STUDIES ON THE MAIN CUTTING FORCE IN TURNING POLYAMIDE PA 66

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Abstract: Polyamide composites are widely employed in various fields of engineering, such as aircraft, automobile, robots and machines due to their good properties. They are generally manufacturing by extrusion, and therefore these materials require additional machining operations. This paper presents the cutting forces obtained at turning this material to understand this better by turning machinability of these technical plastics. Analysis of variance ANOVA indicated factor with most influence on main cutting force.

1. Introduction

Because they have special properties such thermo-plastic material, they started to get a general becoming more so in the automotive industry but also in aircraft, robots and other industries, even and in medical by designing prostheses.
Several criteria may be used to evaluate machinability, but the most important are tool life, cutting forces, power, specific cutting pressure and surface roughness [DAV03, DAV04, MAT06, DAV07].
The study of the dynamics of cutting forces is critical in any machining process for the proper planning and control of the machining operation and for the optimization of the cutting conditions aiming to reduce production costs and times,.
Cutting force analysis plays a vital role in studying the various characteristics of a machining process, for instance, the dynamic stability, positioning accuracy of the tool and roughness of the machined surface [KAN07, WAN05, ZAM06].
This work presented the influence of cutting regime parameters on the main cutting force, the processing by turning a piece of an extruded semi.

2. Experimental

PA 66 polyamide is an important thermoplastic which is broadly used in injection moulded components, with strong commercial advantages due to its low manufacturing cost. Typical examples include gears, cams and rolling bearings. PA 66 polyamide has been reported to have superior wear resistance compared to other polymers due to its ability to from a thin and uniform transfer film while sliding against steel parts [CHE03, CHA04]. The mechanical and thermal properties are indicated in table 1.
Samples of extruded PA 66 polyamide with 50 mm in diameter and a length 100 mm with 5 mm of cutting length were used as work material.

Table no. 1 Mechanical and thermal properties of PA 66 polyamide by the ERTA® Company

Property	
Elastic modulus (MPa)	1650
Rockwell hardness	M88
Charpy impact resistance (KJ/m^2)	No fracture
Yield strength (MPa)	90
Melting temperature (^{0}C)	255
Density (g/cm^3)	1.14
Thermal conductivity at 23^{0}C (w/Km)	0,28
Coefficient of thermal expansion from 23 to 60 ^{0}C (m/mK)	$80 \cdot 10^{-6}$
Coefficient of thermal expansion from 23 to 100 ^{0}C (m/mK)	$95 \cdot 10^{-6}$

Tool material is uncoated cemented carbides without chip breaker (K15), code CNMG 12 08 02. The inserts were mounted on a tool holder, thus resulting in the tool angles presented in table 2.

Table no. 2 Tools geometry

Rake angle γ_n (^{0})	7
Clearance angle α_n (^{0})	5
Cutting edge angle χ_r (^{0})	45
Cutting edge inclination angle λ_s (^{0})	5
Corner radius r_ε (mm)	0.2

Component principal of cutting force, F_c, is a registered trademark strain mounted on the tool holder and the signal is taken from a Spider.
The planning of experiments is very much essential to minimize the experiments. The classical experimental design methods are too complex and time consuming. A large number of experiments have to be performed when the number of process parameters increases. Taguchi's method uses a special design of orthogonal arrays to study the entire parameter space with minimum experiments.

Table no. 3 Process parameters and their levels

Parameters	Code	Unit	Levels		
			1	2	3
Cutting depth, a_p	A	mm	0.5	1	2
Feed rate, f	B	mm/rev	0.1	0.2	0.4
Cutting velocity, v	C	m/min	58.875	117.75	235.5

Table no. 4 Orthogonal array and experiment layout plan

Trial no.	Levels of process parameters			Actual values of process parameters			Cutting force result F_c [N]
	A	B	C	Cutting depth [mm]	Feed rate [mm/rev]	Cutting velocity [m/min]	
1	1	1	1	0,5	0,1	58,875	56.78
2	3	1	1	2	0,1	58,875	105.14
3	1	3	1	0,5	0,4	58,875	86.22
4	3	3	1	2	0,4	58,875	161.22
5	1	1	3	0,5	0,1	235,5	50.47
6	3	1	3	2	0,1	235,5	98.83
7	1	3	3	0,5	0,4	235,5	78.51
8	3	3	3	2	0,4	235,5	145.09
9	2	2	2	1	0,2	117,75	91.12
10	2	2	2	1	0,2	117,75	91.82
11	2	2	2	1	0,2	117,75	90.42
12	2	2	2	1	0,2	117,75	91.82

In the present study, three parameters: cutting depth, feed rate and cutting velocity, were considered and the ranges of the cutting conditions were selected based on preliminary experiments. Since the parameters identified are multilevel variables and their outcome effects are not linearly related, it has been decided to use three-level tests for the cutting conditions.
Based on Taguchi's orthogonal array, the most suitable array for the current investigation is L_8 [10, 11, 12]. The identified process parameters and their levels are given table 3. The orthogonal array and the experimental layout plan of the present study are shown in table 4.

