

Characterization And Impact Of Cutting Parameters On Face-Milled Surfaces Of Pearlitic Ductile Iron

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ABSTRACT: In an attempt to enhance the surface integrity of machined parts in the manufacturing industries, face-milled surface profiles of pearlitic ductile iron were characterized and analysed based on the effects of some cutting parameters. The pearlitic ductile iron used was locally prepared. Atomic Force Microscope and Scanning Electron Microscope were used to characterizing the roughness profile of the machined workpiece. The results showed increase in depth of cut from 400.37 to 652.37 nm at constant cutting fluid flow rate, cutting speed and feed rate. Also, at varying cutting fluid flow rate, the roughness parameter decreased from 733.56 to 272.84 nm at constant feed rate, depth of cut and cutting speed. Similar result was obtained with varying feed rate. However, there exists no definable course as cutting speed increases at constant cutting fluid flow rate, depth of cut and feed rate. In conclusion, it was found that machining at cutting fluid flow rate of 4 l/min, feed rate of 30 mm/rev, depth of cut of 0.2 mm and cutting speed of 1000 rev/min produced better quality surfaces. Therefore, the findings in this study will be useful for the manufacturing industries to improve on the surface reliability of the face milling process.

KEYWORDS: Cutting characterization, cutting parameters, dry cutting, face milling, pearlitic ductile iron, roughness characteristics.

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I. INTRODUCTION

The link between the functional characteristics (such as roughness parameters, layer structure, hardness and residual stress) and the physical properties of a surface can be described as surface integrity. In manufacturing, the kind of surface that is produced by machining operations and its properties are crucial (Isik, 2007). Since surface condition has an impact on appearance, functionality, and dependability, attention is focused on the product's roughness, particularly on the machined surface, in response to the desire for completely automated, high-quality production (Ilori *et al.*, 2016). It depends on the machining circumstances, which are determined by the workpiece, cutting tool, machine tool, cutting fluids, and other cutting parameters (Ezugwu *et al.*, 2004). Therefore, the development of new materials and manufacturing techniques necessitates the adoption of new production circumstances and production methods (Ilori *et al.*, 2017).

Better knowledge of optimizing cutting processes can be utilized to enhance part functionality in surface profile mechanism. Consequently, lot of inquiries have been executed to examine the influence of machining parameters like cutting speed, tool nose radius, depth of cut and feed rate upon

roughness characteristics through machining operations (Thiele and Melkote, 1999). A number of useful qualities of components, for instance, coating, heat transmission, resisting fatigue, capacity of holding a lubricant and wearing, are easily influenced by roughness profiles. Therefore, the preferred surface quality is generally stated and the proper methods are used to reach the desired quality.

In the past work of Arunachalam *et al.* (2004), cubic-boron-nitride cutter was used in milling of age-hardened Inconel 718 to generate surface roughness using coolant, spindle speed and depth of cut as parameters. It was further stated that a better-quality surface was produced with small depth of cut and coolant, whereas the quality of surface diminished with varying cutting speed and high depth of cut. Also, Hayajneh *et al.* (2007) established feed rate as the main parameter that considerably affected the quality of workpiece surface in the course of milling process among depth of cut, spindle speed and feed rate. Likewise, Yusuf *et al.* (2010) applied Taguchi design method in carrying out experiment on influence of process parameters upon the quality of surface of alloys of titanium in milling operation. In the study, it was observed that amid all the process parameters considered, spindle speed influenced the quality of surface substantially. Furthermore, Bembenek *et al.* (2023) examined the impact of standard milling parameters on the quality of the machined surface of

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AISI 304 steel. According to their findings, the examined parameters affected the surface quality, which dynamically increased or decreased the roughness, though not to the same extent as when feed per tooth was taken into consideration. In another development, Rech and Moisan (2003) reported that feed rate influenced the quality of surface of case-hardened steel during turning process when compared with cutting speed effect. Likewise, in the course of turning of case carburized steel with poly cubic-boron-nitride cutter, Gunnberg *et al* (2006) established feed rate and tool nose radius as main factors that controlled the values of roughness parameter against other parameters studied on the material surface topography. In addition, hard turning of bainite B8 steel was observed by Jacobson *et al* (2002) to increase in roughness parameters at varying cutting speed.

Past studies have unambiguously demonstrated the importance of cutting parameters in determining residual stress, roughness and surface finish with emphasis on some other materials (such as steel and cast iron, etc.), which are different from pearlitic ductile iron. However, there is little or no information on the characterization of surface profile of face-milled pearlitic ductile iron using varied cutting parameters (feed rate, cutting fluid flow rate, cutting speed and depth of cut). Thus, this work characterized and analyzed the impact of feed rate, cutting fluid flow rate, cutting speed and depth of cut on the face-milled pearlitic ductile iron. The choice of pearlitic ductile iron for this work is because of its increasing utilization in the manufacturing sector and its wide range of properties that are not seen in other types of cast irons such as high tensile strength, excellent wear resistance, fatigue resistance, toughness, ductility and good machinability.

II. MATERIALS AND METHODS

The materials, equipment and methods used to execute this experiment are stated in the following sections.

Materials

The materials used for this study includes pearlitic ductile iron, cutting fluid and cutting tool (cemented carbide). The pearlitic ductile iron was locally produced in the previous work of Ilori *et al* (2017). The pearlitic ductile iron produced is composed of 93.17% iron, 0.05% phosphorus, 0.25% manganese, 2.90% silicon, 0.03% sulphur, 3.60% carbon and 0.01% magnesium as presented in Table 1. This composition is comparable to those made for commercial purpose. The sample of as-cast pearlitic ductile iron used in this work is displayed in Figure 1. The pearlitic ductile iron production was in accordance with ASTM A536 100-70-03 specification,

Table 1: As-cast Pearlitic Ductile Iron Chemical Composition.

