EUROPEAN JOURNAL OF MATERIALS SCIENCE AND ENGINEERING
Volume 3, Issue 3, 2018: 133-139 | www.ejmse.tuiasi.ro | ISSN: 2537-4338

EFFECT OF CUT THICKNESS AND CUTTING SPEED ON CUTTING FORCES IN ORTHOGONAL CUTTING OF MILD CARBON STEEL (CS1030)

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Abstract

The effects of cut thickness and cutting speed on cutting forces in an orthogonal turning process have been studied using a CNC lathe for 3 different cutting speeds (100, 150 and 200 m/min) at a constant cut thickness of 0.17 mm and 4 different cut thicknesses (0.1, 0.17, 0.24 and 0.31 mm) at a constant cutting speed of 200m/min. Four tool wearlands (0, 0.2, 0.4 and 0.6 mm) were used for both combination of cutting parameters. The forces were measured using a piezoelectric dynamometer. The analysis of variance (ANOVA) was performed and result shows that cut thickness significantly affects cutting forces while cutting speed does not at 95% confidence. At a wearland of VB=0 mm and cutting speed of 200 m/min, the measured power force (F_{cm}) increased as cut thickness increases with the least measured value observed as 802.9 N while at a wearland of VB=0 mm and cut thickness of 0.1 mm, the measured thrust forces (F_{tm}) increases as the cutting thickness is increased with a least observed value of 500.9 N. These form a basis for selecting optimal cutting conditions to machine the mild carbon steel.

Keywords: *orthogonal cutting, power force, thrust force, cut thickness, cutting speed.*

Introduction

Orthogonal cutting has long been accepted as a major manufacturing process due to its inherent advantage and technological capabilities. Much research and development work has been done to study and understand the orthogonal machining processes. One major objective is to continually improve the technological and the economic performance of the process as assessed by the key performance information - force, power, component surface integrity, dimensional precision, tool wear and life, as well as production rate and cost [1]. To achieve this objective, research efforts have been directed towards minimizing cutting forces by optimizing cutting parameters like cutting speed, rake angle, feed rate and cut thickness.

In orthogonal machining, excess material from a work piece is removed in order to convert the material left into the required shape. The cutting force must be enough to overcome the mechanical strength of the workpiece [2, 3]. Cutting tools persistently go through pressure and resisting stresses during machining of metallic and non-metallic work pieces. Cutting factors such as surface accuracy, tool failure, cutting temperature, and vibrations have a strong correlation with cutting forces [4, 5]. Cutting forces have effect on the deformation of the work piece machined, its dimensional precision and chip formed. More clearly, the cutting force is one of the major factors that should be identified in the machining operations [2, 5].

In order to produce high quality products at low cost, an appropriate selection of tool materials, cutting parameters, tool geometry and machine tools becomes necessary. This has brought about several efforts been made so as to reduce cost and improve product quality via the proper knowledge of the cutting process. A significant amount of these studies have been

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tailored towards the measurement and estimation of the cutting forces during the machining process. This is because proper understanding of the cutting forces is necessary as they have effect on the generation of heat, and consequently on tool wear, quality of machined surface and precision of work piece [6].

A number of important researches have been carried out on developing the relationship between tool wear and cutting forces and power in milling operations using the 'mechanistic' approach [5, 7-11].

The geometry of orthogonal cutting is presented in Fig. 1. For analysis, the forces that come into play during orthogonal cutting are divided into two parts; one parallel to the direction of tool movement (cutting or power force, F_{cs}) and another perpendicular to the surface being machined (thrust force F_{ts}).

