Jurnal Tribologi 21 (2019) 35-46

MYTRIBOS
Malaysian Tribology Society
Jurnal Tribologi
Website : jurnaltribologi.mytribos.org
e-issn: 2289-7232
Jurnal Tribologi

Surface integrity study for FC300 cast iron using TiAIN ball end mill

Mohd Hadzley Abu Bakar [1,*], Naim Fahmi [1], Norfauzi Tamin [1], Anis Afuza [1], Raja Izamshah [1], Shahir Kasim [1], Mohd Amran [1], Noorazizi Shamsudin [2], Nurul Fatin Raffi [3]

[1] Advanced Manufacturing Centre (AMC), Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, MALAYSIA
[2] Razak school of Engineering and Advanced Technology, Universiti Teknologi Malaysia, Kuala Lumpur, MALAYSIA
[3] Ingress Technology Sdn. Bhd., Bandar Bukit Beruntung, Rawang, MALAYSIA
*Corresponding author: hadzley@utem.edu.my

KEYWORDS

Surface roughness
Subsurface microstructure
FC300
Machining
Cutting tool
TiAlN

ABSTRACT

Finishing of FC300 gray cast iron predominantly done by manual polishing. Study the surface integrity of FC300 after machining is crucial to investigate the surface characteristics before polishing. This work aims to investigate the surface profiles and subsurface alterations induced by milling of FC300 gray cast iron using TiAlN Ball end mill. Machining trials were performed using CNC variaxis machine in dry condition at the cutting speeds of 66-99 m/min, feed rates of 0.27-0.42 mm/tooth and constant depth of cut of 0.1 mm. The results shows that the surface roughness decreased as the cutting speed increased from 66 m/min to 88 m/min. Smooth and shiny surface profiles appeared at the lower cutting speed of 66 m/min due to effect of lubrication layer that formed from the small fragmented graphite flakes. When the cutting speed increased to 99 m/min, surface profiles appeared with smeared and large graphite flakes probably due to higher rotational impact from the cutting tool. Analysis of subsurface microstructure observed bending effects at the region where worn cutting tool applied. Severe crack nucleation's were evidence to reflect severe rubbing action from worn cutting tool.

Received 27 June 2018; received in revised form 18 August 2018; accepted 24 November 2018.
To cite this article: Abu Bakar et al. (2019). Surface integrity study for FC300 cast iron using TiAIN ball end mill. Jurnal Tribologi 21, pp.35-46.

1.0 INTRODUCTION

Metal stamping is a process to form the metal sheet by pressing the sheet into a closed die. Inside the enclosure die, the sheet was formed, stretched or elongated according to the curvy design of upper and lower dies. For accurate and stringent tolerance of stamped product, the surface profile of the die must be as fine as possible. Fine surface profile also can provide low friction of material sliding during stamping process (Karbasian and Tekayya, 2010). In metal stamping, application FC300 gray cast iron already established as a one of main materials for stamping die. FC300 contains more than 2.14% carbon and presents more refined graphite structures in a pearlite matrix (Okuno et al., 2008). This material reportedly has adequate hardness and strength to withstand high impact pressure from the high load die strokes. FC300 is widely used as stamping die since it has a melting point between 1147°C and 1250°C, which is lower than mild steel, make it easier to be melted and casted (Moonesan et al., 2012). Another advantage of FC300 is this material has less ductility make it easy to be machined as the cutting chips easily become segmented and brittle. FC300 frequently applied as a stamping die for small thin parts such as bonnets, fenders, door panels and roof.

In die machining, the cutting tool used must able to withstand high pressure and temperature for long and interrupted engagement (Nurul et al., 2015). As the long contact time expected to appear, the interaction between cutting tool and stamping die may create some material gradual lost with implication to the tool wear and surface damage (Hamaguchi et al., 2011). The observation of surface damage is very important since irregularities on the surface may form concentration sites for stress development or cracks nucleation (Bhatt et al., 2010). In addition, the sliding force, contact conditions, friction, temperature generation and heat capacity of material also play important role to determine the appearance of microstructure alteration beneath the machined surface which shortened creep and fatigue life of the machined components (Kamely et al., 2012).

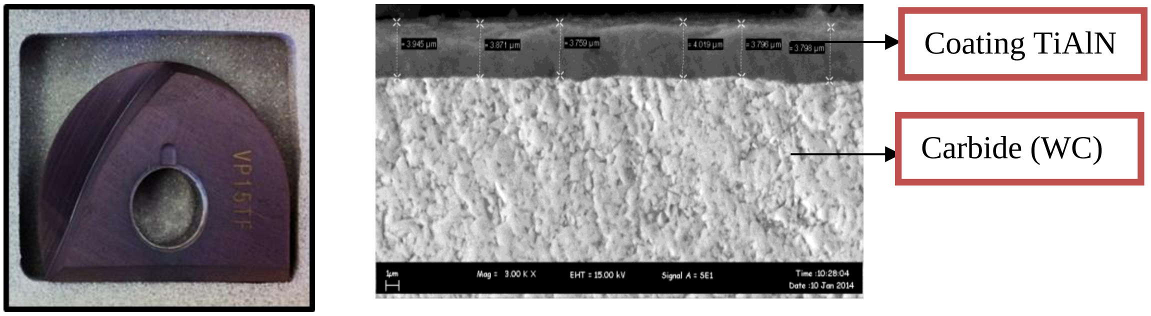
Depended on the facility, machining steel-based dies often operated in wet conditions to extent tool life by providing lubrications and cooling. The cutting tools that suitable for wet conditions are carbide or coated carbides. On the other hand, machining in dry condition also possible to be applied in machining steel-based dies. Ceramic based cutting tools such as alumina, and alos carbides are among most frequently used to machine steel in dry condition (Jaharah et al., 2014, Tamin et al., 2017). In general, FC300 can be machined using rigid tooling by either rough or finish machining to form various shapes and patterns. Machining FC300 alloy can be carried out at higher cutting speed and heavy feed rates, especially in rough cutting. The addition of Al inside provided better machinability of FC300 (Lie et al., 2002). This enable large stock up to 80% of the workpiece weight should be machined into a component. The die is then machined with ultra-precision cutting tool to remove the distortions and to ensure the machined surfaces produced a good finishing and texture. The die is further polished manually in order to get a final finishing (Klocke et al. 2011).