Elements	% (Weight)
Mn	0.25
Mg	0.01
Si	2.90
S	0.03
C	3.60
P	0.05
Fe	93.17

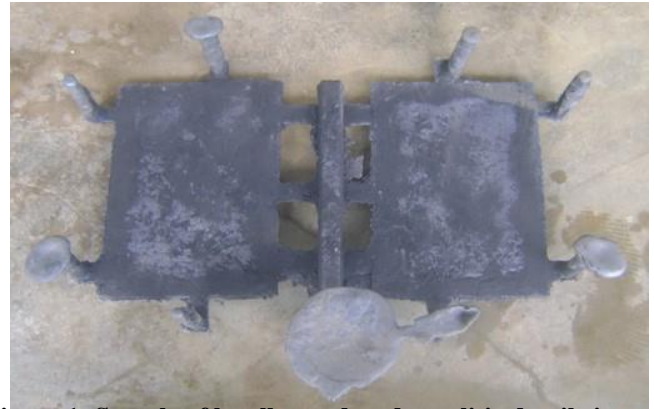


Figure 1: Sample of locally produced pearlitic ductile iron.

The samples produced were heat treated for four hours at temperature of 650 °C, soaked and furnace cooled to get rid of induced casting process stress. Computer numerical control (CNC) vertical milling machining (PRODIS PDC-650H) with 10,000 rpm spindle rotation speed and 15kVA power was used to carry out face milling operation on each sample of ductile iron produced. The ability to accurately define parameter values was made possible by the use of the CNC milling machine. The workpiece sample was clamped directly to the worktable of the milling machine before the machining operation (Figure 2).

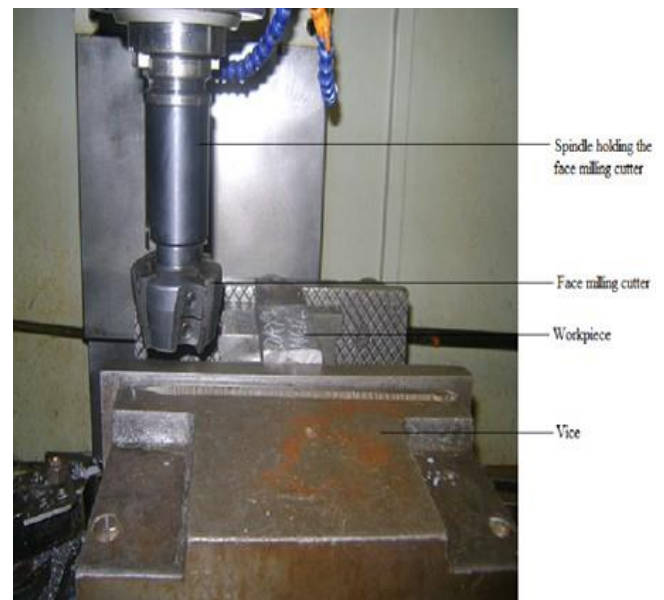


Figure 2: Workpiece clamped to the milling machine worktable.

The design of experiment approach adopted was Taguchi to considerably reduce the number of experimental trials with four parameters considered as cutting factors. There were five test runs carried out for different parameters. Each test was run with a different parameter value while keeping the values of other variables constant. The ranges of parameters and how they were combined are shown in Table 2.

Table 2: Cutting Condition for the Experimentation

Cutting Parameters	Values				
Depth of cut, a_p (mm)	0.2	0.4	*0.6	0.8	1.0
Cutting fluid flow rate, f_l (l/min)	0	1	*2	3	4
Feed rate, f (mm/rev)	10	20	*30	40	50
Cutting speed, v (rev/min)	200	600	*1000	1400	1800

Note: * Value of cutting parameters that were kept constant while the others varied.

Surface profiling of machined pearlitic ductile iron Atomic force microscope (AFM) compartment of a nano-indenter and scanning electron microscope (SEM) were utilized to determine the characteristics roughness profile of the machined workpiece without dent and to observe the morphology of the machined surfaces by visualizing details on the surfaces of machined samples, respectively. The AFM measures the vertical difference between the high and low points of a surface in nanometers. It measures surface variations in vertical stylus displacement as a function of position, thereby conducting topographic analyses by scanning the surface area and produce three-dimension (3D) surface profiles with corresponding values of their roughness. Grzesik and Wanat (2005) recommended that for quality of surface produced during machining, both two- and three-dimension (2D and 3D) characterization of surface quality profile or topography are essential to determine the impact of cutting parameters in detail. The qualities of surface generated in the course of cutting processes have naturally multifaceted textures, shapes and irregularities on profile structures as a result of several process-induced interferences. Therefore, the surface roughness profile parameters utilized in this work are sample length peak-to-valley height (S_z), surface peak or maximum height (S_p) and surface valley or minimum height (S_v). The S_p is always denoted with a positive sign while the S_v is signified with a negative sign to indicate its direction of flow. The S_z which is dependent on S_p and S_v is the addition of both parameters irrespective of their directions. Similarly, SEM visualizes the details on the surfaces of workpieces with higher magnification and resolution, thus having the capability of viewing very tiny particles and structures. It uses a particle beam of electrons to illuminate the specimen and produce a magnified image.

