BÁNKI KÖZLEMÉNYEK
2. ÉVFOLYAM 2. SZÁM

Effect of Interrupted Cutting of Variable Loading on Cutting Tool

Ozden Isbilir*, Ibrahim Etem Saklakoglu**
* Department of Mechanical Engineering, Karabuk University, Karabuk, Turkey
** Department of Mechanical Engineering, Ege University, Izmir, Turkey
ozdenisbilir@karabuk.edu.tr, i.e.saklakoglu@ege.edu.tr

Abstract — **Cutting tools are used in various processes at very different conditions including material behaviors, machining parameters, geometry, and tribological characteristics. For an efficient machining, a cutting tool requires high hardness, high chemical stability, and high wear resistance. Machining can be more challenging in the interrupted cutting due to the alteration in mechanical and thermal loads. When interrupted surfaces are machined, the tool also requires sufficient impact and fatigue resistances. The main goal of this work to investigate the effect of interrupted cutting of variable loading when turning AISI 4140. Based on the experimental results, the main conclusion of this work was the tool life was shorter in the interrupted turning experiments. Although lower tangential cutting forces were measured in the interrupted cutting tests, the intervals deteriorated the tool life. The trends of the tangential cutting forces were observed as expected in the continuous turning at dynamic loading whereas the trends were different and not as expected in the interrupted turning. In both continuous and interrupted turning at dynamic loading, abrasive wear was the major mechanism on the flank surface.**

Keywords: interrupted cutting, variable loading, tool wear, tangential cutting force

1 INTRODUCTION

The importance of cutting parameters has been well recognized in machining operations, particularly turning process [1-4]. It has been clearly noticed that the amount of wear and tool life are greatly dependent on cutting parameters such as the cutting speed, the feed rate and the depth of cutting. The cutting speed is one of the major factors in machining and affects the tool life and cutting forces as well. Due to its importance in the quality of the machined surfaces and the rate of production, it has become the main limitation in the selection of process parameters. The cutting speed is closely related with the plastic deformation during machining, thus induced heat is also dependent on the selection of cutting speed. Furthermore, mechanical stresses on cutting edges and high cutting temperatures due to plastic deformation and friction cause fatigue and wear on cutting tools.

Dimla [1] focused on the effects of cutting conditions on cutting forces in turning. Tests showed that there was a modest rise in the cutting forces as the cutting speed was increased with the use of a new tool. However, there was a nonlinear effect between cutting force and cutting speed when a worn tool was used in the tests. Cutting forces rose when the feed rate and the depth of cut were increased for both worn and unworn inserts utilized in the tests. The results also presented that the effects of the cutting speed and the feed rate were more complex the depth of cut did. Saglam et. al. [2] investigated the effects of geometry and feed rate on the cutting forces in turning of hardened AISI 1040. They performed a series of experimental tests and compared the experimental results with the results of the mathematical model based on Kienzle approach. The study depicted when the feed rate was increased, the cutting forces increased, but the temperature decreased. Korkut and Donertas [5] investigated the influences of the feed rate and cutting speed on cutting forces in the milling of AISI 1020 and AISI 1040 experimentally. According to the findings, the built-up-edge formation was observed on the cutting tools during experiments. This extra geometry on the cutting tool caused to severe damages on tool life owing to increased cutting forces and cutting temperatures. It was noted that the extent of built-up-edge tended to decrease when the cutting speed rose, however, its structure became less stable. Due to BUE formation, there was limited contact with the workpiece at lower cutting speeds, thus lower cutting forces occurred in the milling of both materials at these cutting speed ranges. Authors also noted that cutting forces increased significantly with the rise in feed rate and depth of cut.

Diniz et. al. [6] carried out research on continues, semi interrupted and interrupted turning of hardened steel. In the experiments, two grades, low and high CBN content tools were used to find out more suitable tool for the interrupted machining process. There is a high demand for resistance against wear and shock since there is dynamic loading in interrupted cutting. Authors found that tool life was longer in continuous cutting compared to interrupted cutting. Tool life decreased substantially with the increasing cutting speed due to wear, chipping or breakage of the cutting edge in interrupted cutting tests. Chandrasekaran and Thoors [7] compared tribological characteristics of continuous and interrupted turning. The results showed that the amount of wear developed rapidly in interrupted cutting, thus tool life was found longer in continuous cutting compared to interrupted cutting. The decline of tool life in interrupted cutting varied between 10 and 95% due to workpiece material, cutting parameters and durations. It was also noted that tool life increased at high removal rates in interrupted cutting. Authors noted that interruption durations could likely have a coolant effect on cutting tools.

