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The examination of cutting forces of polyether ether ketone (PEEK) during turning

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Abstract. Engineering plastics are more and more widespread nowadays and are used more and more in industry. The finish machining of these materials can be done by cutting. Two important characteristics can be used to describe the cutting process: forces during cutting and surface roughness. This paper examines the force components during the cutting of a widely used engineering plastic that has favourable properties. In the cutting experiments a full factorial design of experiments was used with the aim of predicting cutting force depending on cutting parameters with a predictive model.

Keywords: polyether ether ketone; engineering plastic; design of experiment; cutting forces;

1 Introduction

The finishing manufacture of the engineering plastics can be cutting. The machinability of engineering plastics is very different from that of widely used metals (e.g. steel, cast iron, aluminum alloys…)

The machinability of unreinforced and carbon fiber reinforced as well as glass fiber reinforced composites was investigated with a K15 hardmetal insert and a PCD (polycrystalline diamond) insert by Petropoulos et al. [1].They investigated the effect of cutting speed and feed rate on the surface roughness parameters and constructed a predictive model which depends on the cutting parameters.

Hanafi et al. [2] cut carbon reinfoced polyether ether ketone (PEEK) (with 30% carbon fiber) with a TiN coated tool. They examined the influence of feed and depth of cut on cutting force.

Unreinforced PEEK and PEEK reinforced with carbon and glass fiber (30%) were investigated by Mata et al. [3]. Predictive models were constructed for cutting force and specific cutting force in which the input parameters were the cutting speed and feed.

Hanafi et al. [4] in another paper investigated the machinability of PEEK reinforced with carbon fiber (30%). They applied the Taguchi method and looked for cutting parameters where cutting force and surface roughness are minimum.

This article investigates the machinability of unreinforced PEEK. An empirical model is constructed with which the resultant cutting force can be easily calculated in the range of examined parameters.

2 Material and methods

2.1 Equipment used

An unreinfoced PEEK rod (diameter is Ø60 mm) was used for the turning experiments.

The tool holder was a modified SDJCR 2525M-11 toolholder which can measure small forces (0…100 N) [5]. The insert was polycrystalline diamond (PCD), code: DCGW 11T304 FN.

A Dougard Eagle BNC-1800 CNC turning machine was used for the turning experiments and the DynoWare software was used to evaluate cutting force.

2.2 Design of experiment used

During the design of experiments (DOE) two factors (v_c – cutting speed, m/min; f – feed, mm) were changed at six levels. The depth of cut parameter was constant (a = 0.5 mm) because the cutting of PEEK is usually finishing machining. The 6 cutting speeds and the 6 feed parameters (full factorial design) resulted in 36 experimental runs. The values of cutting parameters are shown in Fig. 1.

Table 1 The values of cutting parameters

Levels	Cutting parameters		
	cutting speed v_c, m/min	feed f, mm	depth of cut a, mm
1	50	0.05	0.5
2	120	0.12	0.5
3	190	0.19	0.5

Levels	Cutting parameters		
	cutting speed v_c, m/min	feed *f*, mm	depth of cut *a*, mm
4	260	0.26	0.5
5	330	0.33	0.5
6	400	0.4	0.5

2.3 Measured cutting force components

In Fig. 1 shows the 3-D cutting force system during turning. During the turning experiments all three force components (F_c – main cutting force, N; F_f – feed force, N F_p – radial force, N) were measured.