RESULTS AND DISCUSSION

The surface textures obtained at stipulated levels of cutting parameters as a result of face milling operation performed on the samples of pearlitic ductile iron produced were characterized and the impact of each cutting parameter were discussed below.

A. Characterization of Machined Surfaces

The micrographs obtained from the analyses of surface profile of the machined samples show the values of characteristics peak-to-valley height parameters obtained after

machining operation. The micrograph demonstrating typical surface profile and topography formed as a result of the face milling operation are shown in Figures 3 - 10. The surface profiles illustrated in Figures 3a, 4a, 5a, 6a, 7a, 8a, 9a and 10a correspond to the microstructure of the milled surfaces shown in Figures 3b, 4b, 5b, 6b, 7b, 8b, 9b and 10b respectively, which show SEM images for the feed path followed by the mill axis during the machining process. These Figures (3b, 4b, 5b, 6b, 7b, 8b, 9b and 10b) demonstrate the appearance of machined surface with magnifications of 500x and 1000x respectively. The micrographs of the surface topographies confirmed characteristic dispersals of peaks and valleys in tandem with the combination of the cutting parameters used during machining of each workpiece.

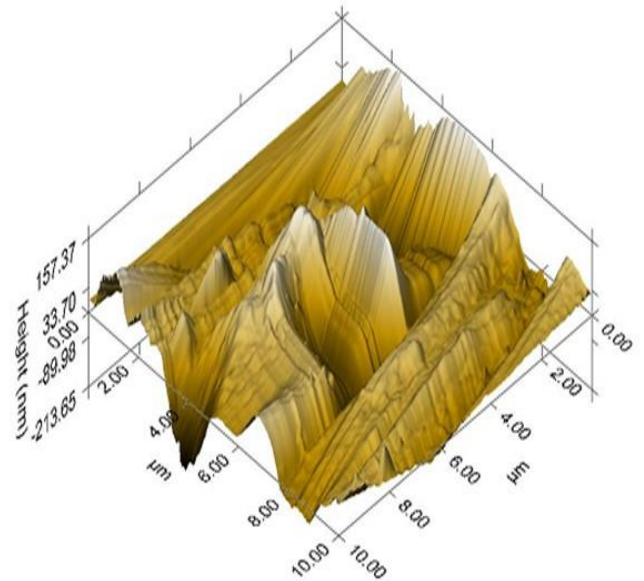


Figure 3a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $a_p = 0.2$ mm, $f_l = 2$ l/min, $f = 30$ mm/rev and $v = 1000$ rev/min.

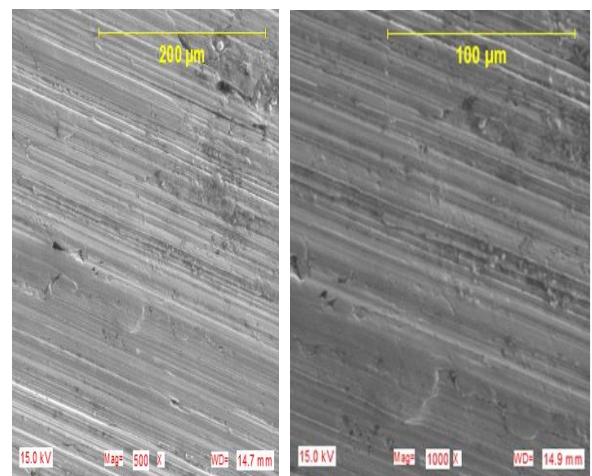


Figure 3b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $a_p = 0.2$ mm, $f_l = 2$ l/min, $f = 30$ mm/rev and $v = 1000$ rev/min.

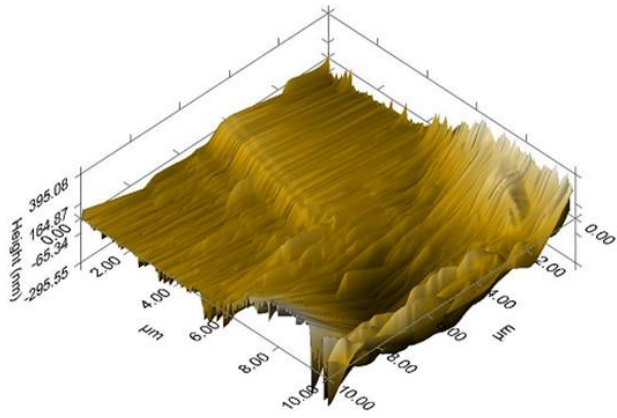


Figure 4a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $a_p = 1.0$ mm, $f_l = 2$ l/min, $f = 30$ mm/rev and $v = 1000$ rev/min.

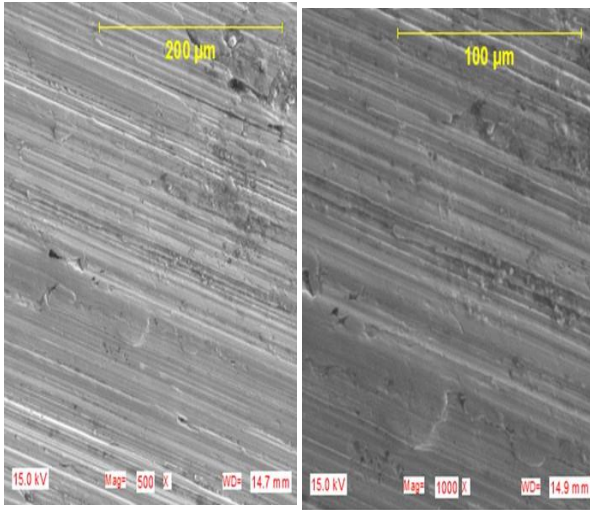


Figure 4b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $a_p = 1.0$ mm, $f_l = 2$ l/min, $f = 30$ mm/rev and $v = 1000$ rev/min.