The vast majority of the researches have carried out research activities on continuous cutting whereas few of them have focused on interrupted cutting [7-14]. However, all these researches have performed their investigations at stable cutting speeds. Nevertheless, almost all cutting tools are used with different cutting speeds in various industries. Not only cutting tools are utilized at different cutting speeds within in a cutting process, but they can be also used in various conditions such as continuous or interrupted cutting. Hence, the cutting process can be more complex due to the alteration in the cutting speed and the characteristic of the metal removal. That is why a better understanding of cutting under variable loading conditions is necessary for the further improvement of cutting tools and machining operations. Thus, an experimental approach has been developed to investigate the effect of the interrupted turning with variable loading.

2 MATERIALS AND METHODOLOGY

The workpiece material used in the tests was AISI 4140 steel, which has a chemical composition of 0.40% carbon, 0.75-1% manganese, 0.80-1.1% chromium, 0.15-0.30 silicon, and 0.15-0.25% molybdenum typically. Solid cylindrical turning workpieces have dimensions of ϕ90 and 300 mm length.

The cutting tool used in the study was ISCAR uncoated carbide cutting insert with an ISO code of SCMT 09T308-19. The carbide inserts were mounted on an ISCAR right-hand tool holder with an ISO code of SSBCR 1616H-09. The tool has 0º rake angle, 7º clearance angle, 75º approach angle, and 0º inclination angle.

The turning experiments were conducted using a DAEWOO Puma 400 CNC lathe which has a maximum power of 22 kW and a maximum spindle speed of 3000 rpm.

Figure 1 Experimental Setup

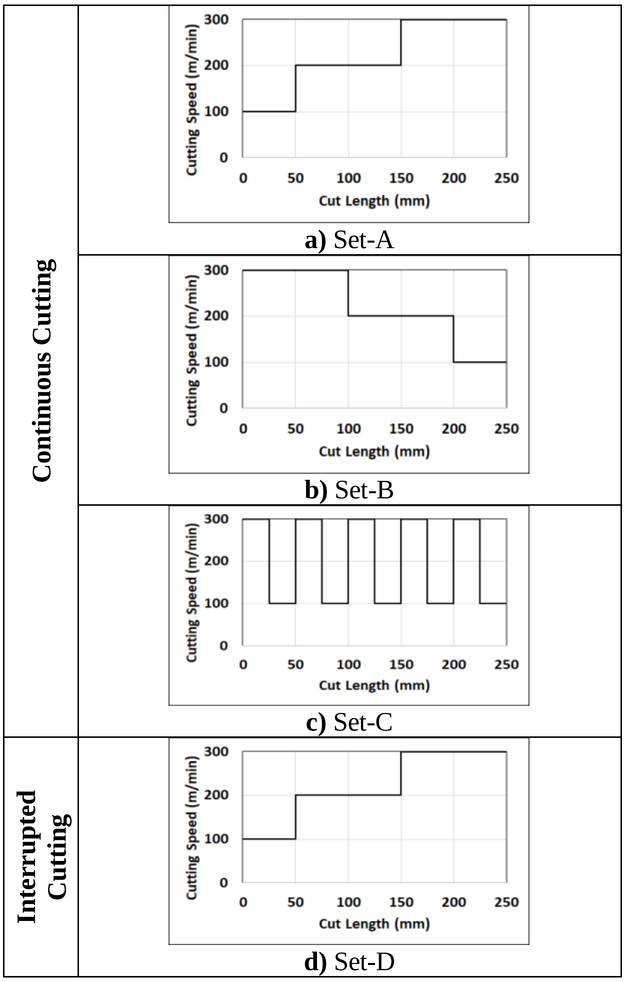
The experimental set up utilized in this study consisted of a load cell, a data acquisition system and a computer (Figure 1). The load cell had a capacity of 10 kN. The load cell was used to collect the signals of the tangential cutting force during turning. The analog signals were collected, amplified and then transformed into digital format. These digital signals were transmitted to the computer and stored by the software.

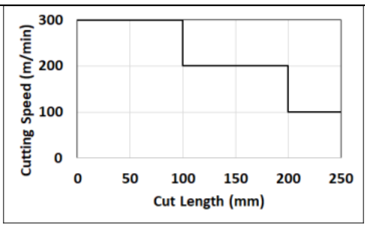
A metal microscope (Metkon brand, IMM-901 model) was used to determine tool life. The flank wear on the cutting edge was observed after each pass and images of the worn region were taken carefully to measure the extent of the wear (VB_B and VB_B max). Cutting inserts were assumed worn and the tests were terminated when VB_B has reached 0.3 mm or VB_B max reached 0.5 mm.

The experiments were carried out at variable loading conditions in both continuous and interrupted turning approaches. Different combinations of cutting speeds were investigated in this study and led to a total of 6 tests. Other machining parameters (feed rate, depth of cut) were kept constant in all tests. Each test was performed in a dry condition. The interruptions were not ensured by a discontinuity in the workpiece geometry. In interrupted tests, the cutting process has been paused for two seconds at each interval, cutting speed was changed then the cutting process continued. However, there was no discontinuity in the cutting process when the cutting speed changed in continuous tests. The test parameters and loading condition are given in Table 1 and Figure 1, respectively.