Analysis of Variance

The analysis of variance (ANOVA) test for significant differences between the process parameters by computing variances is used to estimate the error variance for the effects and is performed on signal/noise ratio to obtain the percent contribution of each of the parameters ANOVA uses the sum of squares to partition the overall variation from the average S/N ration into contribution by each of the parameters and error.

The total sum of squares (SS_T) is given by:

$$SS_T = \sum_{k=1}^{12} (\eta_k - m)^2 \quad (1)$$

The sum of squares due to parameters j is computed as:

$$SS_j = \sum_{i=1}^{r} r[(m_j)_i - m]_i^2 \quad (2)$$

where: r – number of times that level of parameter is repeated in an orthogonal array. In the present study r = 3 for cutting depth, feed rate and cutting velocity. A parameter j with the largest value of SS has a more significant role in controlling the performance characteristic.

The sum of squares of error (SS_E) is:

$$SS_E = SS_T - \sum_{j=1}^{3} SS_j \quad (3)$$

The mean square of each parameter j is:

$$MS_j = \frac{SS_j}{l-1} \quad (4)$$

The percentage contribution of each parameter j is determined as:

$$Q_j = \frac{SS_j}{SS_T} \cdot 100 \quad (5)$$

The F – ratio for each parameter j is given by:

$$F_j = \frac{MS_j}{V_e} \quad (6)$$

where V_e is the mean square of error ($V_e = MS_E$).

The parameter with highest value of F – ratio is the dominant parameter in controlling the performance characteristic.

The results of ANOVA are given in table 5. As seen from ANOVA table, the cutting depth is the most dominant parameter, followed the feed rate and cutting velocity. The cutting velocity has moderate effect in controlling the machinability for polyamide PA 66.

Table no. 5 Summary of ANOVA

Parameter	Degrees of freedom	Sum of squares	Mean square	Percent contribution	F - ratio
Cutting depth, a_p	1	7180.1	7180.1	66.14	124.01
Feed rate, f	1	2970	2970	27.36	51.30
Cutting velocity, v	1	242.7	242.7	2.24	4.19
Error	8	463.1	57.9	4.27	-
Total	11	10855.9	-	-	-

Relationship resulting from the results ANOVA generated using Minitab statistical software is:

$$F_z = 29.3 + 38.6 \cdot a_p + 127 \cdot f - 0.0613 \cdot v$$

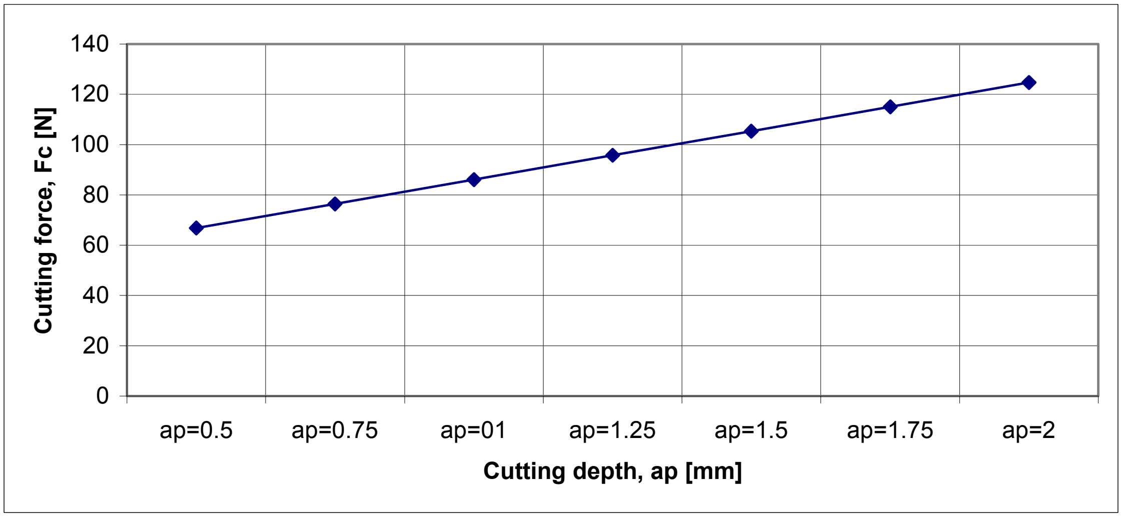

Fig. 1 Influence of cutting depth on cutting force (f = 0.2 mm/rev, v = 117.75 m/min)