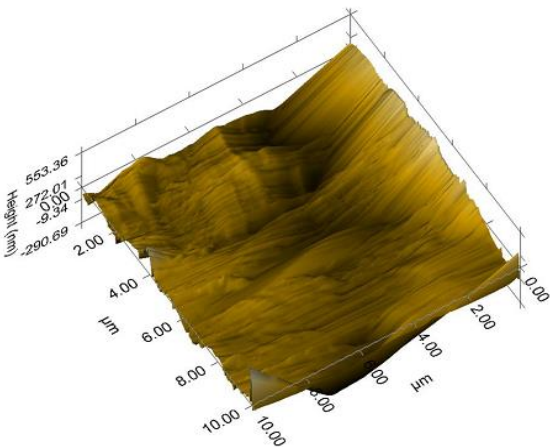


Figure 5a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $f_l = 0$ l/min, $f = 30$ mm/rev, $v = 1000$ rev/min and $a_p = 0.6$ mm.

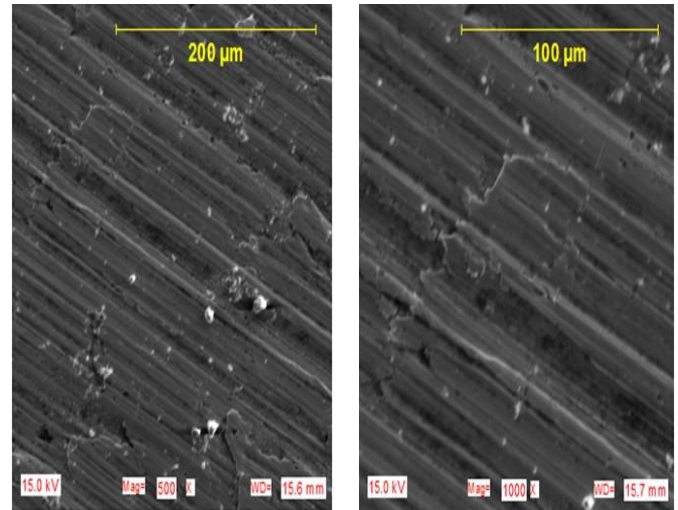


Figure 5b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $f_l = 0$ l/min, $f = 30$ mm/rev, $v = 1000$ rev/min and $a_p = 0.6$ mm.

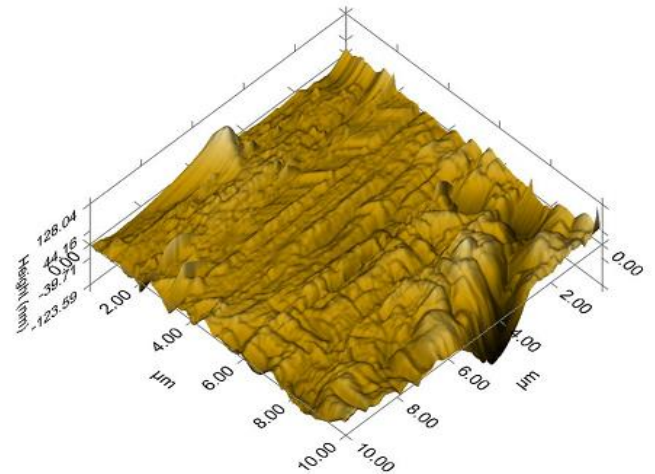


Figure 6a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $f_l = 4$ l/min, $f = 30$ mm/rev, $v = 1000$ rev/min and $a_p = 0.6$ mm.

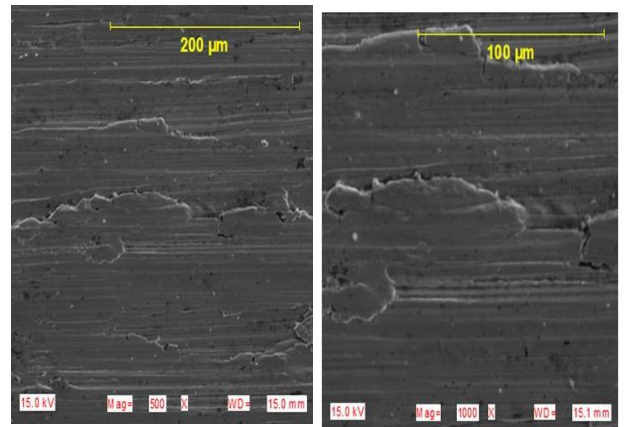


Figure 6b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $f_l = 4$ l/min, $f = 30$ mm/rev, $v = 1000$ rev/min and $a_p = 0.6$ mm.