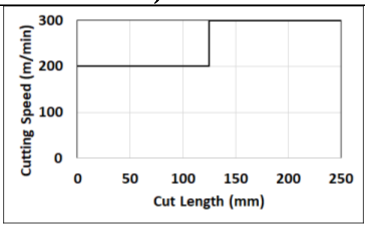
Table 1. Test Parameters

Test	Condition Type	Cutting Speed Vc (m/min)	Feed Rate f (mm/rev)	Depth of Cut a_p (mm)
A		(100-200-300)		
B	Continuous	(300-200-100)		
C		(300-100)	0.2	2
D		(100-200-300)		
E	Interrupted	(300-200-100)		
F		(200-300)		





e) Set-E



f) Set-F

Figure 2. Loading Condition (a, b, c: Continuous cutting; d, e, f: Interrupted Cutting)

3 RESULTS AND DISCUSSION

The aim of the study was to determine the influence of interrupted cutting on tool life and cutting force at variable loading condition. Table 2 illustrates the summary of the experimental results in turning. Force data collected from the dynamometer has been averaged and is presented here. The average values have been calculated after all turning passes.

Table 2. Summary of the Experimental Results

Test	Condition Type	Average Cutting Speed (m/min)	Tool Life (min)	Average Tangential Force (N)	Maximum Tangential Force (N)
A	Continuous	184.62	13.07	827	1187
B		184.62	11.43	797	1089
C		150	12.09	894	1207
D	Interrupted	184.62	10.85	514	662
E		184.62	10.85	603	765
F		240	8.27	498	677

3.1 Tangential Cutting Force

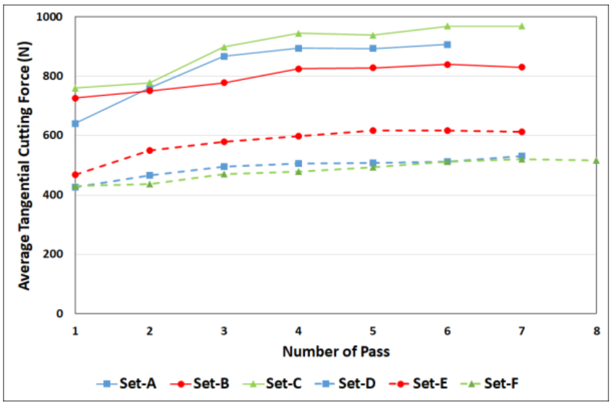
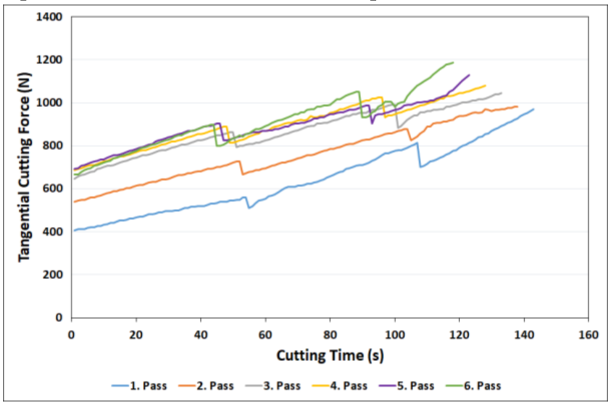


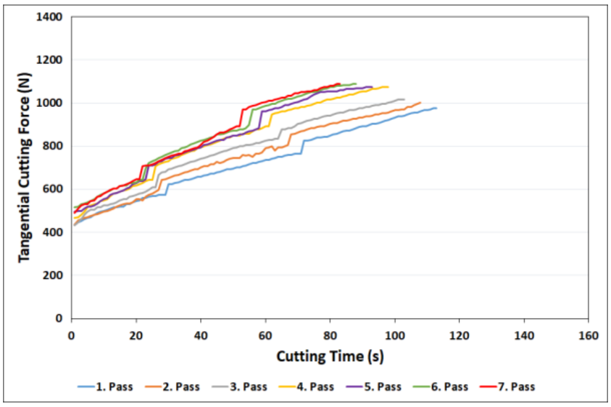
Figure 3. Evolution of the Average Tangential Cutting Force

Figure 3 represents the evolution of the tangential cutting force component throughout the cutting process in both continuous and interrupted turning at variable loading. As it can be noticed obviously, a higher amount of tangential cutting forces were measured in the continuous cutting tests compared to interrupted cutting tests. The intervals of the cutting process in the interrupted experiments affected the tangential cutting force.

