

STUDIES ON MACHINING CHARACTERISTICS OF SILICON NITRIDE CERAMICS

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ABSTRACT: Effects of various parameters such as infeed, speed and rake angle on the ductile machining process are studied. Cutting forces decrease with an increase in cutting speeds due to thermal softening of the workpiece material. Thrust forces increase marginally with an increase in cutting speed. Both cutting and thrust force components increase as the rake angle is decreased from 15° to -45° . Both cutting and thrust forces increase with the increase in infeed.

Keywords: Machining, silicon nitride, cutting force, cutting speed, thrust force

1. INTRODUCTION

Ceramics in recent years have found versatile uses in many applications. But the inherent brittle nature of ceramics makes machining of ceramics prohibitively expensive [1-5]. Recent work on the machining of ceramics has confirmed that brittle materials such as ceramics can be machined in a ductile fashion to obtain a high quality surface finish with minimal subsurface damage. Ductile machining of brittle materials such as germanium, silicon, silicon nitride etc is possible under controlled machining conditions. The mechanism of ductile material removal is either due to thermal softening or high-pressure phase transformation of the workpiece material ahead of the tool [6,7]. The effects of varying machining parameters on temperatures and pressures in the workpiece material was parametrically studied [8]. However, the effect of varying the parameters on the machining forces was not studied.

A study of cutting forces in ductile machining of silicon nitride is presented in this paper. This is accomplished by parametrically studying the effects of varying machining parameters, primarily feed, speed and rake angle.

2. EXPERIMENTAL WORK

A series of single point diamond turning (SPDT) cutting tests were performed using a diamond turning machine (DTM). The work piece material was hot isostatically pressed (HIP) silicon nitride with a hardness value of 15GPa. The cutting tool was a single crystal natural diamond. The sample was mounted on the centerline of the spindle axis and the tool was centered to the spindle axis.

The cutting tests involved a facing cut on a flat work piece. The depth of cut (infeed) was varied for successive cuts and the three orthogonal force components were measured with a dynamometer. The cutting speed and feed rate (cross feed) were also varied to establish a range of typical values.

3. RESULTS AND DISCUSSION

3.1 The effect of Cutting Speed

The cutting speeds were varied from 0.5m/min to 100m/min while keeping infeed = $20\mu\text{m}$, rake angle = -45° and tool tip radius = $10\mu\text{m}$ constant. Machining forces as a function of cutting speed is plotted in Fig-1. Cutting forces decrease with an increase in cutting speeds due to thermal softening of the workpiece material. Thrust forces increase marginally with an increase in cutting speed. A crossover of machining forces occur at high speeds indicating that the material removal may be due to plowing as a result of thermal softening. The force ratio F_c/F_t , called the apparent coefficient of friction, decreases with an increase in speed as can be seen from the graph. For $F_c/F_t > 1$,

material removal is by cutting where plastic deformation of the workpiece occurs. For $F_c/F_t < 1$, the material removal may be more due to rubbing or plowing effects rather than cutting.