Since the final die surfaces come from manual polishing technique, the quality of the die surface strongly depended on the skills of the operator where the evaluation of the surface quality often examined by the touch sensitivity and surface observation (Kakinuma et al., 2013). If the surface finish after machining prepared in fine conditions, the operator may spend minimum polishing time to prepare the die. In contrast, if the surface finish not adequately prepared in good condition, the operator may require longer polishing time to prepare the die. Such situation will raise other issues such as a human error where the polishing stress and force control could be not consistence at all side (Oba and Kakinuma, 2017). Additionally, the worker who performed manually polishing may also face longer repetitive actions and force movements that could induce hand fatigue or improper body posture (Mauro et al., 2015).

Hence, in order to reduce extra manual polishing activities, this research aims to examine the surface profile when machining of FC300 gray cast iron with TiAlN coated carbide ball end mill. Several surface profiles were monitored based on the cutting speed and time variation with the cutting conditions were selected based on the similar situation at industry. For each machining trial, several areas along machined surface and subsurface were monitored to observe the surface profile and alteration beneath the machined surface. Further observation through scanning electron microscope was employed to examine the damage that occurred along machined surface. This study is an extended version from Hadzley et al., 2014.

2.0 EXPERIMENTAL PROCEDURE

The inserts that used in this study was Mitsubishi Carbide ball nose end mill coated with TiAlN (SRFT 30 VP15TF) with diameter of 32mm as shown in Figure 1(a). Figure 1(b) shows the TiAlN coating for the insert used in this study. The material used for the surface integrity assessment was FC300 gray cast iron with dimension 80 mm x 65 mm x 15 mm. Table 1 shows the chemical composition of FC300 gray cast iron. The machining trials were carried out in dry condition using DECKEL MAHO DMU 60 monoBLOCK CNC machine with cutting parameters according to the Table 2. These cutting parameters replicated for the real conditions based on the industry referred. For each machined surface, surface roughness was measured by using surface roughness tester. For surface profile observation, the area of interested were sectioned according to the period of machining, which divided into 0-15 minutes, 20-25 minutes and 40-55 minutes. Each sample per area were then monitored under Scanning Electron Microscopy (SEM) for surface profiles observation. For subsurface observation, the area of interested were selected according to the area where the cutting tool already worn, transitional phases and before worn. For each area, the workpiece material was sectioned and polished using sand papers before observed under SEM.



(a) (b)

Figure 1: (a) Indexable insert for ball end nose (b) Characteristics of TiAlN coating.

Table 1: The composition of FC300 gray cast iron.

Iron grade	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Tensile strength (MPa)	Pearlite ratio (%)
FC300	3.07	1.81	0.87	0.050	0.14	238.1	92

Table 2: Cutting parameters.

Parameters	Value
Cutting speed (m/min)	66, 77, 88, 99
Feed rate (mm/tooth)	0.27-0.42
Axial depth of Cut (mm)	0.1

3.0 RESULTS AND DISCUSSION

3.1 Effect of Cutting Parameter on the Surface Roughness and Surface Profiles

Figure 2 shows the surface profiles that appeared after machining FC300 at lower cutting speed of 66 m/min. General observation of the surface profile highlighted smeared surface with material redepositions, debris particles and slight surface cracks dominated most of the observed area as detailed in Figure 3. Such phenomenon may correspond to the formation of graphite flakes in FC300 that easier to be pulled out from the structure due to its softer condition than surrounding matrics (Yigit et al., 2008). At the lower cutting condition, the graphites pullout may create material redepositions that scratched the machined surface as the tool-material overlapping each other. This resulting smeared surface appeared in most of the cutting area especially at the end of the cutting period.

As the cutting speed increased from 77 m/min to 88 m/min, the surface profiles appeared to be smoother and shiny. This is shown in Figure 4 and Figure 5 where the machined surfaces appeared with less surface damage and minor formation of smearing and debris particles. At higher cutting condition, the high repetition movement between the nose radius and workpiece material generated more sliding contact and frictions, apparently generated high cutting temperature (Liu and Ai, 2004). As the cutting temperature increased, phenomenon such as graphitization of FC300 occurred. Graphitization is formed when the composition of carbon and silicon were mixed and produced a structure hat called graphite flake. During machining, graphite flakes can be pulled out by the shearing force from cutting tool and formed fragmented particle debris. This fragmented debris could trap between cutting tool and workpiece and formed layers of film liquidation when reacted with high temperature (Malakizadi et al., 2013). Such layers would be reacted as a lubricant to protect the tool edge and workpiece material from thermal effect and frictions, which in the end resulting better surface finish (Liu et al., 2005). Figure 6 shows the appearance of surface profile that highlights better surface finish of FC300 (as compared to Figure 3).