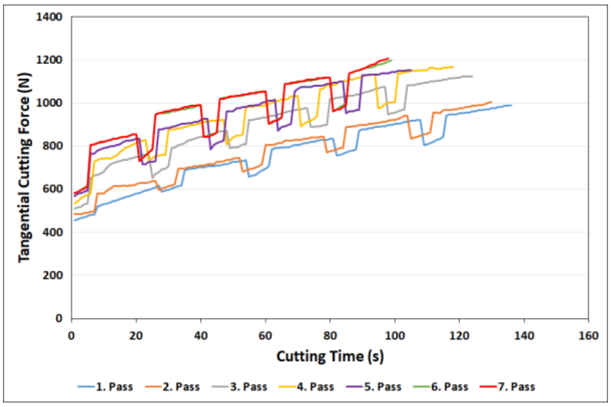
Figure 4 (a,b,c) shows the induced tangential forces at continuous turning process where there was no pause during cutting speed change. As can be seen in the images, there were sudden changes with the expected trends when the cutting speed shifted. However, the effect of cutting speed cannot be digitized since the influence of tool wear could not be isolated. The highest average tangential force and the highest maximum tangential force were measured in the Set-C. The amount of cutting speed variation was the highest and the average cutting speed was the lowest in all experiments, thus this result was expected at Set-C.



