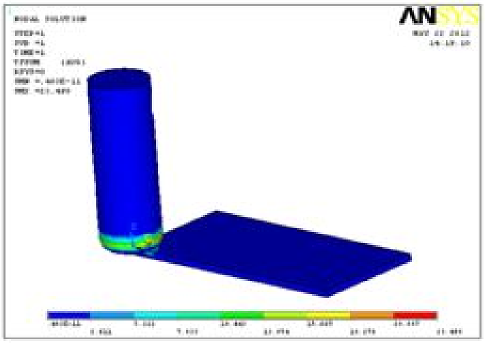


For Mild Steel *For E-Glass*

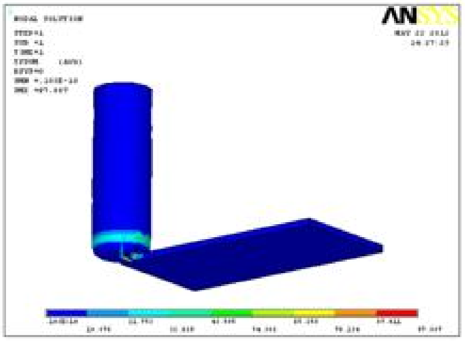


For Allauminium *For Polyster*

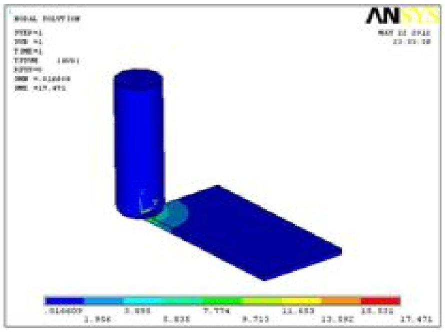
5.2. Thermal Analysis



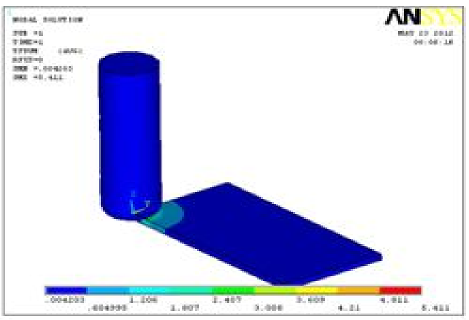
For Mild Steel



For Alluminium



For E-Glass Epoxy



For Polyster

6. Conclusion

In the proposed work, we have discussed the influence of cutting parameters in milling of Mild Steel, Aluminum. E-Glass Epoxy and Polyester composite (i.e.) to study the effect of spindle speed and feed rate on thrust force and torque using carbide milling cutter. The torque changes with the change of speeds and feed. Temperatures are also calculated for all the materials. Temperatures produced while milling is more for Aluminum alloy and less for polyester composite From mathematical calculations, thrust force is more for Aluminum alloy and less for E – Glass Epoxy. Torque is increased by increasing the feed and by decreasing the speeds. By observing the analysis results, the stress values are less for material Polyester composites by applying same thrust force and different torques.

	TORQUE1		TORQUE2		TORQUE3	
	DISP(mm)	STRESS (N/mm^2)	DISP (mm)	STRESS (N/mm^2)	DISP (mm)	STRESS (N/mm^2)
MILD STEEL	0.001676	58.814	0.001778	60.334	0.001924	62.826
ALUMINUM ALLOY	0.001661	56.843	0.001767	58.306	0.001916	60.738
E GLASS	0.001646	59.565	0.001752	61.149	0.001902	63.758
POLYESTER	0.0016	54.367	0.001705	55.962	0.001856	58.64

Structural Analysis

	NODAL TEMPERATURE (K)	THERMAL GRADIENT (K/mm)	THERMAL FLUX (W/mm^2)
MILD STEEL	511	398.411	23.498
ALUMINUM ALLOY	759	866.255	97.877
E GLASS	759	58.236	17.471
POLYESTER	391	18.66	5.411

Thermal Analysis

7. References

1. Cutting tool applications by George Schneider
2. Valery Marinov, Manufacturing by Jr.CMFJE
3. Machining Technology Machine Tools and Operations by HELMI A. YOUSSEF
4. Fundamentals of Machine Tools by PYE
5. Aubert.A. 1999. Properties of opaque and reference surfaces, school of Mines, Paris, PhD thesis.
6. Decenciere.E et al., 2001. Morphological decomposition of the surface of an internal combustion engine cylinder in view of characterizing wear. Wear, 249:482-488
7. Dong.W et al., 1992.Comprehensive study of parameters for characterizing three-dimensional surface topography. I: some inherent properties of parameter variation. Wear, 159:161-171.
8. Jeulin.D et al., 1981.Synthesis of rough surfaces by random morphological models.(proc 3rd European symposium of stereology) 3(1): 239-246.
9. Kweon I ET l., 1994. Extracting topographic terrain features from elevation maps. Computer Vision, Graphics and Image Procressing; Image Understanding, 59(2):171-182.
10. Thomas.T., 1998. Trends in surface roughness. International journal of machine tools and manufacture, 35(5-6):405-411.
11. George Schneider, Book on Cutting tool applications