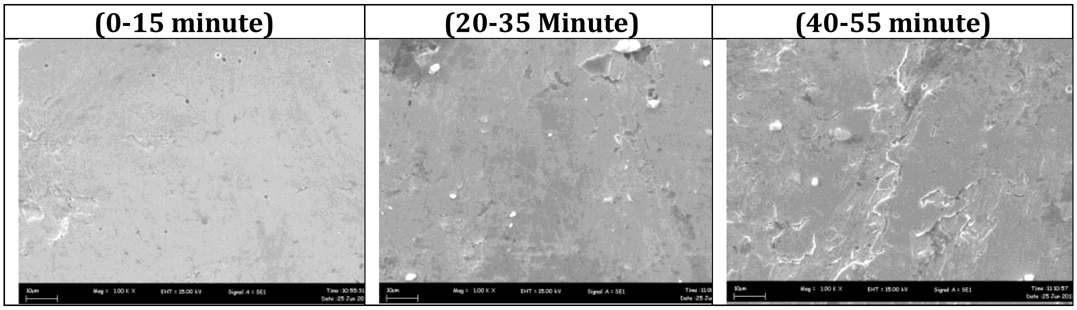


Figure 2: Surface profiles after machining FC300 at lower cutting speed of 66 m/min.

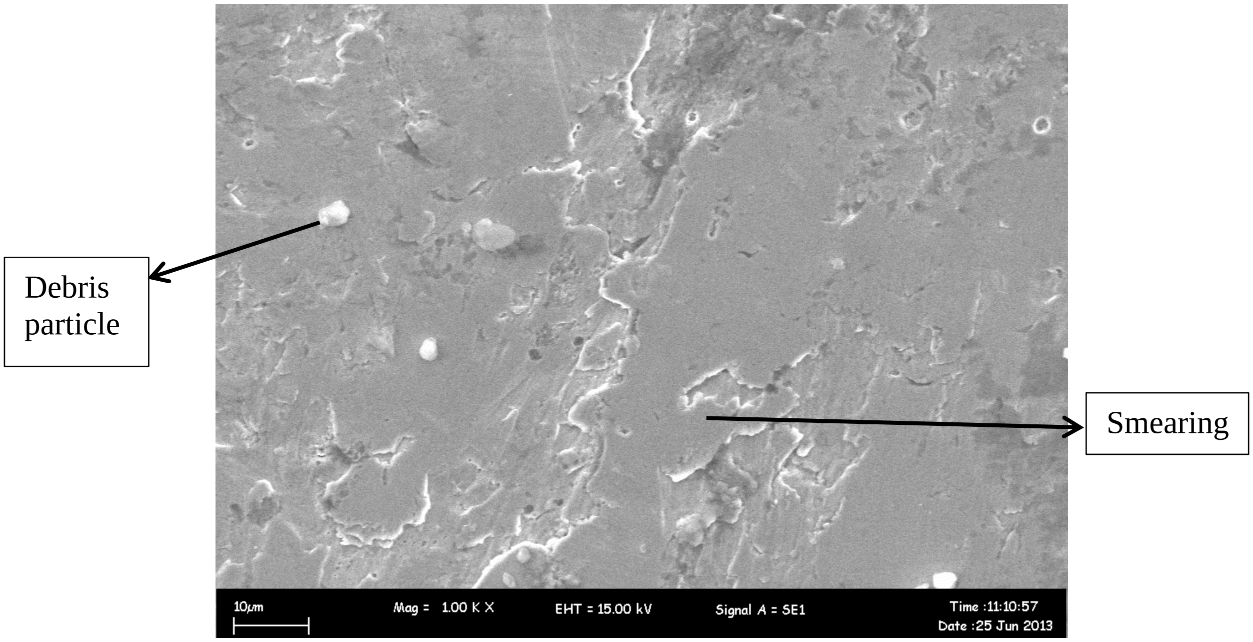


Figure 3 : The surface damage at lower cutting speed of 66 m/min.