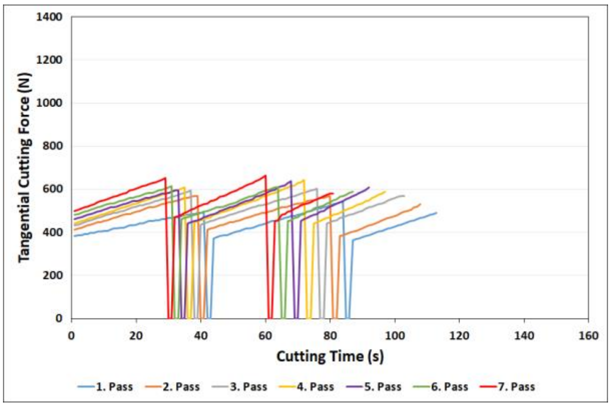
Set-A



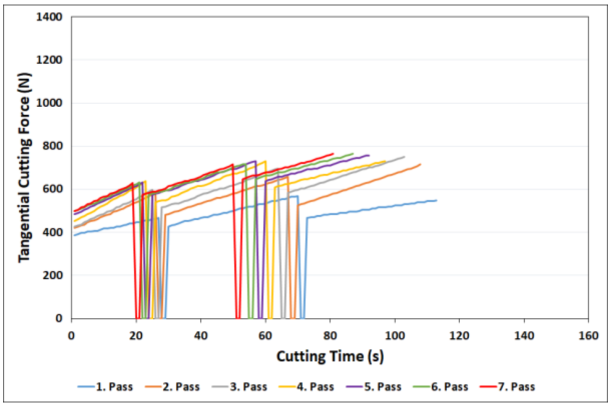
Set-B



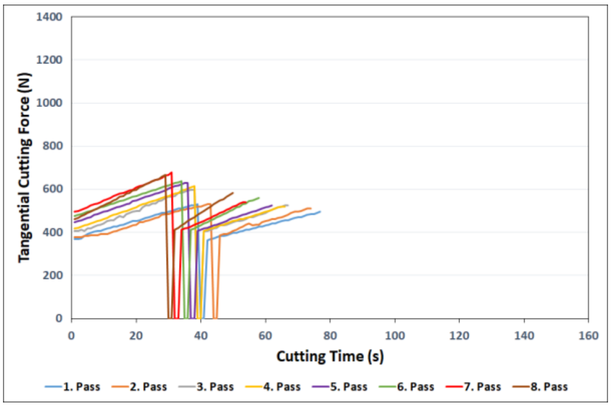
Set-C



Set-D



Set-E



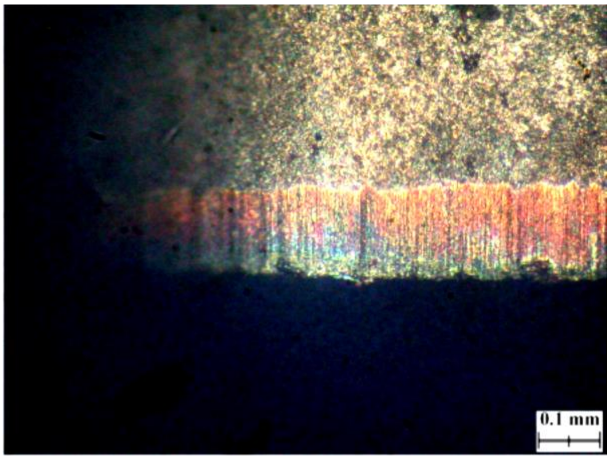
Set-F

Figure 4. Evolution of the Tangential Cutting Force

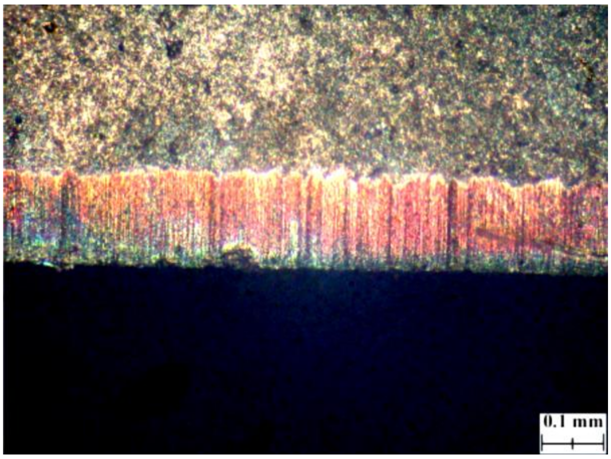
Figure 4 (d,e,f) displays the induced tangential forces at interrupted turning process where there were idling times during cutting speed change. As can be seen in the images, tangential forces dropped to zero in forces since there was no cutting action in the idling times. Then the force started surprisingly from lower levels comparing to the values just before the pauses in all interrupted turning experiments. Dynamic condition and a possible cooling in idling time could lead to a relaxation in the workpiece stresses. Due to these, average and maximum tangential forces were measured much lower compared to continuous turning experiments. However, the effect of cutting speed cannot be expressed clearly due to the relaxation process and the influence of tool wear. The highest average tangential force and the highest maximum tangential force were measured in the Set-E.

3.2 Wear and Tool Life

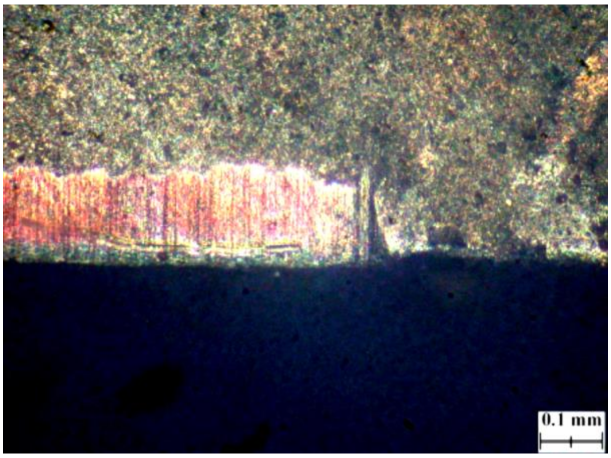
Indirect measurements of wear were carried out using an optical microscope by magnifying the cutting edge 100X. The flank wear images were taken after each pass as shown in Figure 5. The maximum width of the flank wear land VB_B max and the average width of the flank wear land VB_B were measured and compared with the appropriate criteria until they reached any of them as the standard required [15]. In all cutting experiments, VB_B reached the tool wear criterion first, so it was considered that all tools are worn regularly.



(a)



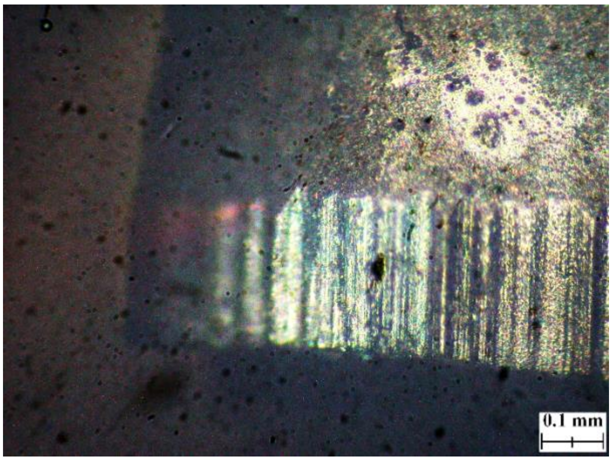
(b)



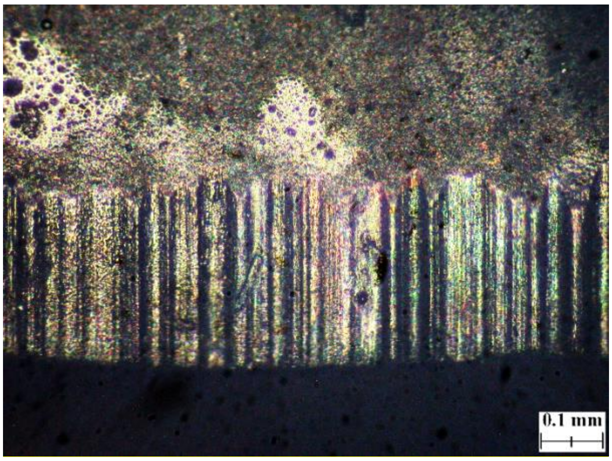
(c)