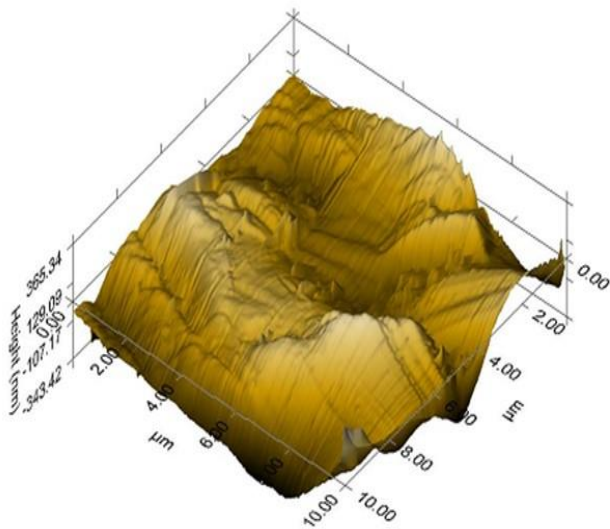


Figure 7a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $f = 10$ mm/rev, $F_l = 2$ l/min, $v = 1000$ rev/min and $a_p = 0.6$ mm.

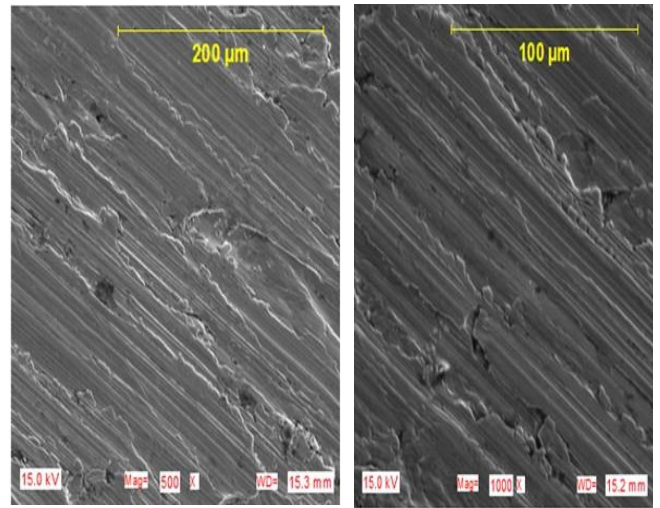


Figure 8b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $f = 50$ mm/rev, $F_l = 2$ l/min, $v = 1000$ rev/min and $a_p = 0.6$ mm.

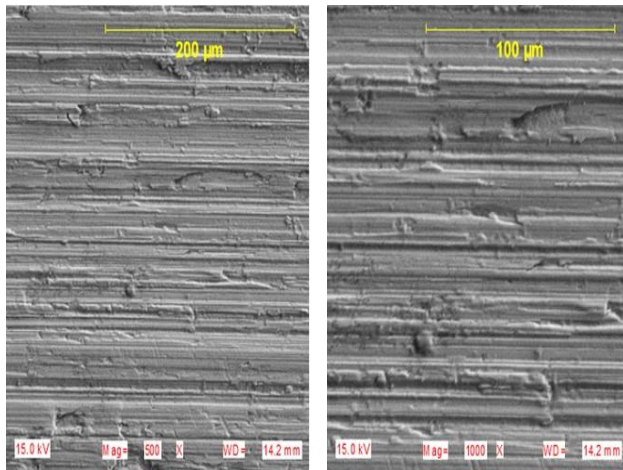


Figure 7b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $f = 10$ mm/rev, $F_l = 2$ l/min, $v = 1000$ rev/min and $a_p = 0.6$ mm.

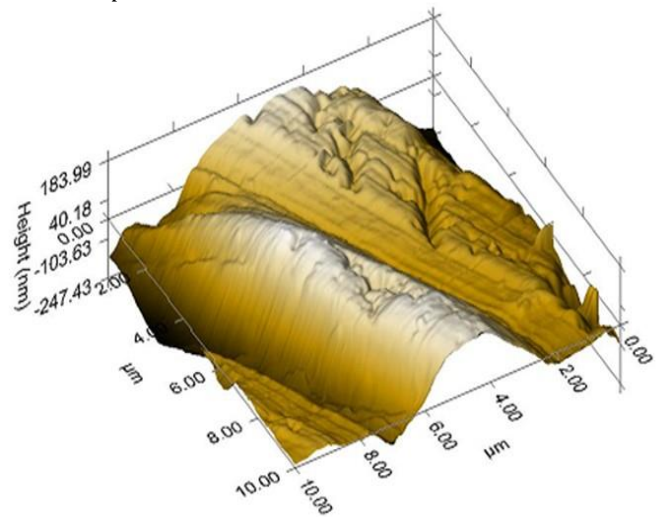


Figure 9a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $v = 200$ rev/min, $F_l = 2$ l/min, $f = 30$ mm/rev and $a_p = 0.6$ mm.

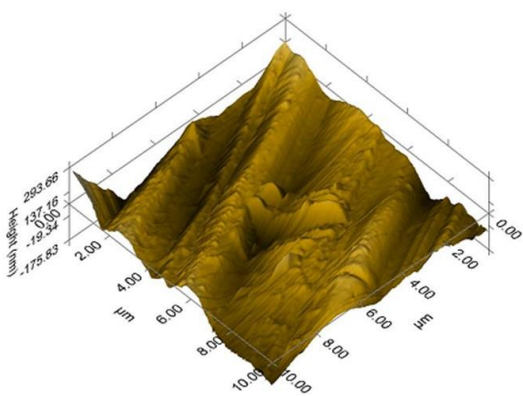


Figure 8a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $f = 50$ mm/rev, $F_l = 2$ l/min, $v = 1000$ rev/min and $a_p = 0.6$ mm.

