

Prediction of cutting forces of SPTTs produced from scrapped mating rings of face seals

¹Oshuoha, I. C., ²Williams, O. A. and ³Odiakaose, C.

¹Mechanical Engineering Department, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria

²Aerospace Engineering Department, Federal University of Technology, IkotAbasi, Akwalbom State, Nigeria

³Chemical Engineering Department, Federal University Wukari, Taraba State, Nigeria

Onuhwilliams0@gmail.com; odiakaose@fuwukari.edu.ng

Paper History

Received: 27th July, 2025

Accepted: 12th Sept, 2025

Published: September, 2025

Abstract:

Turning operations are crucial in production processes especially for manufacturing cylindrical parts. The scrapped mating ring of face seals have been reused and studied as single point turning tool (SPTT), which has exhibited excellent turning abilities. The scrapped mating ring was strengthened. The strengthened, unstrengthened and standard tungsten carbide, were used to produce SPTTs with the following signatures: nose radius of 2mm, positive rake angles of 3°, 5° and 8° respectively and used to perform turning operations on mild carbon steel (CS1030). Cutting forces and surface finish were measured using kistler type 3-component piezoelectric dynamometer and surface profilometer. The factors used for the experiment are cutting speed, depth of cut, federate, rake angle and tools. The responses were cutting force and surface finish. With the results, predictive equations were derived for cutting forces of the three tools under consideration. The statistical analysis showed that linear cutting force, the model, depth of cut and federate are significant; whereas cutting speed, rake angle and tools are not significant at 95% confidence level. This research will provide the machine tools' shop with tools of minimized wear, surface roughness, chatter and dimensional inaccuracies.

Corresponding author

Oshuoha, I. C.

ifechukwudeoshuoha@gmail.com

Keywords: Cutting force, Predictive equations, Signatures, SPTTs, Strengthened

1. Introduction

In today's world of increasing environmental awareness and sustainability, it is crucial to find innovative ways to repurpose materials that would otherwise go to waste. One such opportunity lies in the evaluation of single point turning tools from scrapped mating rings of face seals. A single point cutting tool consists of a sharpened cutting part called its point, only one cutting edge as well as the shank; and the point of the tool is bounded by the face (along which the chips slides as they are cut by the tool), the side flank or major flank the end flank or minor flank and the base. Single point cutting tools are among the cutting tools used during machining operations and to be precise turning operation. Turning operation is widely used in the manufacturing industry, especially for mass production [1]. The operation is employed to create cylindrical parts by removing the material in the axial direction using a cutting tool. These cylindrical parts are essential components in many engineering products. Thus, the process of turning plays a vital role in successfully manufacturing a product. This operation involves various cutting conditions, tool geometries, and modes of tool failure that significantly affect the productivity and quality of the machining process [2].

Afolalu, *et al.* [3] opined that cutting tool wear is the main challenge of modern machining industries which reduces the goal of achieving high tool performance in the area of its dimensional accuracy, surface finish, high production rate, high wear on the cutting tools and high economy of machining in term of cost saving.

Geometry of cutting tool such as rake angle, wearland etc. is very important in determination of strength and quality of machined surfaces. Rake angle is a cutting-edge angle that has large effect on cutting resistance, chip disposal, cutting temperature and tool life. Increasing rake angle in the positive (+) direction improves sharpness. Increasing rake angle by 1° in the positive (+) direction decreases cutting power by about 1% [4]. In the previous study carried by Oshuoha [5] single point tool with only one rake angle was produced which cannot be totally relied on for practical applications. This research produced single point cutting tools with three different rake angles of 3, 5 and 8° respectively. Optimization of cutting parameters cutting speed, depth of cut, feed, and rake angle is also of paramount concern for machinist in order to obtain good, machined surfaces of acceptable standard. This research optimized cutting parameters for optimal surface finish and cutting forces.

In addition, by utilizing these discarded materials (scrapped mating ring of face seal), will not only reduce waste but also save valuable resources that would have been used to manufacture new tools. This process not only benefits the environment but also has economic advantages by reducing production costs. Furthermore, by evaluating and repurposing these materials, we can create high-quality tools that can perform just as effectively as newly manufactured ones. This not only showcases ability to think creatively and problem-solving but also demonstrates our commitment to sustainability. Thus, evaluation of single point turning tools from scrapped mating rings of face seals is a win-win situation for both the environment and industry [6]. The aim of this study is to model cutting forces and optimize the turning operation.