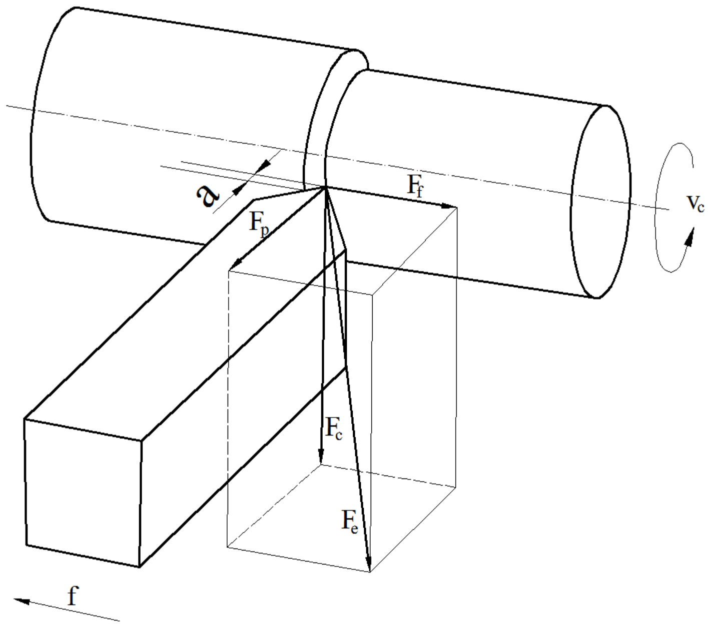

Fig. 1. The 3-D cutting force system during turning

From the measured values the resultant force (F_e) was calculated in the following way:

$$F_e = \sqrt{F_c^2 + F_f^2 + F_p^2} \quad (1)$$

3 Results

After the calculation of F_e (resultant) cutting force values, the significance tests were performed for the input parameters and it was found that only feed has a linear effect on F_e. It is shown in Fig. 2.

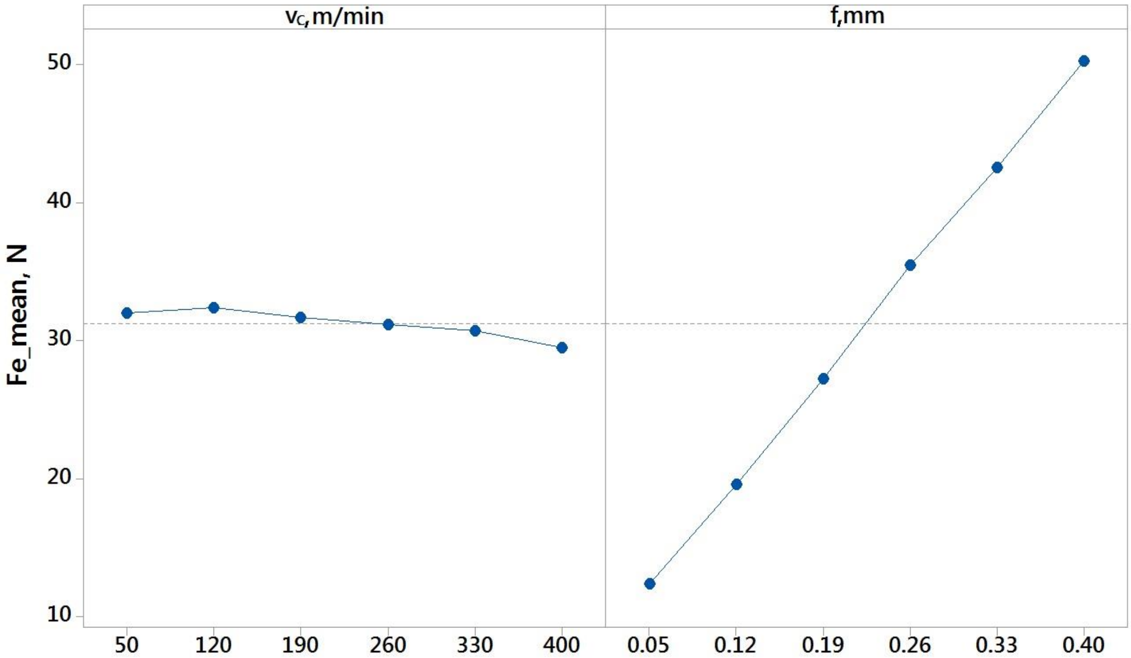

Fig. 2. The main effect plots

After the significance tests an empirical model was constructed to estimate F_e:

$$F_e = 6.76 + 108.94 \cdot f \quad (2)$$

$(R^2=0.9887)$

where F_e, (N) is the resultant cutting force and f, (mm) is feed.