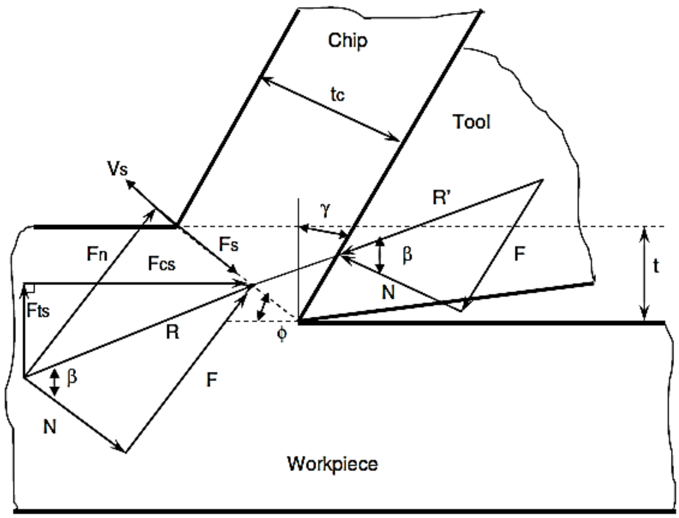

Fig. 1. Geometry of orthogonal cutting process

Many factors such as those related to feeding, cutting tool, and work piece affects the forces applied by the cutting tool [12]. The rake angle has much effect on the forces developed during orthogonal machining. Therefore, cutting forces increase with decrease in rake angle. Also, the organization of the material elements in relation to the cutting tool edge and cutting path affects the mechanical properties of the material and subsequently, the required cutting forces [13]. According to Roger et al. [2], the depth of cut also affects the orthogonal cutting forces. Therefore, the parallel force increases with increase in depth of cut.

Amit and Gorana [6] investigated how tool rake, tool shape, tool radius and tool material affects the cutting forces while machining a mild steel work piece. Results of the study indicated that the process parameters significantly affect the cutting forces.

Roger et al. [2] evaluated how rake angle, cutting direction, and depth of cut affects cutting forces and surface finish of black spruce wood. Results of the study indicated that rake angle increases as the cutting forces, torn grain, waviness, and roughness are decreased. The smallest cutting forces and the best surface finish were obtained with 65^o of rake angle. Cutting forces and surface finish were more affected by depth of cut than by cutting direction variations at this angle.

Rao et al. [14] studied the effect of speed, feed and depth of cut on cutting forces and surface roughness while working with a ceramic tool and the work material of AISI 1050 steel. The results showed that the feed rate had a significant effect on the cutting forces and surface roughness. The depth of cut had a significant effect on the cutting forces, but had no significant effect on the surface roughness. Kamely and Noordin [4] examined the effect of cutting tool materials on cutting forces in finished hard turning of a cold worked steel tool. Results obtained showed that, the cutting forces were affected directly by cutting tool material at a constant depth of cut and feed rate.

In the reported studies, effect of cut thickness and cutting velocity on cutting forces seems to have little or no attention as its affects cutting forces in orthogonal cutting of metals.

The aim of this work is to study the effect of cut thickness and cutting speed on cutting forces in orthogonal machining of mild carbon steel (CS1030). The work is limited to the use of CNC lathe (T-6 series) cutting of mild carbon steel, CS1030 under lubricated condition using UFA hydrosol as coolant.

Materials and Methods

Orthogonal cutting tests were conducted by using ‘sharp’ tools and tools with wearlands using a CNC lathe. The wearlands were artificially generated and checked for their sizes to ensure they were within 3% of their specified sizes. Wearland zero represents sharp tool. The workpiece used was mild carbon steel, CS1030 which is a medium tensile material with low hardenability. Its chemical composition and mechanical properties are stated in Table 1 [15].

The work pieces were cylindrical in shape with 3 mm wall thickness and diameters of 100 mm. They were machined from one end. The feed rates were set on the lathe to correspond to the cut thickness t in orthogonal cutting and the wall thickness of the workpiece was taken as the width of the cut, b.

Cut thicknesses and cutting speeds were selected for the tests at a rake angle of $\gamma=0^0$ shown in Table 2. The selection of the range of cutting conditions was based on ISO 3685 [16]. Wearland of 0 mm represents sharp tool.

Table 1. Chemical compositions and mechanical properties of CS1030 [15]

C	Mn	P	S	Density, ρ (Kg/m^3)	Tensile strength (MPA)	Hardness (BHN)
0.3%	0.6%	0.04%	0.05%	$8.03x10^3$	463.7	126

Table 2. Summary of the level of parameters used in the orthogonal cutting test

Wearland, VB (mm)	0	0.2	0.4	0.6
Cut thickness, t (mm)	0.1	0.17	0.24	0.31
Rake angle, γ (^{0})	-5	0	5	
Cutting speed (m/min)	100	150	200	

A full factorial experimental design was used in this study. 144 tests were conducted using 12 inserts (3 rake angles x 4 wearland sizes) were conducted. For the purpose of this present study, rake angle of $\gamma=0^0$ because cutting forces are lower with increase in rake angle [5]. The force components were measured using a piezoelectric dynamometer mounted on the tool post.