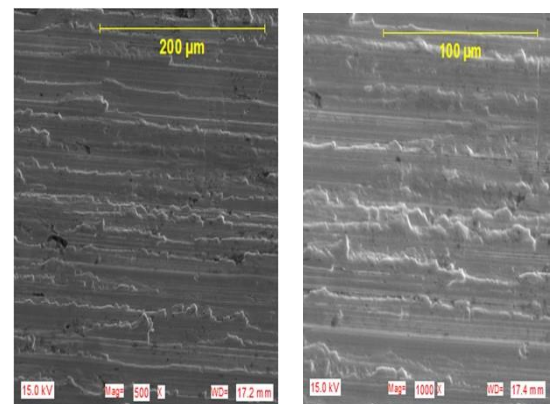


Figure 9b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $v = 200$ rev/min, $F_l = 2$ l/min, $f = 30$ mm/rev and $a_p = 0.6$ mm.

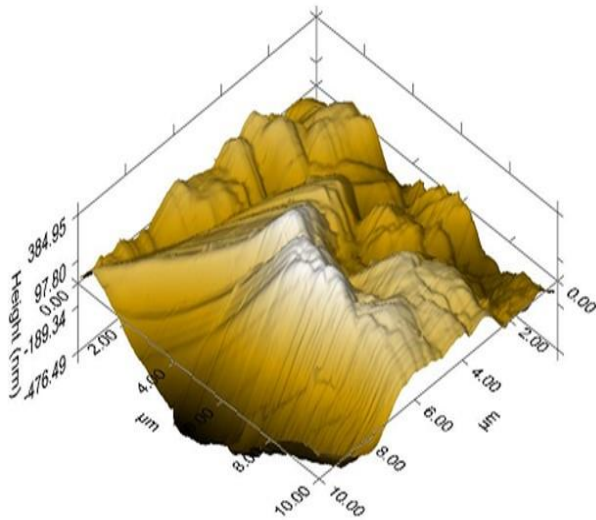


Figure 10a: 3D surface profile showing peak-to-valley height of machined surface. Cutting parameters: $v = 1800$ rev/min, $f_l = 2$ l/min, $f = 30$ mm/rev and $a_p = 0.6$ mm.

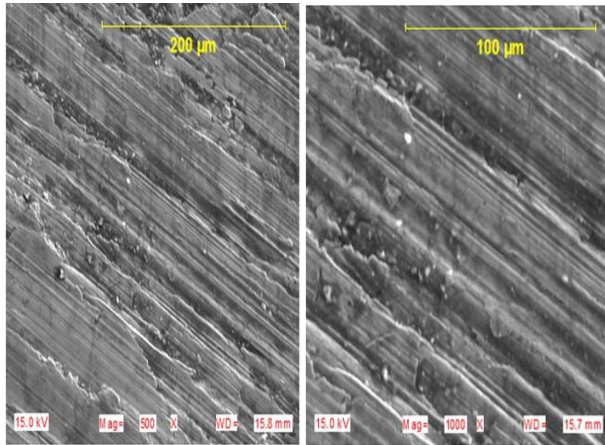


Figure 10b: Surface topography of machined surface obtained by SEM at magnification of 500x and 1000x. Cutting parameters: $v = 1800$ rev/min, $f_l = 2$ l/min, $f = 30$ mm/rev and $a_p = 0.6$ mm.

These micrographs obtained from each workpiece after machining show the feed marks due to the rubbing effect of the cutting tools with the workpiece in the course of face milling process at changing combination of the cutting parameters. The marks are produced by the cutting tool edges on the milled surface during each cutting tool revolution and depend on the position of the edges during the cutting process. These could be explained by the influence of the built-up edges on the machined surfaces. There is a higher tendency towards plastic and elastic deformation of the workpiece surface that involved variations on profile obtained. It is obvious from the surface profile Figures that the quantities of peaks and valleys height are definitely dependent on how the machined workpiece and cutting parameters are combined. Figure 3a shows the least depth of cut (0.2 mm) at constant values of cutting fluid flow rate (2 l/min), cutting speed (1000 rev/min) and feed rate (30

mm/rev) that resulted in low peak of 157.37 nm S_p and deep valley of -213.65 nm S_v , which describes the extent of roughness characterized by the machined surface. Similarly, Figure 4a presents the highest depth of cut (1.0 mm) at constant values of cutting fluid flow rate (2 l/min), cutting speed (1000 rev/min) and feed rate (30 mm/rev) led to the peak height of 395.08 nm S_p and deep valley of -295.55 nm S_v . These illustrate the magnitude of roughness characteristic values of the machined surface of the pearlitic ductile iron. It can be deduced that at low depth of cut, the roughness parameters values are lower compared to values obtained when depth of cut is high. Thus, as the depth of cut increased, cutting tool removed more chips from the workpiece surface as well as increasing the energy expended in making the chips. This agreed with the work of Abiodun *et al.* (2018). The aforementioned variances in the characteristic dispersals between valleys and peaks according to the surface profile could be clarified with regards to adequate plastic deformation of rigid peaks and minor tampering into the crucial part of the material. However, the surface produced in Figure 5a shows the least cutting fluid flow rate at 0 l/min (dry cutting), that resulted to the peak height of 553.36 nm S_p and deep valley of -290.69 nm S_v at constant values of depth of cut (0.6 mm), cutting speed (1000 rev/min) and feed rate (30 mm/rev). Also, Figure 6a shows the highest cutting fluid flow rate (4 l/min) that resulted to the peak height of 128.04 nm S_p and deep valley of -123.59 nm S_v at constant values of depth of cut (0.6 mm), cutting speed (1000 rev/min) and feed rate (30 mm/rev). These demonstrate the significant difference between machining at dry and wet cutting conditions. Though, in the course of dry cutting condition, the roughness characteristics of the surface of the pearlitic ductile iron are high which amount to poor surface finish. However, in wet cutting condition, the roughness characteristics decrease significantly thereby resulted in enhanced surface quality. The lessening in roughness characteristics with respect to rise in cutting fluid flow rate was expected since the heat convection rate near the cutting area deepened by high cutting fluid flow rate then reduced amount of heat surrounded the cutting tool-workpiece edge. This is consistent with the works of Abiodun *et al.* (2018) and Ilori *et al.* (2018). Similar result was observed in Figures 7a and 8a, with least and highest feed rates (10 and 50 mm/rev respectively) at constant values of cutting speed (1000 rev/min), depth of cut (0.6 mm) and cutting fluid flow rate (2 l/min). However, Figures 9a and 10a show that there is no precise direction between the least and highest cutting speeds (200 and 1800 rev/min respectively) at constant values of cutting fluid flow rate (2 l/min), depth of cut (0.6 mm) and feed rate (30 mm/rev).

