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Investigation of Relationship between the Surface Roughness and Residual Stress on Pearlitic Ductile Iron Face Machined

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Abstract: *This study investigates the relationship between surface roughness and residual stress in face-milled pearlitic ductile iron in order to enhance the surface quality of machined parts used in manufacturing. Locally prepared pearlitic ductile iron was utilized. The cutting factors that were explicitly taken into consideration in this study were cutting speed, depth of cut, fluid flow rate and feed rate. Taguchi's design served as the foundation for the experiment, which used an orthogonal array with five levels for each factor. The experimental data were statistically analyzed using correlation and multiple regression analyses. The findings show a substantial positive relationship ($R = 0.938$, $p \leqslant 0.01$) between surface roughness and surface residual stress, which is statistically significant. The depth of cut and feed rate increased the surface residual stress by 511.212 and 0.668 units respectively, while a unit increase in cutting speed and fluid flow rate (-0.100 and -453.350 units respectively) decreased it. Likewise, the surface roughness increased by 53.958 and 0.063 units, respectively, with an increase in the depth of cut and feed rate. However, a unit increase in cutting speed and fluid flow rate resulted in a reduction in surface roughness (-0.003 and -21.132 units, respectively). It can be deduced from the multiple regression analysis that surface residual stress and surface roughness are associated with all cutting factors. These results can be used as a guide to improve the surface integrity of machined items. Thus, the study provided important information on the best cutting parameters for producing a significantly good surface finish during face milling operations in manufacturing industries.*

Keywords: *Surface Roughness, Cutting Factors, Surface Residual Stress, Correlation and Regression Analyses, Pearlitic Ductile Iron*

1. INTRODUCTION

Machining processes are very common in manufacturing technology. They are applied in manufacturing of almost every mechanical part. Due to their frequent use, they must be precise, efficient and inexpensive [1]. Two common machining techniques in the metal cutting industry are turning and milling [2]. The method of milling involves passing the work through a revolving multipoint cutter to remove metal. Face milling process is extensively employed in industrial machining for the rapid and precise cutting of large, flat surfaces [3, 4]. The primary benefit of face milling is the high output rate due to the large cutter diameter, which results in a high material removal rate. Usually, the integrity of the workpiece's surfaces is changed by machining procedures and final finishing touches. The surface properties (microstructure, hardness, surface residual stress, and surface roughness) that affect a part's functionality are indicated by surface integrity. One of the crucial characteristics that can significantly affect a component's corrosion resistance, wear resistance, and fatigue life is surface residual stress [5]. Additionally, the need for fully automated and high-quality production draws attention to the product's surface condition, particularly the machined surface's roughness, as it impacts the product's dependability, look, and functionality [6]. As a result, adoption of new circumstances in production strategies is necessary for the development of new materials and manufacturing technologies. Cast iron is a useful engineering material that has been used in various forms for many thousand years. It is basically an iron-carbon alloy [7]. Gray cast iron is strong under compression but not under tension, making it unsuitable for applications requiring a sharp edge or flexibility. Keith Mills' invention of ductile iron in 1943 revolutionized the cast iron family, overcoming its limitations [8]. This was accomplished by combining gray iron's castability with steel's hardness. Ductile iron, which contains nodular or spheroidal graphite in its matrix, is more flexible and elastic than other types of cast iron [8]. Pearlitic ductile irons are spheroids of graphite in a pearlite matrix. Good blend of cementite and ferrite (Fe_3C) is called pearlite. Pearlitic ductile iron is comparatively hard with moderate ductility, high tensile strength, moderate heat conductivity and impact resistance, good machinability and good wear resistance [5, 9]. There has been extensive investigation into the machining of various ductile irons using various cutting tools. However, there is a scarcity of data on the relationship between surface roughness and residual stress in face milling of pearlitic ductile iron. Hence, this study correlates the influence of different cutting factors on surface roughness and residual stress in face machined of pearlitic ductile iron in order to establish relationship between the two surface properties.