Results and Discussion

Effect of cut thickness on cutting forces

As presented in Fig. 2 and 3, the cutting forces increase with increase in cut thickness. The cutting force for a wearland of 0.6 mm is increasing gradually for various cut thickness. As the wearland is decreased to 0 mm the value of cutting forces decreases with the least measured value of the power force (F_{cm}) observed as 802.9 N at a cut thickness of 0.1 mm at a cut thickness of 0.1 mm compared to the cutting force obtained for a wearland of 0.6 mm. The measured thrust forces (F_{tm}) also increased as the cutting speed is increased with a least observed value of 500.9 N at 0.1 mm cut thickness. Increasing wearland also increased the cutting forces. This could be attributed to the development of built up edge.

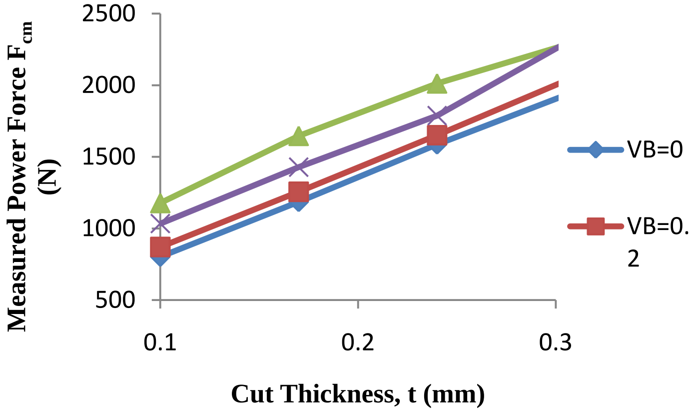

Fig. 2. Effect of cut thickness on measured power forces (F_{cm}) at V=200 m/min, $\gamma = 0^0$

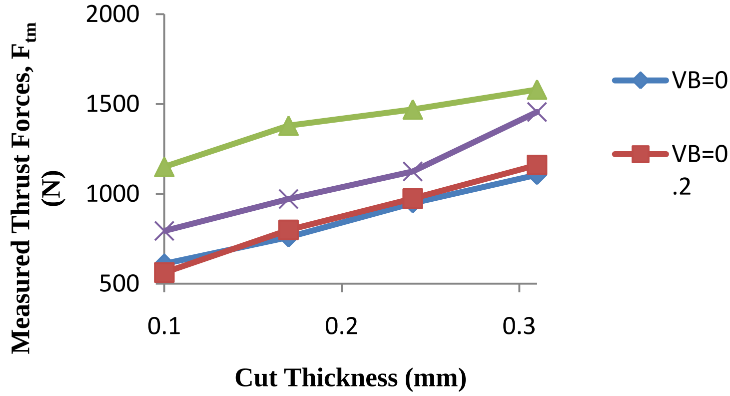

Fig. 3. Effect of cut thickness on measured thrust forces (F_{tm}) at V=200 m/min, $\gamma = 0^0$

For cut thicknesses that are higher, the forces are higher in relation to the other three wearlands (0.2, 0.4 and 0.6 mm). This could be attributed to the tempering of the work material as a result of heat generated during machining as well as the effect of active rake angle due to the formation of built up edge. This is similar to trends observed by Sivaraman et al. [17].

Effect of cutting speed on cutting forces

As shown in Fig. 4 and 5, the power force and thrust force decreases with an increase in cutting speed. As the wearland rises from 0 to 0.6 mm, the value of all the forces are raised. As the cutting speed is raised with a wearland of 0mm, the machining becomes stable, amounting to a reduction in force. The reduction of force for various speeds is reasonable for wearlands of 0.2 and 0.4 mm. For a wearland of 0.6 mm, the cutting forces are reduced up to 150 m/min due to material tempering and then the forces are steadily reduced. This trend is similar to previous reports [18-20].