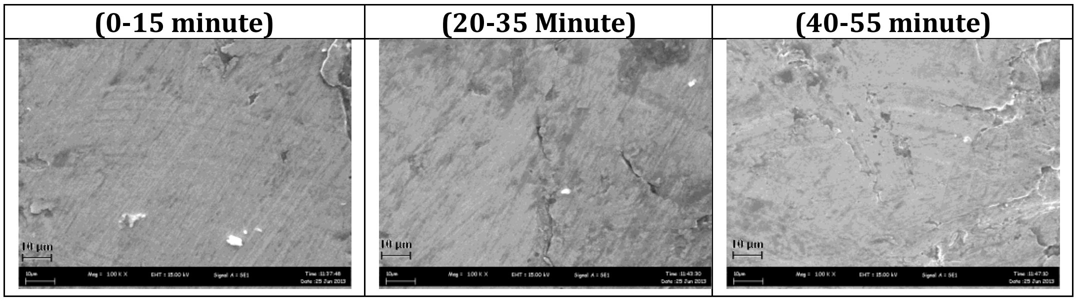
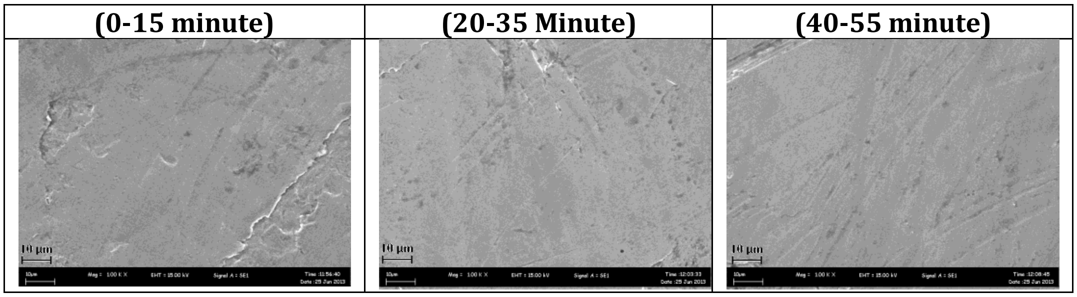
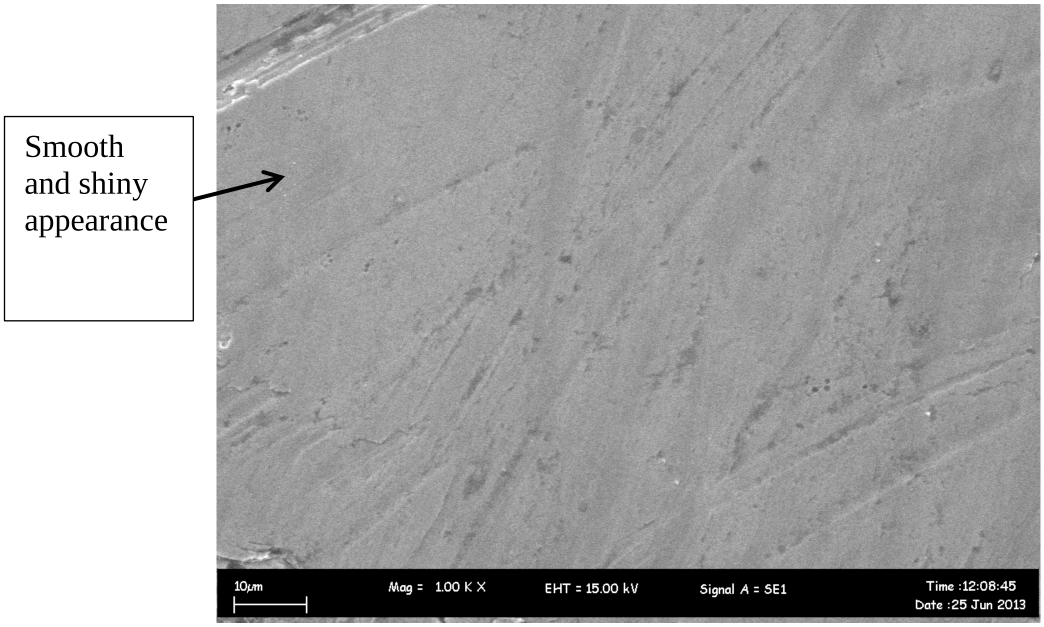


Figure 4: Surface profiles after machining FC300 at the cutting speed of 77 m/min.



(0-15 minute) **(20-35 Minute)** **(40-55 minute)**

Figure 5: Surface profiles after machining FC300 at the cutting speed of 88 m/min.



Smooth and shiny appearance

Figure 6: Surface appearance at lower cutting speed of 88 m/min.

Figure 7 shows the surface characteristics after machining FC300 at the higher cutting speed of 99 m/min. The images clearly show that rough surface conditions of most of the observed area. As the cutting speed increased to 99 m/min, higher cutting speed generated higher pressure at the contact interfaces between cutting tool and workpiece material (Kamal et al., 2018). On the same time, faster chip velocity could slide away the graphite debris and restricting the access of fragmented debris to the contact interfaces. This inhibited the assessment of molten film layer to form a lubricative layer, hence unable to provide protective layer to the cutting tool and workpiece (Desaigues et al., 2016). In addition, higher shearing force from rotational cutting tool may create a larger graphite pull out, leading to significant surface smearing along the machined surface (Ozcelik and Bayramoglu, 2006). Figure 8 highlights the obvious appearance of graphite flake, cracks and surface smearing that facilitate rough characteristics of FC300 after machining at 99 m/min.