2. MATERIALS AND METHODS

2.1 Materials

Cutting fluid, a cemented carbide cutting tool, and pearlitic ductile iron were the materials used in this investigation. The study employed Azeolar lubricant, a soluble oil with additives. Ilori et al. [5] had previously developed the pearlitic ductile iron utilized locally in compliance with the ASTM A536 100-70-03 standard. Its chemical makeup is 2.90% silicon, 0.03% sulphur, 0.01% magnesium, 0.05% phosphorus, 0.25% manganese, and 93.17% iron. This composition is similar to ones designed for commercial use. The experimentation was conducted at Engineering Materials Development Institute (EMDI), Akure, Nigeria. Also, the equipment made use of are rotary furnace, computer numerical control vertical milling machining (PRODIS PDC-650H), X-ray diffractometer and nano-indenter.

2.2 Methods

The as-cast samples of pearlitic ductile iron were heat treated at 650 ^{o}C, held for four hours and then cooled in the furnace in order to relieve any induced stress during casting process. Each treated ductile iron sample was subjected to a face milling procedure using milling machine. The experiment design strategy used was Taguchi, which significantly decreased the quantity of experimental testing by using cutting speed, depth of cut, fluid flow rate and feed rate as the cutting factors. Each factor has five levels of value assigned to it (Table 1). The total experimental runs obtained using Taguchi's design approach is 25.

Table 1: Levels of cutting factors

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

2.2.1 Determination of surface roughness and residual stress

The residual stress on the machined surfaces was determined with X-ray diffractometer (PANalytical XPERT-PRO). Also, the roughness of machined surfaces was measured using nano-indenter (HYSITRON Nanomechanical Test Instrument) without indentation.

2.2.2 Data analysis

The experimental data were subjected to correlation and multiple regression analyses. The surface roughness and residual stress are the dependent variables while the cutting factors are the independent variables. The correlation analysis was used to examine the relationship between the surface roughness and residual stress which gave an estimate as to the degree of association between the two surface properties. Likewise, a linear functional relationship between the cutting factors and the surface residual stress was established using multiple regression analysis. Similarly, a functional link between the cutting factors and surface roughness was established through multiple regression model.

3. RESULTS AND DISCUSSION

The experimental analysis result between the dependent (surface roughness and residual stress) and independent (cutting factors) variables of the faced machined pearlitic ductile iron is presented in Table 2.

3.1 Correlation between the Surface Roughness and Residual Stress of the Machined Surfaces

The correlation matrix shows the level of significance, direction, strength and degree of association between the cutting factors and the surface roughness as well as the residual stress in face machined of pearlitic ductile iron (Table 3). There was no correlation between the depth of cut and feed rate ($R = 0.000$, $p \leq 0.05$), cutting speed ($R = 0.000$, $p \leq 0.05$) or fluid flow rate ($R = 0.000$, $p \leq 0.05$). Similarly, there was no linear relationship between the feed rate and cutting speed ($R = 0.000$, $p \leq 0.05$) or fluid flow rate ($R = 0.000$, $p \leq 0.05$). Also, there was no linear relationship between the cutting speed

Table 2: Influence of cutting factors on surface roughness and residual stress

Independent variables				Dependent variables	
Cutting speed (rev/min)	Depth of cut (mm)	fluid flow rate (l/min)	Feed rate (mm/rev)	Surface roughness (nm)	Surface residual stress (MPa)
200	0.2	0	10	101.78	2058.66
600	0.2	1	20	66.25	1329.16
1000	0.2	2	30	49.63	984.80
1400	0.2	3	40	20.07	703.07
1800	0.2	4	50	18.98	127.01
600	0.4	2	10	64.47	1004.65
1000	0.4	3	20	30.41	725.13
1400	0.4	4	30	21.73	149.75
1800	0.4	0	40	102.92	2137.54
200	0.4	1	50	90.28	1382.55
1000	0.6	4	10	40.05	459.14
1400	0.6	0	20	107.77	2166.10
1800	0.6	1	30	95.71	1548.46
200	0.6	2	40	56.91	1058.43
600	0.6	3	50	50.47	749.18
1400	0.8	1	10	97.66	1922.66
1800	0.8	2	20	69.66	1049.23
200	0.8	3	30	61.39	866.66
600	0.8	4	40	51.13	590.74
1000	0.8	0	50	132.85	2463.04
1800	1.0	3	10	75.16	923.03
200	1.0	4	20	47	590.75
600	1.0	0	30	154.7	2586.25
1000	1.0	1	40	101.94	1463.39
1400	1.0	2	50	96.26	1172.25