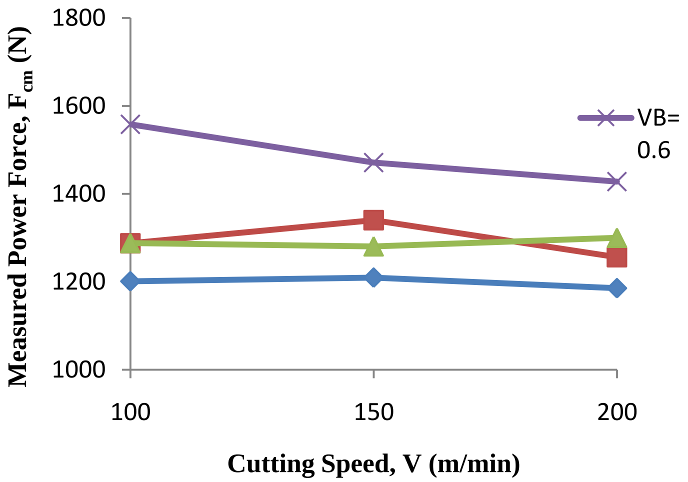

Fig. 4. Effect of cutting speed on measured power forces (F_{cm}) at $\gamma = 0^0$, t=0.17 mm

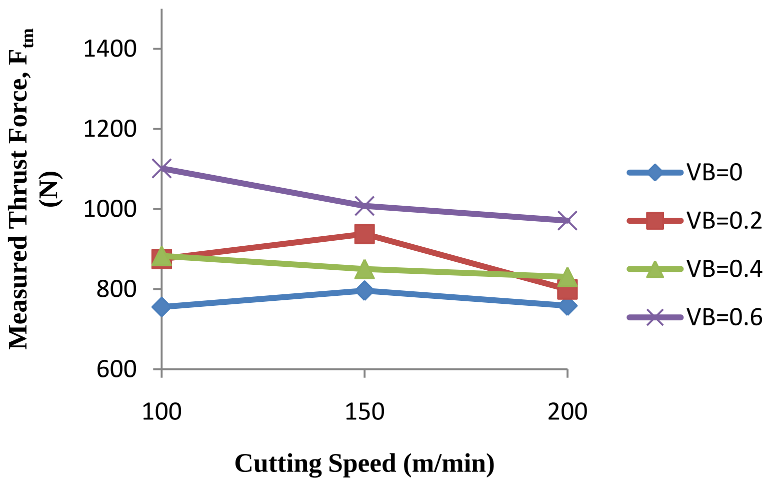

Fig. 5. Effect of cutting speed on measured thrust forces (F_{tm}) at $\gamma = 0^0$, t=0.17 mm

ANOVA for cutting forces

Since the measure power force and thrust force portray the same trend, analysis of variance was carried out at 95% confidence to ascertain the significant contribution of cut thickness and cutting speed on only power force (F_{cm}). From Table 3 a P-value of 0.00000752 ($P<0.05$) shows that, cut thickness has significant influence on the cutting forces. However, Table 4 has a P-value of 0.885478 ($P>0.05$) which indicates a non-significant effect of cutting speed on cutting forces.

Table 3. ANOVA for effect of cut thickness on cutting forces

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3131451	3	1043817	29.88651	7.52E-06	3.490295
Within Groups	419112.2	12	34926.02			
Total	3550563	15				

Table 4. ANOVA for effect of cutting speed on cutting forces

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3841.287	2	1920.643	0.123286	0.885478	4.256495
Within Groups	140208.3	9	15578.7			
Total	144049.6	11				

Conclusion

The influence of cut thickness and cutting speed on cutting forces (power forces and thrust forces) in orthogonal cutting of mild carbon steel (CS1030) have been studied. Results of the study showed that there are significant correlations between the measured cutting forces and cut thickness for sharp and worn tools. Both the measured power and thrust forces increases linearly with cut thickness increasing. This is confirmed by an ANOVA in Table 3 which shows that cut thickness has substantial effect on the cutting forces with a P-value of 0.00000752 ($P<0.05$). However, Table 4 indicates a P-value of 0.885478 ($P>0.05$), showing an inconsequential effect of cutting speed on cutting forces. It can therefore be concluded that, using a sharp tool with a wearland of VB = 0 mm and a cut thickness of 0.1 mm at any cutting speed will decrease the cutting forces. Any increase in cut thickness will increase the cutting forces as studied.

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Received: July 2, 2018
Accepted: September 02, 2018