2. Materials and Methods

The face seal is cut using a diamond disc cutting plate to form an insert on a shank. A popular way to strengthen the cutting tips nowadays comprises the following steps, firstly, put the scrapped pieces of cutting tips in alcohol to remove grease or oil, then put it into an open container and sprinkle some urea (10% of the weight of pieces of face seal). Then, heat it to 180°C. After that, urea will melt and flow into the tungsten carbide through the blowhole. Next, keep the status for about 15 minutes and then cool the tips to a temperature lower than the melting temperature of urea. At last, suddenly heated the tips to about 700°C the urea would depolymerize [7]. The hardness and strength of face seal tips will be improved.

The most suitable metal for the shank is steel of about 0.5% carbon, in order to minimize the injurious effects of vibration and chatter on the brittle tip, the shank should be of generous cross-sectional proportion. To

accommodate the tip a step or cavity is machined. Care being necessary to ensure that all surfaces are flat so that the tip is everywhere supported against pressure introduced when cutting. Failure to do this might result in bending stresses being introduced on the tip in service and its subsequent cracking/ failure [8], to affix the cutting edge to the shank. The insert is soldered using the oxy-acetylene device, after arranging the insert. Then the diamond grinding wheel is used to shape the tool to the required specification.

Three sets of tools, namely: standard tungsten tool strengthened and unstrengthened scrapped mating ring of face seal respectively. The tools were configured with a nose radius 2mm, positive rake angles of 3°, 5° and 8° respectively.

The experimental design was made using design expert software and a total of thirty-five (35) runs of experiment, with five factors at various levels as indicated in Table 1. The 35 runs of experiments is a combination five (5) factors; cutting speed, feed rate, depth of cut, rake angle and tools, and two responses – cutting force and surface finish were shown in Table 2. Physical, Mechanical and Chemical properties of the workpiece- mild steel (CS1030) as described in Iplakayaa, et al. [9].

Table 1: Process parameters and their limits

Values in coded form	Spindle speed (M) (m/min)	Feedrate (f) (rev/min)	Depth of cut (d) (mm)	Rake angle (°)
-1	150	0.1	0.1	3
0	170	0.2	0.17	5
+1	200	0.3	0.34	8
		0.4	0.4	
		0.5	0.5	

Table 2: Experimental Results of surface finishes and cutting forces

Run	Factor 1 A: cutting speed (m/min)	Factor 2 B: feed rate (mm)	Factor 3 C: depth of cut (mm)	Factor 4 D: rake angle (°)	Factor 5 E: tools	Response 1 surface finish (μm)	Response 2 cutting force (N)
1	150	0.1	0.5	8	Treated	0.79	12.58
2	150	0.1	0.1	8	Treated	0.75	2.52
7	200	0.1	0.1	8	Treated	0.55	2.41
33	200	0.4	0.34	8	Treated	0.62	23.17
35	150	0.5	0.17	8	Treated	0.91	14.30
11	150	0.4	0.5	8	Untreated	0.92	35.58
15	170	0.2	0.17	8	Untreated	0.68	7.06
20	170	0.2	0.17	8	Untreated	0.68	7.06
8	200	0.5	0.1	8	Standard	0.64	8.06
10	170	0.5	0.5	8	Standard	0.70	41.28
14	200	0.1	0.5	8	Standard	0.58	12.05
28	150	0.3	0.34	8	Standard	0.85	19.50
19	170	0.3	0.1	5	Treated	0.69	5.63
27	170	0.3	0.1	5	Treated	0.69	5.63
30	150	0.4	0.5	5	Treated	0.87	35.58
4	170	0.5	0.17	5	Untreated	0.74	14.04
18	200	0.5	0.5	5	Untreated	0.65	40.29
22	150	0.1	0.4	5	Untreated	0.85	10.06
29	200	0.2	0.17	5	Untreated	0.57	6.89
34	170	0.5	0.17	5	Untreated	0.74	14.04
5	170	0.1	0.17	5	Standard	0.71	4.20
9	150	0.3	0.1	5	Standard	0.82	5.74
13	200	0.4	0.34	5	Standard	0.61	23.17
16	200	0.4	0.34	5	Standard	0.61	23.17