Table 3: Linear correlation coefficients of cutting factors, surface roughness and residual stress

	Depth of cut	**Feed rate**	**Cutting speed**	**Fluid flow rate**	**Surface residual stress**	**Surface roughness**
Depth of cut	1	-	-	-	-	-
Feed rate	0.000	1	-	-	-	-
Cutting speed	0.000	0.000	1	-	-	-
Fluid flow rate	0.000	0.000	0.000	1	-	-
Surface residual stress	0.214	0.014	-0.042	-0.951**	1	-
Surface roughness	0.441*	0.026	-0.027	-0.863**	0.938**	1

**, Correlation is significant at the 0.01 level
*, Correlation is significant at the 0.05 level

and fluid flow rate (R = 0.000, $p \leq 0.05$). On the other hand, the surface residual stress and the depth of cut have a weak, positive and significant correlation (R = 0.214, $p \leq 0.05$) or feed rate (R = 0.014, $p \leq 0.05$). An inverse relationship was observed between the surface residual stress and cutting speed (R = -0.042, $p \leq 0.05$) or fluid flow rate (R = -0.951, $p \leq 0.01$). The relationship between surface residual stress and fluid flow rate was very strong and significant. The correlation between surface roughness and depth of cut (R = 0.441, $p \leq 0.05$) was moderate, positive and significant. The connection between surface roughness and feed rate (R = 0.026, $p \leq 0.05$) was also positive but very weak and significant. However, the correlation between surface roughness and cutting speed (R = -0.027, $p \leq 0.05$) was very weak, negative and significant, while that of surface roughness and fluid flow rate was also negative but very strong and significant (R = -0.863, $p \leq 0.01$). Additionally, a substantial, very strong and positive correlation was found between surface roughness and surface residual stress (R = 0.938, $p \leq 0.01$). This suggests that as the surface residual stress increased, surface roughness also increased in a closely related linear manner. The multiple regression model for the surface residual stress and cutting factors can be expressed in the Equation (1).

$$SRS = 511.212\, a_P + 0.668\, f - 0.100\, v_c - 453.350\, \mathrm{Fl} + 1848.234 \quad (1)$$

where surface residual stress (MPa) = SRS, cutting speed (rev/min) = v_c and fluid flow rate (ml/min)= Fl, depth of cut (mm) = a_P and feed rate (mm/rev) = f.

The values for the coefficient of determination (R^2) and correlation coefficient (R) were 0.952 and 0.976, respectively (Table 4). This shows that 95.20% of variation in surface residual stress is explained by the explanatory factors (that is, the cutting factors) at the specified condition. This linear relationship is significant at the 0.05 level, according to the significance of correlation test. The beta coefficients of a_P and f in the equation and Table 5 implies that a unit increase in the depth of cut and feed rate increased the surface residual stress by 511.212 and 0.668 units respectively.

Table 4 Regression analysis of surface residual stress (model summary)

R	**R square**	**Adjusted R square**	**Standard error of the estimate**	**R Square change**	**F Change**	**Significance F change**
0.976_a	0.952	0.943	164.89564	0.952	99.493	0.000

a. Predictors: (constant), cutting speed, depth of cut, fluid flow rate and feed rate
b. Dependent variable: Surface residual stress

Table 5 Regression analysis of surface residual stress (coefficients)

Model	**Beta (B)**	**Standard error**	**t**	**Significance**
(Constant)	1848.234	133.962	13.797	0.000
Depth of cut	511.212	116.599	4.384	0.000*
Feed rate	0.668	2.332	0.286	0.777
Cutting speed	-0.100	0.117	-0.855	0.402
Fluid flow rate	-453.350	23.320	-19.441	0.000*

a. Dependent variable: Surface residual stress
*, Significant at 0.05 level of significance