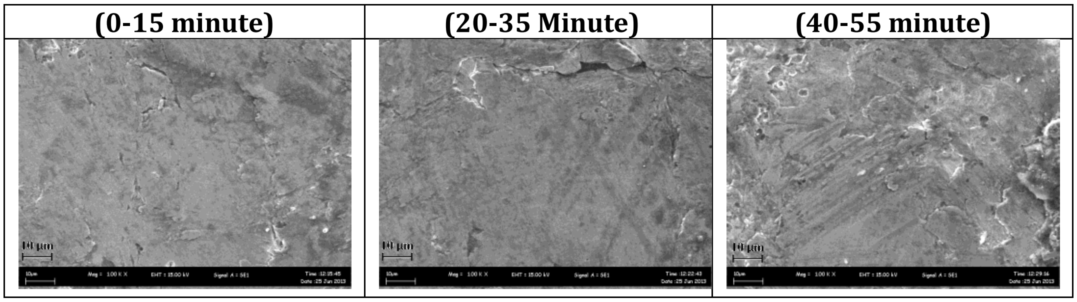
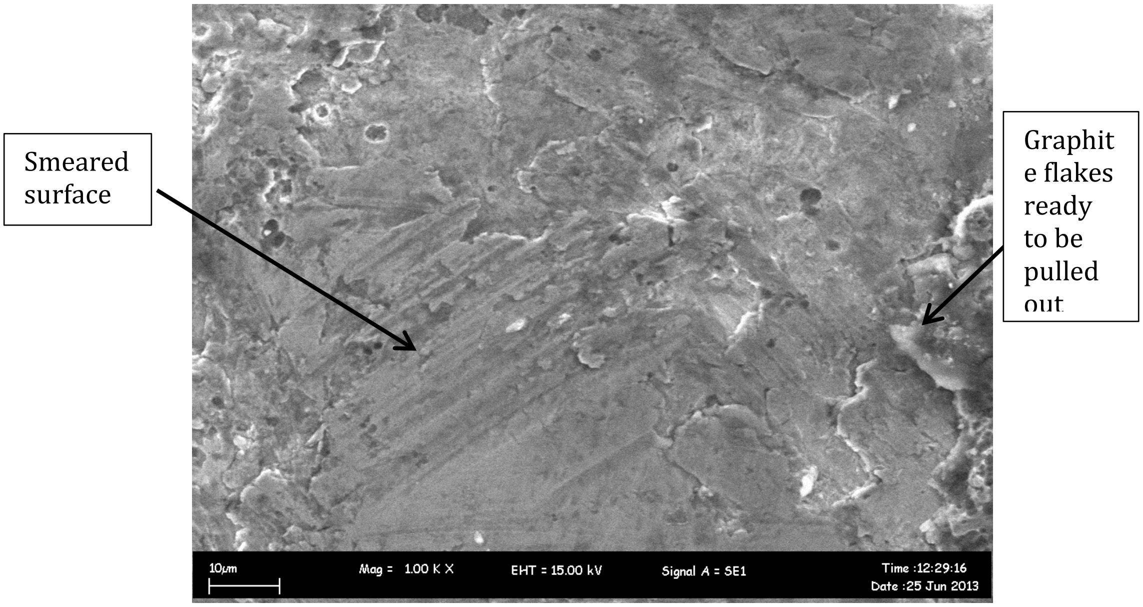

(0-15 minute) **(20-35 Minute)** **(40-55 minute)**

Figure 7: Surface profiles after machining FC300 at the cutting speed of 99 m/min.


Smeared surface

Graphite flakes ready to be pulled out

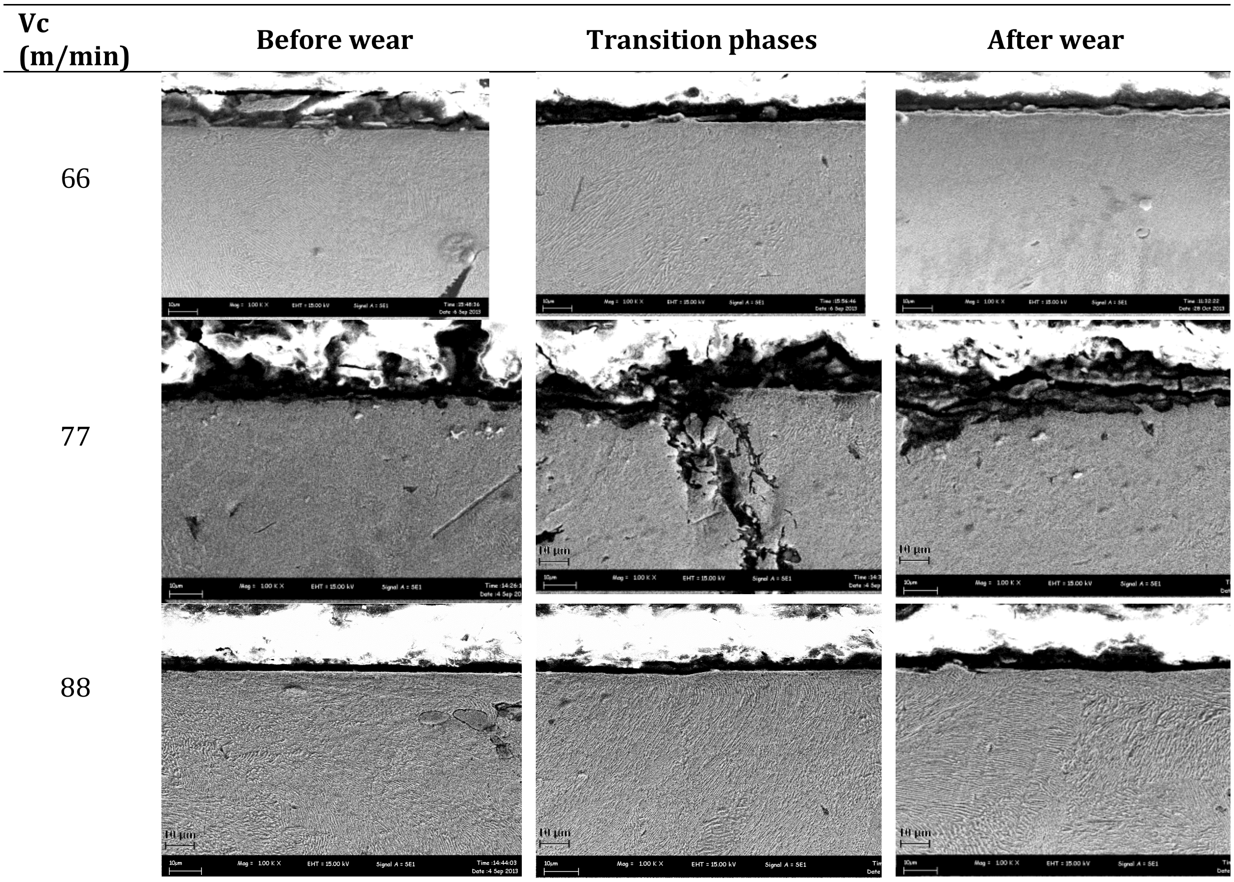
Figure 8: Surface appearance at lower cutting speed of 99 m/min.