B. Impact of Cutting Parameters on Machined Surface

In this subsection the impacts of the cutting parameters (depth of cut, cutting fluid flow rate, feed rate and cutting speed) were discussed.

1) Machined surface profiles as affected by the depth of cut

The mean values of the sample length peak-to-valley height parameter which depict the degree of their roughness with various depth of cut of 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm

and 1.0 mm at average values of 1000 rev/min cutting speed, 30 mm/rev feed rate and 2 l/min cutting fluid flow rate are 400.37 nm, 498.64 nm, 502.16 nm, 546.00 nm and 652.37 nm, respectively, as shown in Table 3. This implies that the roughness characteristic of the pearlitic ductile iron that was machined is dependent on depth of cut used. As the depth of cut increases the roughness parameter increases at constant cutting fluid flow rate, feed rate and cutting speed.

Table 3: Surface profile parameters as affected by depth of cut.

Depth of Cut (mm)	Peak or maximum height Sp (nm)	Valley or minimum height Sv (nm)	Peak-to-valley Sz [maximum height + minimum height] (nm)
0.2	214.4246	-185.9490	400.3736
0.4	239.9674	-258.6708	498.6382
0.6	277.1766	-224.9876	502.1642
0.8	303.0982	-242.9004	545.9986
1.0	355.0892	-297.2810	652.3702

This outcome aligns with earlier reports by Sosa *et al* (2007) and Uyaner *et al* (2012) who established increment in roughness during machining of plates of ferritized ductile iron as depth of cut increased. Also, the cutting force and cutting area increased by means of increase in depth, which altered the flow of chip direction during machining thereby affecting the state of deformation (roughness characteristics) of the machined layer. In related studies, Uyaner *et al* (2012) and Ilori *et al* (2016) agreed that the increased cutting force and cutting area possibly caused several alterations in the position and shapes of workpiece and tool, in this manner affected machining quality and increased workpiece surface roughness. Consequently, with the increment in depth, the stress induced at the surface became more tensile since the pearlitic ductile iron has fairly reduced thermal conductivity (Ilori *et al*, 2017). The part of the temperature generated was maintained on the surface and in the process of cutting, the heat increased because of the uninterrupted action of cutting tool therefore causing the thermal impact prevailing over the mechanical influence. Additionally, surface roughness increased as depth of cut became higher. However, better surface roughness characteristic was observed at low depth of cut while high values of surface roughness characteristic was obtained at high depth of cut as a result of high values of peak-to-valley height parameter, which is in agreement with the observations made by Arunachalam *et al* (2004) and Ilori *et al* (2016).

2) Machined surface profiles as affected by cutting fluid flow rate

Table 4 shows the varying cutting fluid flow rate of 0 l/min, 1 l/min, 2 l/min, 3 l/min and 4 l/min as the average values of the machined sample length peak-to-valley height parameter decrease from 733.56 nm to 272.84 nm at constant values of 1000 rev/min cutting speed, 30 mm/rev feed rate and 0.6 mm depth of cut.

Table 4: Surface profile parameters as affected by cutting fluid flow rate.

Cutting fluid flow rate (l/min)	Peak or maximum height Sp (nm)	Valley or minimum height Sv (nm)	Peak-to-valley Sz [maximum height + minimum height] (nm)
0	390.19	-343.37	733.56
1	376.76	-305.73	682.49
2	279.43	-219.14	498.57
3	203.60	-208.48	412.07
4	139.78	-133.07	272.85

Machining from the dry condition (0 l/min) to the wet cutting conditions (1 - 4 l/min) depicts tremendous reduction in roughness characteristics of the face-milled surface of the pearlitic ductile iron (Table 4). In other words, face-milling by means of dry condition intensified the surface roughness thus producing an inadequate surface quality whereas face-milling at wet condition minimized surface roughness hence, resulting in good quality surface. This outcome is consistent with the contributions of Kuram *et al* (2010), Zhou *et al* (2012) and Ilori *et al* (2016) who stated that machined surfaces generated by means of cutting fluid were top-quality compared to surfaces produced in the process of dry condition. Dry cutting condition promotes tensile stress on the surface which results to higher values of surface roughness owing to the rise in the thermal effect during machining caused by the tool wear and reduced thermal conductivity of the pearlitic ductile iron; whereas wet machining condition results in less tensile stress and low values of surface roughness (Ilori *et al*, 2016 and Ilori *et al*, 2017). Also, the use of cutting fluid lowers friction and increases the heat removal from the workpiece surface, thus resulting in the dominance of less tensile surface residual stresses and better surface roughness.