However, the surface residual stress decreased with a unit increase in the vc and Ʃl (-0.100 and -453.350 units respectively). Thus, surface residual stress (SRS) increased considerably with increase in depth of cut (a_p) and very mildly with feed rate (f) while it decreased mildly with increase in cutting speed (v_c) and tremendously with fluid flow rate (Ʃl). With a 95.20% confidence level, the value of surface residual stress can also be predicted using Equation (1) for a given fluid flow rate, cutting speed, depth of cut and feed rate. For surface residual stress, the depth of cut has positive coefficient value (511.212) indicating positive direction, which means that increasing the depth of cut degrades the surface finish by inducing tensile residual stress on the surface. According to Wyatt and Berry [10], fatigue cracks are more likely to occur on a machined surface with tensile residual stress brought on by the machining process than on a machined surface with compressive residual stress. The surface finish is significantly affected by the depth of cut ($F = 99.49$, $p < 0.05$). The influence of feed rate also has positive coefficient value (0.668) and positive direction. The feed rate has a very weak impact on the surface finish and is significant ($F = 99.49$, $p < 0.05$). The positive direction indicates that as the feed rate increases, the surface finish likewise degrades. This is because, as the feed rate increases, the cutting tool's subsequent grooves get farther apart during the cutting process [11]. The cutting speed has negative coefficient value (-0.100) and negative direction. Due to the negative direction, surface finish is improved by increasing the cutting speed. The prevailing consensus is that machinability is enhanced by increasing the cutting speed. This could be as a result of the built-up edge formation continuously decreasing as the cutting speed rises [11]. Although it shows a weak effect, the cutting speed has a significant ($F = 99.49$, $p \leq 0.05$) impact on the surface finish.

The fluid flow rate also has negative coefficient value (-453.350) and negative direction. The negative direction means that increase in the fluid flow rate tends to create compressive surface residual stress or less tensile residual stress and improves the surface finish of machined surfaces. While tensile residual stress is typically detrimental to fatigue and creep life of material, compressive residual stress or less tensile surface residual stress is typically advantageous to these same qualities [12]. The influence of the fluid flow rate is significant ($F = 99.49$, $p \leq 0.05$) on the surface finish and has the best positive influence on surface finishing. When cutting fluid is applied, the machined surface experiences little to no tensile residual stress. According to Ilori et al. [5], machining in a wet condition increases surface residual stress, which prolongs the workpiece material's service life, whereas machining in a dry condition increases surface residual stress, which is harmful to the workpiece material. Also, M'Saoubi *et al.* [13] state that lubrication conditions, in addition to machining parameters like depth of cut, feed rate, and cutting speed, affect the kind of surface residual stress. Furthermore, the linear multiple regression model for the surface roughness and cutting factors can be expressed in Equation (2).

$$SR = 53.958\, a_P + 0.063\, f - 0.003\, v_c - 21.132\, \text{Ʃl} + 82.221 \tag{2}$$

where surface roughness (nm) $= SR$, a_P, f, v_c and Ʃl are as defined earlier. The correlation coefficient (R) value was 0.970 and coefficient of determination (R^2) value was 0.941 as shown in Table 6. This indicates that 94.10% of variation in surface roughness at the stated condition is explained by the cutting factors. According to the correlation test, this linear relationship is significant at the 0.05 level. The beta coefficients of a_p and f in the equation and Table 7 indicates that a unit increase in the depth of cut and feed rate increased the surface roughness by 53.958 and 0.063 units respectively. While the beta coefficients of v_c and Ʃl (-0.003 and -21.132 units respectively) were found to be significant in reducing the surface roughness (a unit increase in the cutting speed and fluid flow rate decreased the surface roughness). Therefore, surface roughness (SR) increases with depth of cut and feed rate, but decreases with cutting speed and fluid flow rate.