3.2 Effect of Cutting Parameter on the Subsurface Microstructure Alteration

The analysis of subsurface microstructure is very important to assess the appearance of the plastic deformation under the machined surface. The evidence of this microstructure alteration beneath the machined surface is considered unfavorable and should be avoided as it can accelerates fatigue failure of the components (Ulutan and Ozel, 2011). The main factors that affected to the surface microstructure alteration are cutting parameters and tool wear (Bhatt et al., 2010). In addition, the sliding force, contact conditions, friction, temperature generation and heat treatment and heat capacity of material also play important role to determine the appearance of microstructure alteration beneath the machined surface. Figure 9 shows the selected subsurface microstructure beneath the surface machined surface within the cutting parameters investigated. The figures show the image of initial machining process until the tool became worn. It clearly indicates that the increasing of tool wear increases the microstructure alteration.

At the early stage of machining, the microstructure beneath the machined surface shows a uniform grain orientation with homogeneity distribution of dendrites along the cross-section surface. This is shown in Figure 10 where the subsurface profiles appeared in fine microstructure without significant microstructure alterations. The relatively fine cross-sectional surface profiles attributed to the fact that the cutting tool still maintains its sharpness at the early stage of machining time. The sharp edges of the cutting tool will act as a stress concentrator that enable the surface to be machined cleanly, thereby resulting in lower surface distortion and better subsurface profiles (Mhamdi et al., 2012). Such fine surface structure reflects the ability of these cutting conditions to perform machining with more precise tolerance while improving the fatigue strength of the machined component.

As the machining prolonged, the microstructure of the pearlite beneath the machined surface started to show some bending effect as shown in Figure 11. At this stage, the workpiece material was exposed to thermal and mechanical effects that can lead to softening state of the surface and subsurface microstructure (Sun and Guo, 2009). This softening state of the machined surface promotes easy plastic deformation along the direction of the cutting tool movement, especially when the cutting tool worn (Yang et al., 2010). The bending effect could facilitate uneven residual stress and localization strain beneath the machined surface. This consequently could provide lower fatigue life when stress concentration applied.



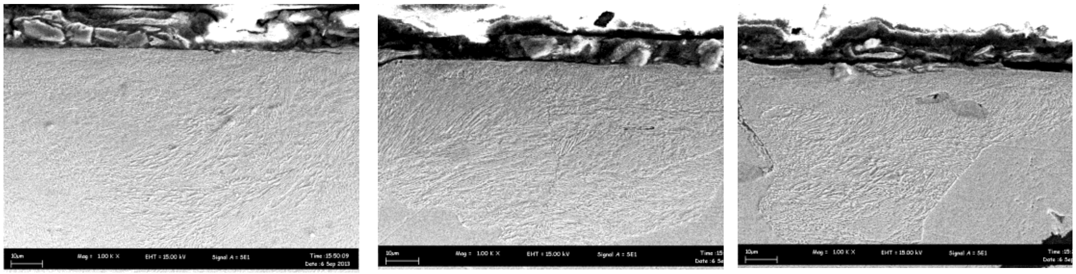


Figure 9: Subsurface profile beneath the machined surface.

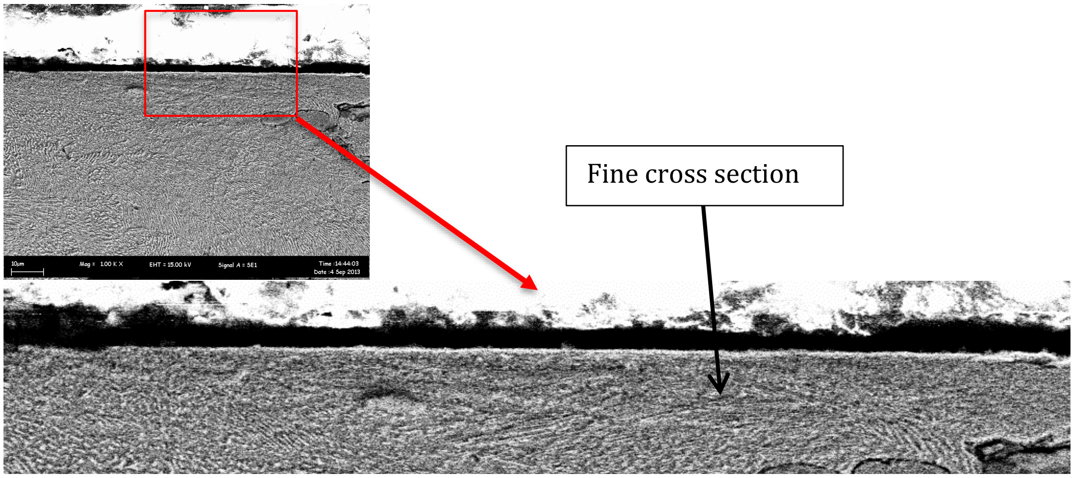


Figure 10: SEM microphotographs beneath the machined surface at the cutting speed of 88 m/min cutting speed and 5000 mm/min feed rate before the tool wear.