Figure 5. Measurement of Flank Wear, AISI 4140 at Set A after 1st Pass a) Zone C b) Zone B c) Zone A + N

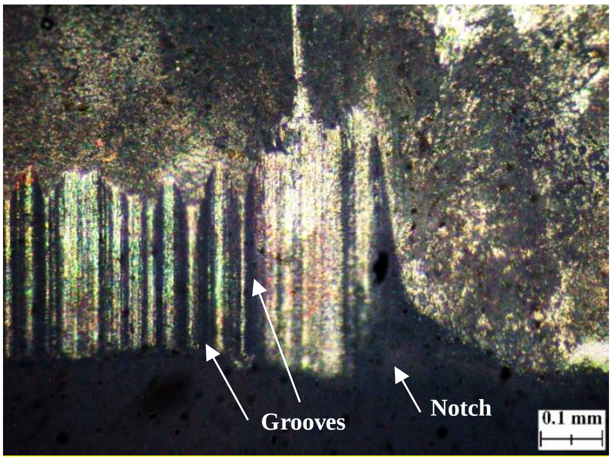
As can be noticed in Figure 5 and Figure 6, abrasive scratches were visible on the worn flank faces. According to Trent and Wright [16], these scratches are typical of abrasive wear. Abrasion may be occurred due to friction with hard particles from the workpiece. It can be happened by hard particles from cutting tool after removal of the binder of the cutting tool material due to friction with the workpiece. These hard particles could create three body effect and rub against the tool and consequently damages the resistance and causing wear.



(a)



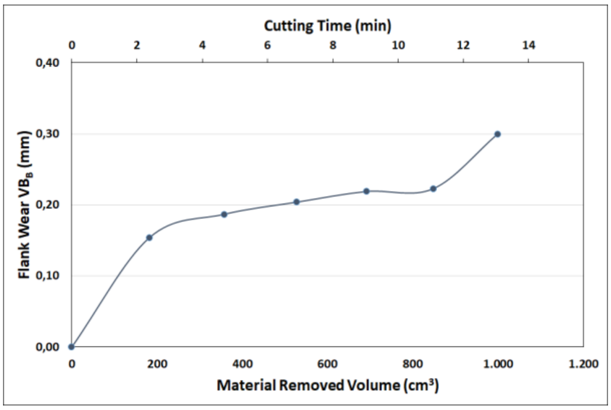
(b)



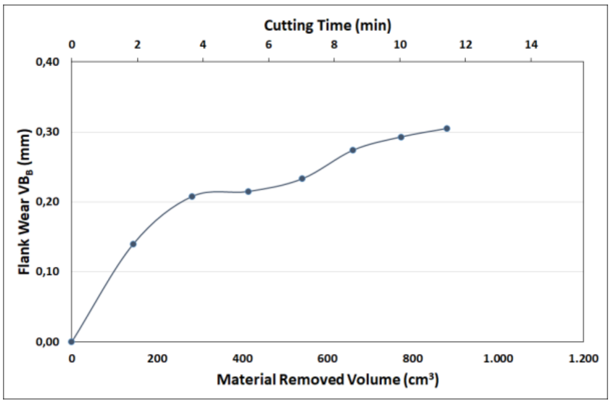
(c)

Figure 6. Flank Wear, AISI 4140 at Set F after 8th Pass a) Zone C b) Zone B c) Zone A + N

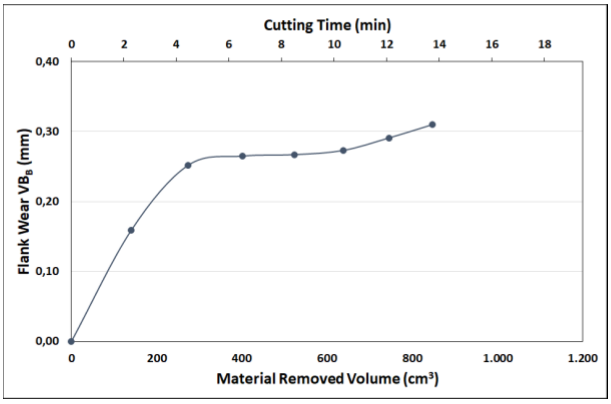
Some minor chipping was observed on the cutting edges at the beginning stages of turning. As can be seen in Figure 6, plastic deformation and notch formation observed on the flank face of the cutting tools, which was the end of tool-workpiece contact as stated by Grzesik [8]. These defects can be associated with a strong cutting force and stress gradients on the flank face. On the left side of the notched region (Figure 6-c), cutting was performed with the maximum chip thickness hence the maximum cutting force acting on the cutting tool. Whereas on the right side of the notch region, there was no contact between the cutting tool and workpiece hence no force was exerted on this region. Notch formation was found higher in the continuous cutting experiments possibly due to the higher amount of cutting forces.