Run	Factor 1 A: cutting speed (m/min)	Factor 2 B: feed rate (mm)	Factor 3 C: depth of cut (mm)	Factor 4 D: rake angle (o)	Factor 5 E: tools	Response 1 surface finish (μ m)	Response 2 cutting force (N)
6	200	0.5	0.17	3	Treated	0.64	13.70
21	200	0.1	0.5	3	Treated	0.56	12.05
24	150	0.1	0.34	3	Treated	0.81	8.55
31	170	0.5	0.34	3	Treated	0.72	28.07
17	170	0.3	0.4	3	Untreated	0.73	22.51
23	150	0.2	0.1	3	Untreated	0.86	4.23
32	170	0.3	0.4	3	Untreated	0.73	22.51
3	150	0.5	0.1	3	Standard	0.90	8.41
12	150	0.4	0.4	3	Standard	0.88	28.47
25	150	0.1	0.5	3	Standard	0.84	12.58
26	200	0.1	0.1	3	Standard	0.55	24.10

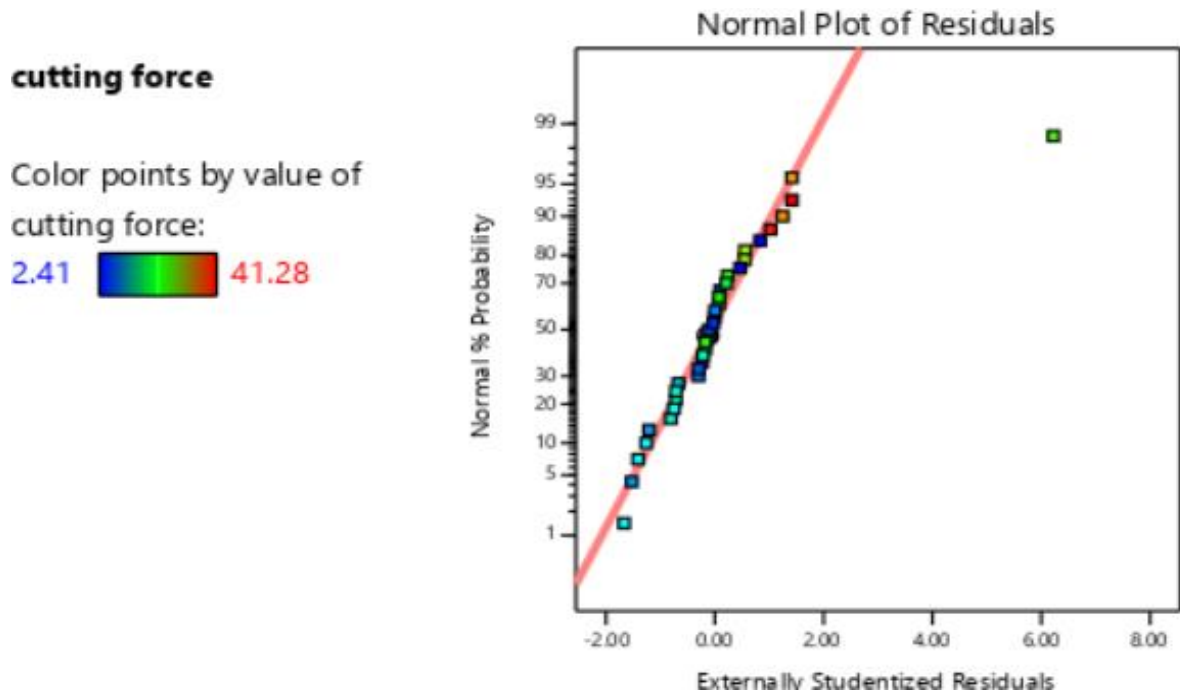


Figure 1: Normal Plot of Residuals for cutting force

The graph shows the variation between the predicted cutting force and the measured cutting forces. They both have a high correlation clustering along the line, the variation spans from 2.41 to 41.28N. The colour change

shows the variation, the smaller cutting forces are represented by colour blue, green is transformation colour and the larger ones are represented by red colour.