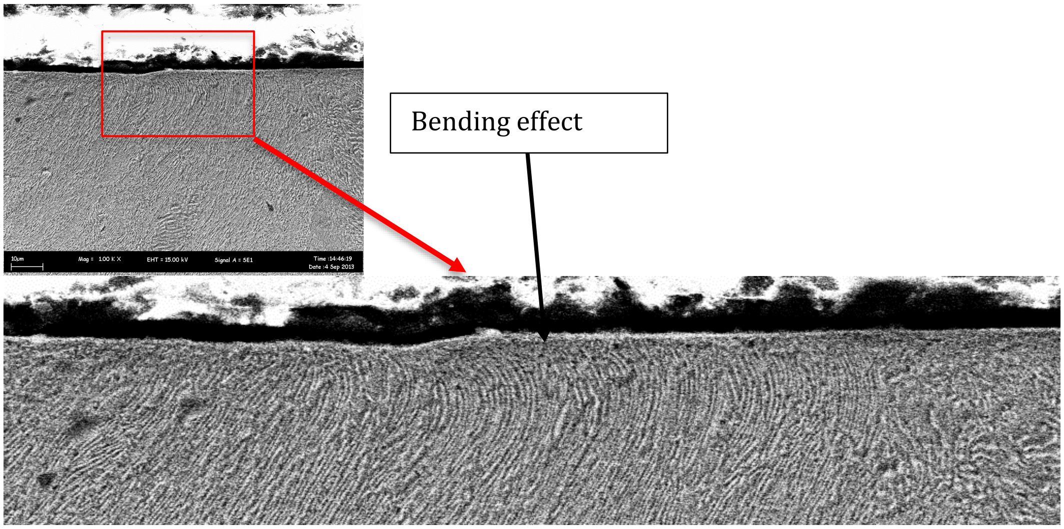


Figure 11: SEM microphotographs that shows bending effect beneath the machined surface at during transition period the cutting speed of 88 m/min

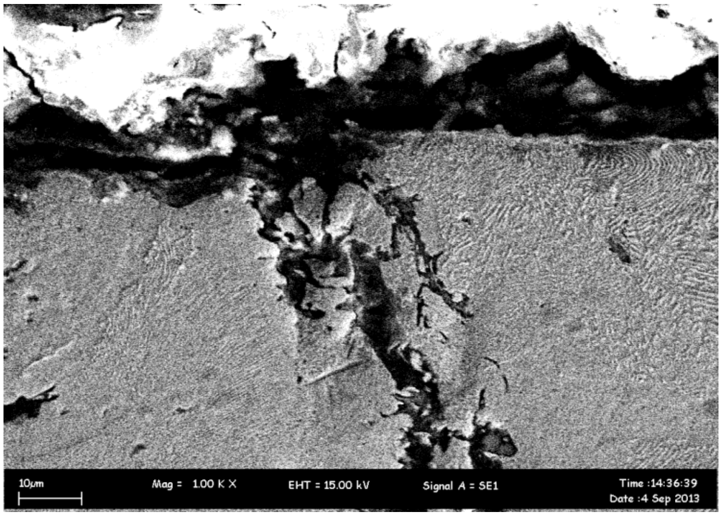


Figure 12: SEM microphotographs of the crack's nucleation beneath the machined surface at the cutting speed of 77 m/min.

4.0 CONCLUSION

This work presents the surface integrity of FC300 gray cast iron when machined with TiAlN Ball end mill. From the surface integrity of FC300 assessments, the surface roughness decreased as the cutting speed increased from 66 m/min to 88 m/min. At the lower cutting speed, small pull out graphitization particles that trapped between cutting tool and workpiece provided lubrication when reacted with heat. This consequently facilitated better surface finish with smooth and shiny appearance. The surface roughness however demonstrated higher value of when cutting speed increased to 99 m/min. Higher shearing force from rotational cutting tool promoted early tool wear and create a larger graphite pull out, leading to significant surface smearing along the machined surface.

The observation of subsurface microstructure presents significant bending effect as the machining period prolonged. Increase of cutting speed relatively increased the cutting temperature and induced the softening conditions of the machined surface. The shearing load from the feed force pushed the surface and subsurface into the bending distortions. On the same time, high temperature generation induced severe tool wear that aggressively rubbed the machined surface. In consequence, higher shear force generated crack beneath the machined surface that leading to the crack nucleations.

ACKNOWLEDGEMENT

The authors would like to thank Faculty of Manufacturing Engineering and Universiti Teknikal Malaysia Melaka (UTeM) for their support that enabled this work to be carried out through the grant of FRGS/1/2017/TK03/FKP-AMC/F00341.

REFERENCES

Bhatt, A., Attia, H., Vargas, R., & Thomson, V. (2010). Wear Mechanisms of WC Coated and Uncoated Tools in Finish Turning of Inconel 718. Tribology International, 43, 1113–1121.

Desaigues, J.E., Lescalier, C., Bomont-Arzur, A., Dudzinski, D. and Bomont, O. (2016) Experimental Study of Built-up Layer Formation during Machining of High Strength Free-cutting Steel. Journal of Material Processing Technology, 236, 204–215.

Hamaguchi, K., Kagata, Y., Shizuka, H., & Okuda, K. (2011). Effect of Tool Tilting Angle on Tool Wear and Surface Roughness in Micro Ball End Milling. Advanced Materials Research, 325, 606-611.

Hadzley, M., Bakar, A., Fatin, N., Raffi, M., Izamshah, R., Abdullah, R., & Siti Sarah, A. (2014). Surface Integrity of a High Speed Milling FC300 Gray Cast Iron. Applied Mechanics and Materials, 465, 642-646.