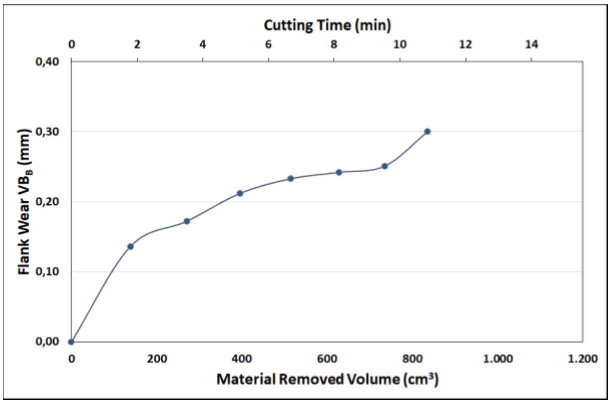
Set-A



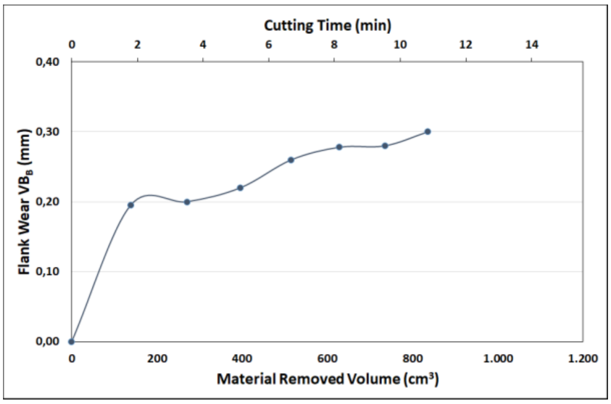
Set-B



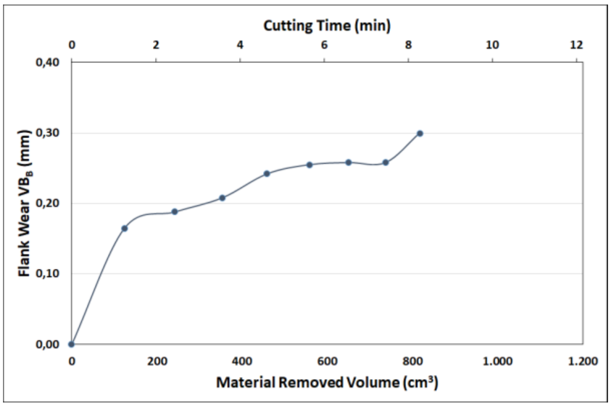
Set-C



Set-D



Set-E



Set-F

Figure 7. Evolution of the tool life for continuous and interrupted with variable loading

Figure 7 displays the curves of tool flank wear with regard to material removed volume and cutting time as well, to present the progress of wear and performances of cutting tools on continuous and interrupted cutting at variable loading. It can be seen in these figures, volumes of removed material were less at interrupted cutting experiments than continuous cutting ones even though all experiments performed at variable cutting speeds. The differences in the extent of cut material were between 4 and 16%. As seen in these images, the flank wear curves grew steeper in the interrupted cutting experiments.

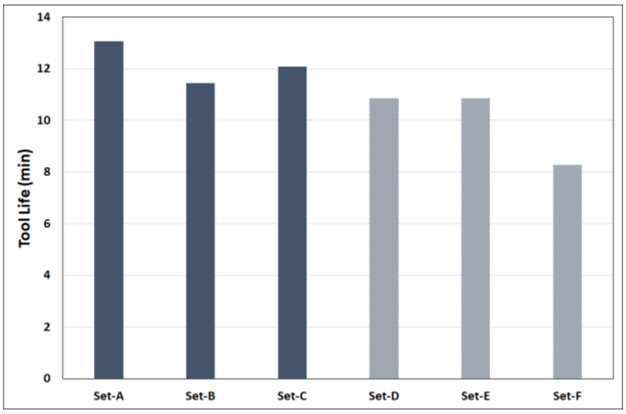


Figure 8. Tool lives

Figure 8 represents the experimental results of tool life in all the tests. Based on the experimental findings, it can be stated that interrupted cutting influenced tool life even there was not any discontinuity in the workpiece geometry. Even though both continuous and interrupted cutting approaches were carried out at variable cutting speeds, the results indicated that interrupted cutting caused to shorter tool lives between 5 and 32% compared to continuous cutting. Although the fact that the continuous cutting involves higher tangential cutting forces and possibly higher cutting temperatures, the interrupted cutting approach stimulated wear mechanisms. Pauses during cutting speed change in interrupted cutting could hinder the heat propagation through the workpiece and cutting tool since the rotation of the workpiece can generate air cooling. Diniz and Oliveira [9] also stated this for interrupted cutting where there are discontinuities in the geometry such as grooves in the workpiece. During the idling times, there was no cutting action hence there were no cutting forces as can be seen in Figure 4(d,e,f). For these reasons, the shorter tool life in interrupted turning could be attributed to cyclic thermal and mechanical stresses.