Table 3: Analysis of variance for linear model Response : cutting force

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	3018.70	6	503.12	12.99	< 0.0001	Significant
A-cutting speed	21.77	1	21.77	0.5622	0.4596	Not significant
B-feed rate	1085.18	1	1085.18	28.02	< 0.0001	Significant
C-depth of cut	1862.22	1	1862.22	48.08	< 0.0001	Significant
D-rake angle	2.62	1	2.62	0.0676	0.7967	Not significant
E-tools	24.60	2	12.30	0.3176	0.7305	Not significant
Residual	1084.40	28	38.73			
Lack of Fit	1084.40	23	47.15			
Pure Error	0.0000	5	0.0000			
Cor Total	4103.10	34				

Factor coding is coded. Sum of squares is Type II Classical

The Model F-value of 12.99 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case B

and C are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. Case(s) with leverage of 1.0000: PRESS statistic not defined.

Focus on the model maximizing the Adjusted R^2 and the Predicted R^2 as shown in Table 5. The Predicted R^2 of 0.5258 is in reasonable agreement with the Adjusted R^2 of

0.6791; i.e. the difference is less than 0.2. Figure 2 and 3 shows the pattern of variation of cutting forces with cutting speed and federate.

Table 4: Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	6.22	0.7357	0.6791	0.5258	1945.50	Suggested
2FI	2.74	0.9744	0.9378	0.6629	1383.21	
Quadratic	2.82	0.9806	0.9341	0.2803	2953.16	
Cubic	0.0000	1.0000	1.0000		*	Aliased