3) Machined surface profiles as affected by feed rate

Similar result was observed with varying feed rate of 10, 20, 30, 40 and 50 mm/rev. The mean values of the parameter for the machined surface profile decrease from 532.17 nm to 502.80 nm at average values of 0.6 mm depth of cut, 2 l/min cutting fluid flow rate and 1000 rev/min cutting speed as shown on Table 5.

Table 5: Surface Profile Parameter as Affected by the Feed Rate.

Feed rate (mm/rev)	Peak or maximum height Sp (nm)	Valley or minimum height Sv (nm)	Peak-to-valley Sz [maximum height + minimum height] (nm)
10	294.11	-238.06	532.17
20	265.13	-265.89	531.02
30	310.85	-210.45	521.31
40	252.19	-260.04	512.23
50	267.45	-235.35	502.81

The surface roughness characteristics decreases with increments in the feed rate, and this agreed with observation made by Grzesik and Zak (2012) that low values of feed rate have negative influence on the surface roughness, while elevated feed rate values guarantee a favorable impact on surface roughness. The profile and topography of the machined surfaces consist of peaks, valleys and long grooves in a trend corresponding to feed rate (Figures 7 and 8). These peaks, valleys and long grooves are generated by the cutting tools' geometry. The analysis of the face-milled surfaces using 3D and SEM revealed the reliance of roughness characteristics on the feed rate. The presence of an intense plastic flow was observed from the machined surface at low and high feed rates (Figures 7b to 8b above). Regardless of the point that a good quality surface was attained with a small feed rate, a close inspection of the surface machined showed substantial material flow occurred during the machining. Also, a characteristic material side flow (from SEM micrograph) which is the change in position of the workpiece material in the trend opposed to the feed path in such a way that burrs created on the feed mark edges, was observed. The workpiece material generated sufficient high temperature in the machining zone to cause complete plastic deformation. The material of cutting chip drifted in a perpendicular way to that of the chip and adhered to the machined surface, which caused damages to the quality of surface machined, even when the roughness characteristics was retained within the anticipated tolerance. Additionally, the stuck material could be rigid and coarse, in a way that it rubs and wears surface that touches the machined surface (Rech and Moisan, 2003).

4) Machined surface profiles as affected by cutting speed

The average values of the roughness characteristics peak-to-valley height parameter observed ranged from 512.56 nm - 568.31 nm as presented in Table 6. With varying cutting speed of 200, 600, 1000, 1400 and 1800 rev/min at the constant values of depth of cut (0.6 mm), cutting fluid flow rate (2 l/min) and feed rate (30 mm/rev), apparently, there is no

definable trend. When cutting speed increases, there was rise in temperature of the cutting process that caused thermal deformation on the pearlitic ductile iron's face-milled surface and thereby inducing tensile residual stress. The surge in temperature softened the metal and facilitated dislocation in the grain boundary of the surface machined.

Table 6: Surface Profile Parameter as Affected by Cutting Speed

Cutting speed (rev/min)	Peak or maximum height Sp (nm)	Valley or minimum height Sv (nm)	Peak-to-valley Sz [maximum height + minimum height] (nm)
200	277.85	-234.71	512.56
600	239.85	-260.06	499.91
1000	279.85	-248.04	527.89
1400	275.12	-215.76	490.88
1800	317.09	-251.22	568.31

This result agreed with previous work of Arunachalam *et al* (2004) and Ilori *et al* (2017). The extent of mechanical deformation with low cutting speed was not as immense as when cutting speed was high. Also, the magnitude of roughness parameters increased with increase in cutting speed, even though not consistent, attributable to vibration of milling cutter and wear rate of the tool aroused from high cutting speed. Similarly, the thermal and mechanical deformations formed influence the basic mechanism in variation of the roughness characteristics parameters. Likewise, the highly non-linear combination of thermal and mechanical deformations modified the characteristics of the roughness profile. Furthermore, the variation in the roughness parameters is expected as a result of the non-uniform deformation of surfaces shown in the micrographs (Figures 9b and 10b).

IV. CONCLUSION

The study characterized and analyzed the impact of feed rate, cutting fluid flow rate, cutting speed and depth of cut on the face-milled pearlitic ductile iron. Out of the four cutting criteria considered, cutting fluid flow rate, feed rate and depth of cut have positive and negative impacts on the roughness characteristics of the machined surfaces, respectively while cutting speed exhibit no precise trend. Given its influence on a product's functionality, appearance, and dependability, the requirement for high quality in production places a strong emphasis on the state of a product's surface, especially the roughness of the machined surface. Thus, in order to improve surface reliability in the face milling process in the production industries, this work concluded that machining at cutting fluid flow rate of 4 l/min, cutting speed of 1000 rev/min, depth of

cut of 0.2 mm with feed rate of 30 mm/rev will produce better quality surfaces.

AUTHOR CONTRIBUTIONS

O. O. Ilori: Conceptualization; Data Curation; Formal Analysis; Investigation; Methodology; Supervision; Visualization; Writing - Draft Preparation and Final Editing. **T. F. Oyewusi:** Data Curation; Formal Analysis; Methodology; Validation; Writing - Reviewing and Editing, and Final Editing. **O. A. Fadare:** Investigation; Methodology; Resources; Validation; Writing - Reviewing and Editing. **F. F. Adeyemi:** Investigation; Methodology; Resources; Writing - Draft Preparation.

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