CONCLUSIONS

The paper presents the effect of the interrupted cutting on cutting tools at variable loading in turning. The results highlighted in this paper were determined from the analysis of an experimental work concentrated on the tangential cutting force components, tool wear, and life in continuous and interrupted turning of AISI 4140. It can be concluded that:

- A higher amount of tangential cutting force occurred in all the continuous turning experiments compared to the interrupted turning. The intervals of the cutting process in the interrupted experiments affected the tangential cutting force.
- The trends of the tangential cutting forces were observed as expected in the continuous turning at dynamic loading whereas the trends were different in the interrupted turning.
- In both continuous and interrupted turning at dynamic loading, abrasive wear was the major mechanism on the flank surface. Minor chipping and noticeable notch formation were also observed in the experiments.
- Although the tangential cutting force was lower in the interrupted turning experiments at dynamic loading, cutting tools worn quicker than the ones in continuous

turning experiments. Thus, tool life was shorter in the interrupted cutting experiments.

ACKNOWLEDGEMENT

The authors thank Ege University Scientific Research Projects Coordination for its financial support in the research project (No. 2006-MUH-033).

REFERENCES

[1] Dimla Sr, D. E. (2004). The impact of cutting conditions on cutting forces and vibration signals in turning with plane face geometry inserts. *Journal of Materials Processing Technology*, 155-156, 1708-1715.

[2] Saglam, H., Unsacar, F., Yaldiz, S. (2006). Investigation of the effect of rake angle and approaching angle on main cutting force and tool tip temperature. *International Journal of Machine Tools and Manufacture*, 46(2), 132-141.

[3] Günay, M., Aslan, E., Korkut, İ., Şeker, U. (2004). Investigation of the effect of rake angle on main cutting force. *International Journal of Machine Tools and Manufacture*, 44(9), 953-959.

[4] Senthil Kumar, A., Raja Durai, A., Sornakumar, T. (2006). The effect of tool wear on tool life of alumina-based ceramic cutting tools while machining hardened martensitic stainless steel. *Journal of Materials Processing Technology*, 173(2), 151-156.

[5] Korkut, I., Donertas, M.A. (2007). The influence of feed rate and cutting speed on the cutting forces, surface roughness and tool–chip contact length during face milling. *Materials & Design*, 28(1), 308-312.

[6] Diniz, A.E., Gomes, D.M., Braghini Jr, A. (2005). Turning of hardened steel with interrupted and semi-interrupted cutting. *Journal of Materials Processing Technology*, 159(2), 240-248.

[7] Chandrasekaran, H., Thoors, H. (1994). Tribology in interrupted machining: role of interruption cycle and work material. *Wear*, 179(1-2), 83-88.

[8] Grzesik, W. (2008). Influence of tool wear on surface roughness in hard turning using differently shaped ceramic tools. *Wear*, 265, 327–335.

[9] Diniz, A.E., Oliveira, A.J., (2008). Hard turning of interrupted surfaces using CBN tools. *Journal of Materials Processing Technology*, 195, 275–281.

[10] A. de Godoy, V. A., Diniz, A.E. (2011). Turning of interrupted and continuous hardened steel surfaces using ceramic and CBN cutting tools. *Journal of Materials Processing Technology*, 211, 1014–1025

[11] José de Oliveira, A., Diniz, A.E., Ursolino, D.J. (2009). Hard turning in continuous and interrupted cut with PCBN and whisker-reinforced cutting tools. *Journal of Materials Processing Technology*, 209, 5262–5270.

[12] Chou, Y.K. Evans, C.J. (1999). Cubic boron nitride tool wear in interrupted hard cutting. *Wear*, 225–229, 234–245

[13] Pavel, R. Marinescu, I. Deis, M., Pillar, J. (2005). Effect of tool wear on surface finish for a case of continuous and interrupted hard turning. *Journal of Materials Processing Technology*, 170, 341–349

[14] Sayit, E., Aslantas, K., Çiçek, Ç. (2009). Tool Wear Mechanism in Interrupted Cutting Conditions. *Materials and Manufacturing Processes*, 24(4), 476-483

[15] International Organization for Standardization, (1993). *Tool-life testing with single-point turning tools*, ISO 3685

[16] Trent, E.M., Wright, P.K., (2000). *Metal Cutting, fourth ed*. Butterworth-Heinemann, Oxford.