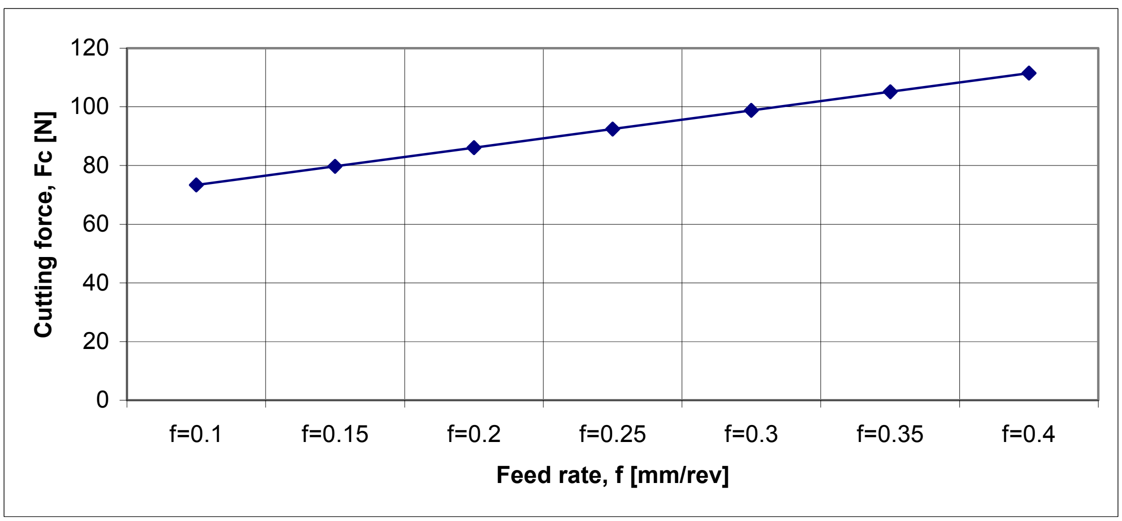

Fig. 2 Influence of feed rate on cutting force (ap = 1mm, v = 117.75 m/min)

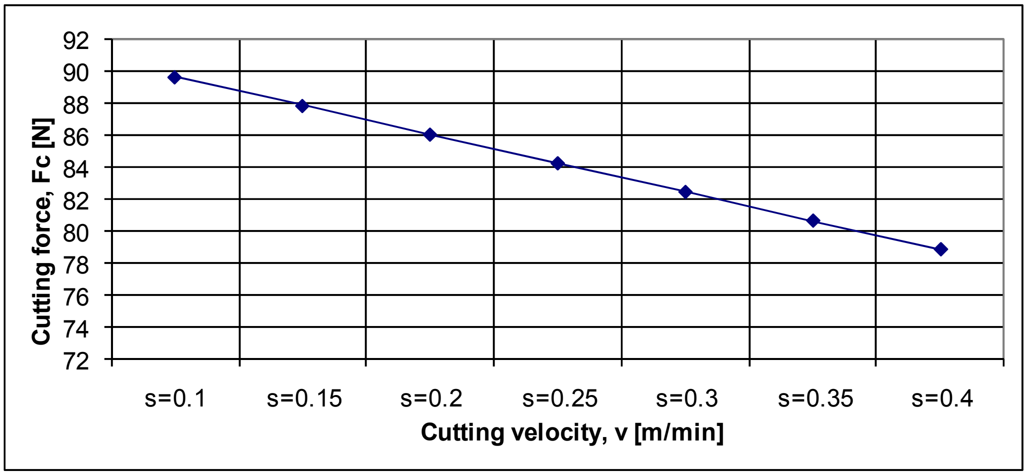

Fig. 3 Influence of cutting velocity on cutting force (ap = 1 mm, f = 0.2 mm/rev)

3. Conclusion

Of the analysis of variance ANOVA and in figures 1 – 3 finds that most influence on cutting force a have cutting depth and feed rate. Influence of cutting velocity is very small and increase its cutting force decreases. Influence of cutting depth and feed rate it is shown by the growth of the cutting force with their increase.

The ANOVA resulted in around 4,27% error, indicating the presence of interaction effects of the process parameters.

And our study reveals that cutting force analysis plays a vital role in studying the various characteristics of a machining process, for instance, the dynamic stability, positioning accuracy of the tool and roughness of the machined surface.

Taguchi method and analysis of variance ANOVA help to identify the interaction effects on the principal parameters of the process.

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