Table 6 Regression analysis of surface roughness (model summary)

R	R Square	Adjusted R square	Standard error of the estimate	R Square change	F Change	Significance F change
0.970_a	0.941	0.929	9.39570	0.941	79.840	0.000

a. Predictors: (constant), cutting speed, depth of cut, fluid flow rate and feed rate
b. Dependent variable: Surface roughness

Table 7 Regression analysis of surface roughness (coefficients)

Model	Beta (B)	Standard error	t	Significance
(Constant)	82.221	7.633	10.772	0.000
Depth of cut	53.958	6.644	8.122	0.000*
Feed rate	0.063	0.133	0.471	0.642
Cutting speed	-0.003	0.007	-0.503	0.621
Fluid flow rate	-21.132	1.329	-15.904	0.000*

a. Dependent variable: Surface roughness
*, Significant at 0.05 level of significance

This supported Ilori et al. [14] earlier research. Thus, equation (2) can be employed to envisage the estimated amount of surface roughness for a given cutting speed, fluid flow rate, depth of cut and feed rate with 94.10% confidence level. Furthermore, for surface roughness, the depth of cut has a positive coefficient value (53.958), suggesting a positive direction and implying that increasing the depth of cut degrades the surface quality. The depth of cut significantly affects the surface finish ($F = 79.84$, $p < 0.05$). This is in contrast to what Hayajneh et al. [11] found in their multiple regression analysis regarding how machining factors affect surface roughness. According to their analysis, the depth of cut has a negative value (-3.9), indicating that a deeper cut results in a better surface quality. Likewise, the influence of feed rate has positive coefficient value (0.063) and positive direction. The impact of the feed rate is significant ($F = 79.84$, $p \leq 0.05$) on the surface finish but has a weak effect. The positive direction indicates that when the feed rate increases, the surface finish somewhat deteriorates. This is in line with the findings of Hayajneh et al. [11], who found that feed had a positive (12.82) influence in a positive direction, indicating that surface polish declined as cutting feed increased. This is because when the feed rate increases, the cutting tool's subsequent grooves get farther apart during the cutting motion. Additionally, Davim [15] noted that there is a physical and statistical impact of the feed factor (0.32) on surface roughness. Similarly, the negative coefficient value (-0.003) of cutting speed suggests that surface quality was improved by increasing cutting speed. The influence of the cutting speed is significant ($F = 79.84$, $p \leq 0.05$) on the surface finish and has a weak effect. This also supports the finding by Hayajneh et al. [11] that the cutting speed effect has a negative value (-7.05) and a negative direction, indicating that surface finish is improved by increasing spindle speed. It is commonly recognized that machinability is enhanced by faster cutting speeds. This could be because, as cutting speed increases, the built-up-edge formation continuously decreases. In addition, Davim [15] reported that cutting speed (0.29) has measurable and statistically significant influence on surface roughness. Also, the fluid flow rate has negative coefficient value (-21.132) which implies that rise in the fluid flow rate improves the surface finish. The influence of the fluid flow rate is significant ($F = 79.84$, $p \leq 0.05$) on the surface finish and has the best positive influence on surface finishing. The application of cutting fluid produces a smooth surface free of built-up edges [16]. In contrast to machining under wet conditions, which produced a good surface finish, Ilori et al. [6] found that machining under dry conditions increased surface roughness, resulting in a poor surface quality.

4. CONCLUSION

The correlation between surface roughness and residual stress is clearly positive, strong, and statistically significant at the 99% confidence level ($r = 0.938$, $p \leq 0.01$). In order to forecast surface residual stress and surface roughness of face-milled pearlitic ductile iron, a multiple regression model was established as well, and the beta coefficients of the four cutting factors were empirically obtained. The depth of cut and feed rate increased the surface residual stress by 511.212 and 0.668 units respectively, while a unit increase in cutting speed and fluid flow rate (-0.100 and -453.350 units respectively) decreased it. Likewise, the surface roughness increased by 53.958 and 0.063 units, respectively, with an increase in the depth of cut and feed rate. However, a unit increase in cutting speed and fluid flow rate resulted in a reduction in surface roughness (-0.003 and -21.132 units, respectively). It can be deduced from the multiple regression analysis that surface residual stress and surface roughness are associated with all cutting factors. Nevertheless, it has been shown that surface roughness and residual stress are significantly impacted by flow rate of the cutting fluid and depth of cut. These results can be used as a guide to improve the surface integrity of machined items. Therefore, the study provided important information on the best cutting parameters for producing a significantly good surface finish during face milling operations in manufacturing industries.