Jaharah, A. G., Muhammad, R., Che Hassan, C. H. (2014). Performance of Green Machining: a Comparative Study of Turning Ductile Cast Iron FCD700. Journal of Cleaner Production, 85, 289-292.

Kakinuma, Y., Igarashi, K., Katsura, S. & Aoyama, T. (2013). Development of 5-axis Polishing Machine Capable of Simultaneous Trajectory, Posture and Force Control. CIRP Annals of Manufacturing Technolgy, 62(1), 379-382.

Kamal, O., Jaharah, G., Shahfizal, R., & Shahir K. (2018). Surface Roughness of Hypereutectic Al-Si A390 in High Speed Milling, Jurnal Tribologi, 16, 42-40.

Kamely, M.A., Noordin, M.Y., Bani Hashim, A.Y., Yahya, S.H. & Dan, M.M.P. (2012). The Performance of Low Cost Cutting Tools when Machining Hardened Steel of 60 HRC. Journal of Advanced Manufacturing Technology, 6 (1).

Karbasian, H. & Tekkaya, A.E. (2010). A Review on Hot Stamping. Journal of Materials Processing Technology, 210, 2103–2118.

Klocke, F., Dambon, O. & Behrens, B. (2011). Analysis of defect mechanisms in polishing of tool steels, Production Engineering Research Development, 5, 475-483.

Liu, J., Yamazaki, K., Ueda, H., Narutaki, N. & Yamane Y. (2002). Machinability of pearlitic cast iron with cubic boron nitride (CBN) cutting tools, Journal of Manufacturing Science and Engineering 124, 820-832.

Liu, N., Loftus, M., & Whitten, A. (2005). Surface Finish Visualisation in High Speed, Ball Nose Milling Applications. International Journal of Machine Tools & Manufacture, 45, 152–1161.

Liu, Z.Q., & Ai, X. (2004) High-Speed Milling of Cast Iron with Ceramic and PCBN Tools. Key Engineering Materials, 259-260, 446-450.

Malakizadi, A., Sadik, I., & Nyborg, L., (2013). Wear Mechanism of CBN Inserts during Machining of Bimetal Aluminum-grey Cast Iron Engine Block. Procedia CIRP, 8, 188-193.

Mauro, C.L., Fisher, E., Korpan, D. & Medrano, P.A. (2015). Ergonomic Redesign of a Traditional Jewelry-Polishing Workstation. Ergonomics in Design, 23(1), 4-12.

Mhamdi, M-B., Boujelbene, M., Bayraktar, E., & Zghal, A. (2012). Surface Integrity of Titanium Alloy Ti-6Al-4V in Ball end Milling. Physics Procedia, 25, 355 – 362.

Moonesan, M., Honarbakhsh Raouf, A., Madah, F., & Habibollah zadeh, A. (2012). Effect of Alloying Elements on Thermal Shock Resistance of Gray Cast Iron. Journal of Alloys and Compounds, 520, 226– 231.

Nilsson, A., Kirkhorn, L., Andersson, M., & Stahl, J.-E. (2011). Improved Tool Wear Properties in Sheet Metal Forming using Carbide Steel, a Novel Abrasion Resistant Cast Material. Wear, 271 (9-10), 1280-1287.

Nurul Fatin, M.R., Mohd Hadzley, A.B., Izamshah, R. & Amran, M.A. (2015). An Experimental Study of Wear Mechanism on High Speed Machining of FC300 Gray Cast Iron Using TiAlN Coated Carbide Cutting Tool. Applied Mechanics and Materials, 761, 257-261.

Oba, Y. & Kakinuma, Y (2017). Simultaneous tool posture and polishing force control of unknown curved surface using serial-parallel mechanism polishing machine. Precision Engineering, 49, 24–32.

Okuno, S., Okada, Y., Omori, N., Morimoto, H., Tsuda, K. & Itoh, M. (2008). Development of "ACE-COAT AC410K" Insert Grade for Cast Iron Turning. SEI Technical Review, 67, 11-15.

Ozcelik, B., & Bayramoglu, M. (2006). The Statistical Modeling of Surface Roughness in High-Speed Flat End Milling. International Journal of Machine Tools & Manufacture, 46, 1395–1402.

Sun, J., & Guo, Y.B. (2009). A Comprehensive Experimental Study on Surface Integrity by End Milling Ti–6Al–4V. Journal of Materials Processing Technology, 209, 4036–4042.

Ulutan, D., & Ozel, T. (2011). Machining Induced Surface Integrity in Titanium and Nickel Alloys: A Review. International Journal of Machine Tools & Manufacture, 51, 250–280.

Tamin, N.F., Azlan U.A.A., Hadzley, M., Remle N.S., Osman, M.H. & Yusoff, M.R. (2017). Study on Surface Integrity of AISI 1045 Carbon Steel when machined by Carbide Cutting Tool under wet conditions, MATEC Web of Conferences, 97, 01075, 1-5.

Yang, Z., Zhang, D., Yao, C., Ren, J., & Huang, X. (2010). Surface Integrity in High-Speed Milling of Titanium Alloy Tc11. Proceedings 2010 International Conference on Mechanic Automation and Control Engineering, 3334-3337.

Yigit, R., Celik, E., Findik, F., & Koksal, S. (2008). Effect of Cutting Speed on the Performance of Coated and Uncoated Cutting Tools in Turning Nodular Cast Iron. Journal of Materials Processing Technology, 204, 80–88.