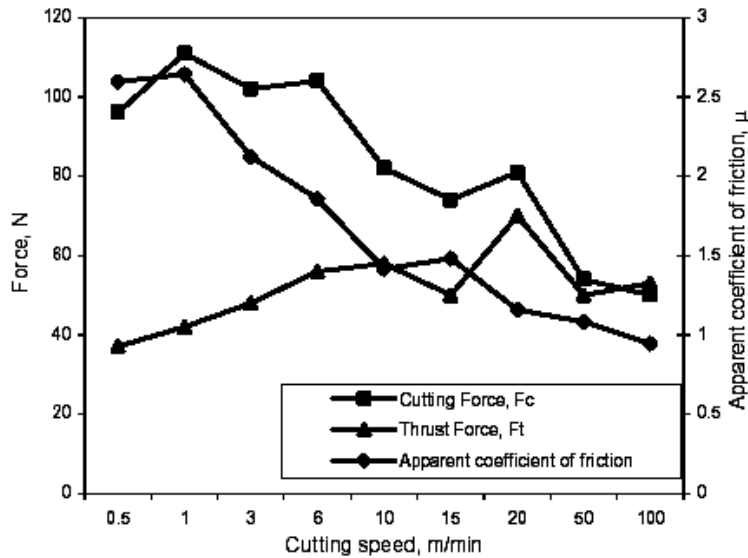


Fig-1 The variation of cutting and thrust forces with cutting speed

3.2 Variation of Rake Angle

Study of Machining forces were carried out with the machining parameters: Cutting speed = 300m/min, infeed = $10\mu\text{m}$, tool tip radius = $1\mu\text{m}$. The machining force components as a function of rake angle are shown in Fig-2. Both cutting and thrust force components increase as the rake angle is decreased from 15° to -45° with a crossover at -45° . The thrust force component increases at a much higher rate than the cutting force component. The force ratio obviously decreases at higher negative rake angles possibly due to plowing effects.

3.3 Variation of Infeed

The effects of variation of infeeds on the machining forces are studied by setting the parameters as, cutting speed = 300 m/min, tool tip radius = $1\mu\text{m}$, rake angle = -45° . Machining forces as functions of infeed are shown in Fig-3. Both cutting and thrust forces increase with the increase in infeed. A crossover can be observed at low feeds implying material removal by plowing rather than cutting. Cutting force dominates thrust force even at depths greater than the critical depth of cuts.

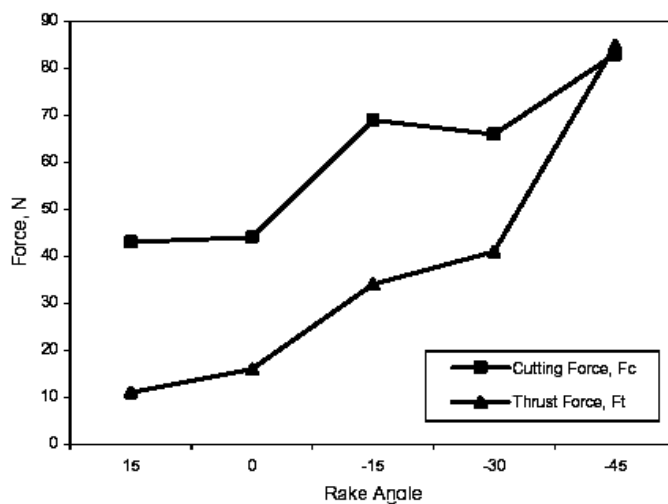


Fig-2 The variation of cutting and thrust forces with rake angle

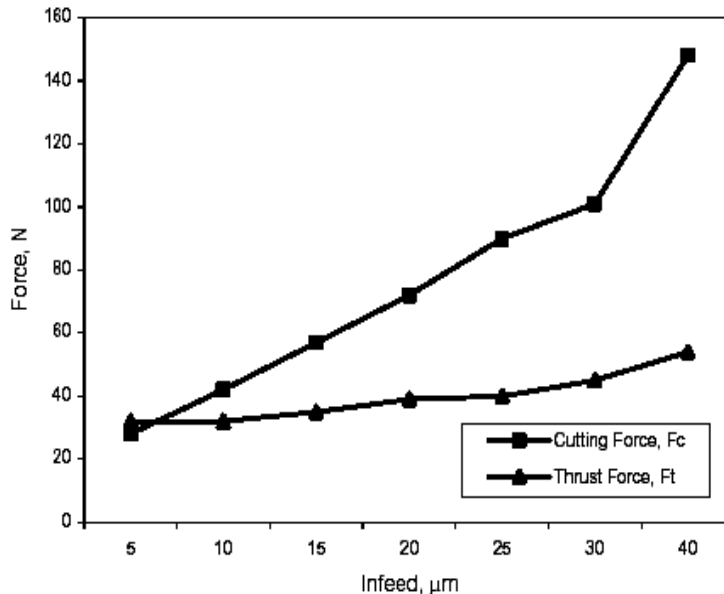


Fig-3 The variation of cutting and thrust forces with infeed

4. CONCLUSIONS

The important conclusions made from this work are as follows:

- Cutting forces decrease with an increase in cutting speeds due to thermal softening of the workpiece material.
- Thrust forces increase marginally with an increase in cutting speed.
- Both cutting and thrust force components increase as the rake angle is decreased from 15° to -45° .
- Both cutting and thrust forces increase with the increase in infeed.

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