REFERENCES

[1] Abiodun, M. O., Ilori, O. O. & Adeleke, K. M. (2018). Effect of Maize-Starch Based Cutting Fluids and Machining Parameters on Temperature Generated in Turning of AISI 304 Stainless Steel. International Journal of Multidisciplinary Sciences and Engineering, 9 (6): 18–23.

[2] Asfour, S., Chakraborty, P., Cho, S., Onar, A. & Lynn, M. (2007). Modeling tool wear progression by using mixed effects modeling technique when end-milling AISI 4340 steel. *Journal of materials processing technology.* 205, 190 - 202.

[3] Ezugwu, E. O., Richetti, A., Machado, A. R., Da Silva, M. B. & Bonney, J. (2004). Influence of the number of inserts for tool life evaluation in face milling of steels. *International Journal of Machine Tools & Manufacture* 44, 695–700.

[4] Diniz, A. E. & Filho, J. C. (1999). Influence of the relative positions of tool and workpiece on tool life, tool wear and surface finish in the face milling process. *Wear* 232, 67 - 75.

[5] Ilori, O. O., Adetan, D. A. & Umoru, L. E. (2017). Effect of Cutting Parameters on the Surface Residual Stress of Face-Milled Pearlitic Ductile Iron. International Journal of Materials Forming and Machining Processes, 4 (1): 38-52.

[6] Ilori, O. O., Adetan, D. A. & Umoru, L. E. (2016). Effect of Cutting Parameters on the Surface Roughness Generated during Face Milling Operation of Pearlitic Ductile Iron with Cemented Carbide Tool. Acta Technica Corviniensis-Bulletin of Engineering Tome IX, 4: 137-144.

[7] Karl, B. R. (2006). Metal Casting. Dept. of Materials Science and Engineering, Michigan Tech. University, USA.

[8] Degarmo, E. P., Black, J. T. & Kohser, R. A. (2003). Materials and Processes in Manufacturing (9th Edition), Wiley.

[9] Ductile Iron Society. (2014). Ductile Iron Data for Design Engineers. Retrieved from www.ductile.org/didata/section3/3part1.htm.

[10] Wyatt, J. E. & Berry, J. T. (2006). A new technique for the determination of superficial residual stresses associated with machining and other manufacturing processes. *Journal of Materials Processing Technology:* 171, 132–140.

[11] Hayajneh, M. T., Tahat, M. S. & Bluhm, J. (2007). A Study of the Effects of Machining Parameters on the Surface Roughness in the End-Milling Process. *Jordan Journal of Mechanical and Industrial Engineering*, 1(1), 1 – 5.

[12] Arunachalam, R. M., Mannan, M. A. & Spowage, A. C. (2004). Residual stress and surface roughness when facing age hardened Inconel 718 with CBN and ceramic cutting tools. *International Journal of Machine Tools & Manufacture*. 44, 879–887.

[13] M'Saoubi, R., Outeiro, J. C., Changeux, B., Lebruna, J. L. & Morao, D. A. (1999). Residual stress analysis in orthogonal machining of standard and resulfurized AISI 316L steels. *Journal of Materials Processing Technology* 96, 225 – 233

[14] Ilori, O. O. , Oyewusi T. F., Fadare O. A. & Adeyemi F. F. (2024). Characterization and Impact of Cutting Parameters on Face-Milled Surfaces of Pearlitic Ductile Iron. *Nigerian Journal of Technological Development*, 21(2), 32-41.

[15] Davim, J. P. (2003). Design of optimization of cutting parameters for turning metal matrix composites based on the orthogonal arrays. *Journal of Materials Processing Technology*, 132, 340 – 344.

[16] llori, O. O., Adeleke, K. M., Abiodun, M. O. & Idowu, I. A. (2018). Maize-Starch Based Cutting Fluids and Process Parameters Influence on Cutting Force in Turning of AISI 304 Stainless Steel. Journal of Nigeria Institute of Mechanical Engineering, 8 (2), 102-110.