The results of the residuum investigation are shown in Fig 3. The difference of the measured and estimated values is illustrated in a probability plot. Fig. 3 shows that the errors of our equation (2) show normal distribution and their average is close to zero while standard deviation is 1.4 N.

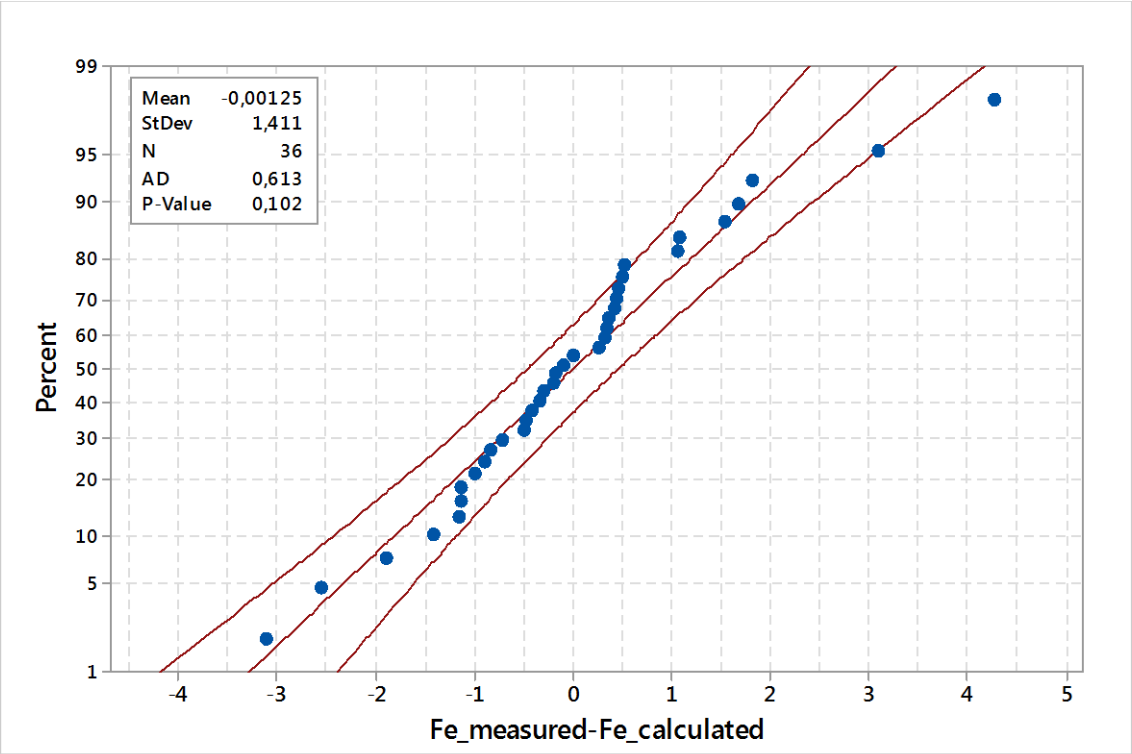

Fig. 3. The errors of eq. 2 in a probability plot

4 Conclusions

In this article the machinability of unreinforced PEEK was investigated during turning with a PCD tool. Our research mainly focused on cutting force and its estimation. The cutting tests were performed with the help of DOE with 6 cutting speeds and 6 feeds resulting in 36 experimental runs.

Our tests proved the following:

- In the turning of PEEK the resultant cutting force only depends on feed; cutting force has no effect on it.
- An empirical model was built which can predict the resultant cutting force in finish machining in the investigated parameter range.
- The residuum test proved that the difference of calculated and measured values (the error of the model) follows normal distribution. Its expected value is close to zero, while its standard deviation is quite low (1.4 N).

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