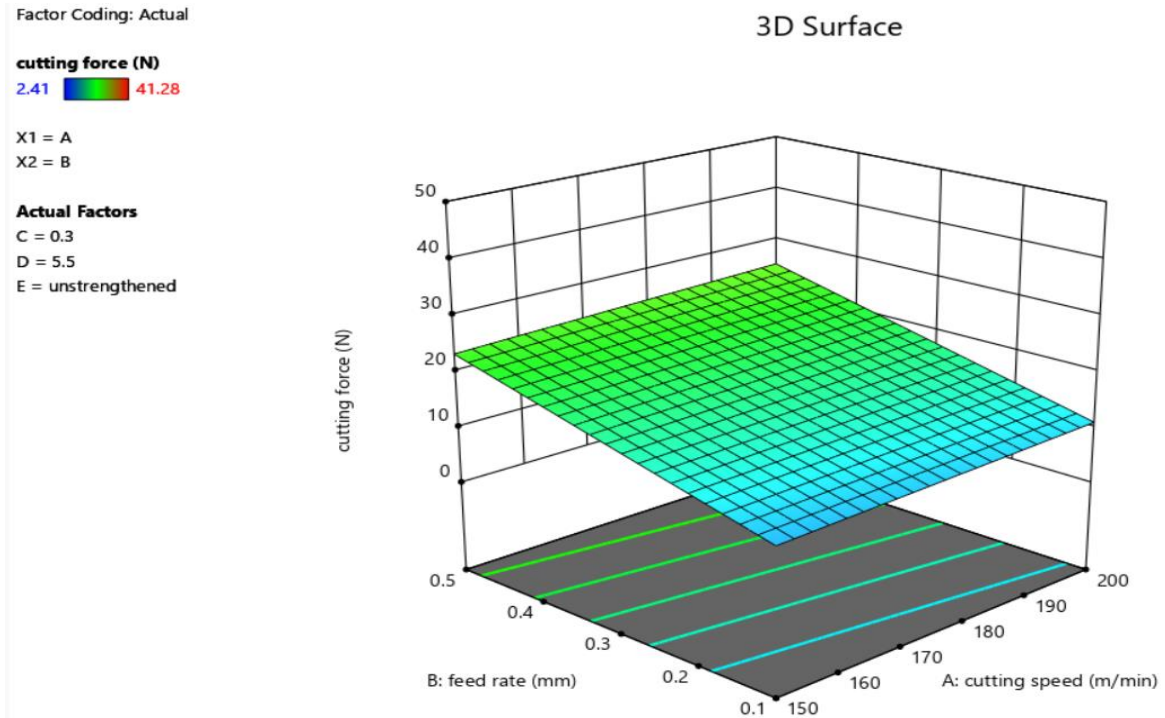


Figure 2: Effect of Cutting speed and feed rate on cutting force

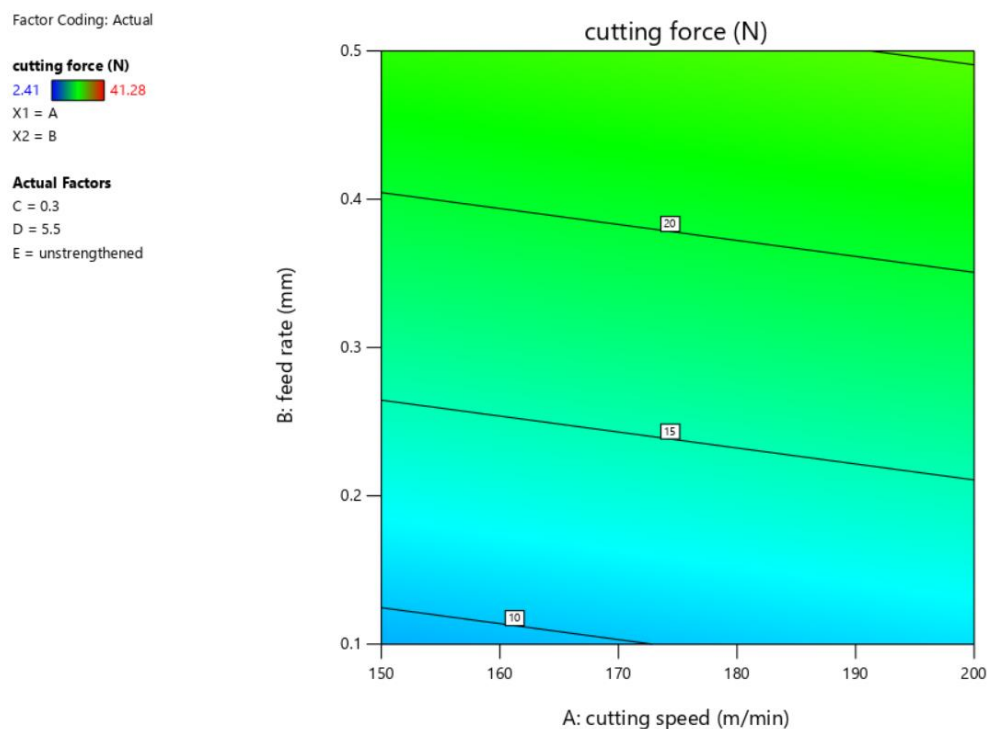


Figure 3: Variation of feed rate with cutting speed on cutting force

Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 13.234 indicates an adequate signal. This model can be used to navigate the design space.

Table 5: Fit Statistics

Std. Dev.	6.22	R ²	0.7357
Mean	15.98	Adjusted R ²	0.6791
C.V. %	38.95	Predicted R ²	0.5258
		Adeq Precision	13.2342

3. Discussion

It was observed in Table 2 that when the feed rates were increased, all cutting forces were increased for different rake angles of 8°, 5° and 3° investigated. This is because at higher feed rates, the frictional coefficient between the tools inserts and work material is higher when compared to lower feed rates because of increase in contact area. The volume of material removed from the work piece also increases at higher feed rate. Hence, higher cutting forces are required to shear the material. It can be observed that the minimum cutting force of 2.41N was obtained when the feed rate was at 0.1 mm for 8° rake angle for treated tool bit. It was also observed that the cutting forces continuously increase with feed; the increase was more prominent at lower rake angles while less at higher rake angles. as reported by Korkmaz, *et al.* [10] and Mia, *et al.* [11]

The cutting force for treated tool ranged from 2.41 - 23.17N, 5.63 - 35.58N and 8.55 - 28.07N for rake angles of 8°, 5° and 3° respectively. While cutting force for untreated tool ranged from 7.06 - 35.58N, 8.89 - 40.29N and 4.23 - 22.51N respectively for rake angles of 8°, 5° and 3°. The cutting force for the standard tungsten carbide tool varied from 8.06 - 41.28 N, 4.20 - 23.17N and 8.41 - 28.47N for rake angles of 8°, 5° and 3° respectively. This implies that the treated tool with rake angle of 8° and cutting speed of 200 m/min gave the optimum cutting force compared to untreated and standard which gave minimum values as 4.23N and 4.20N observed at 23rd and 5th run respectively.

Table 2 shows the influence of the depth of cut on cutting forces that are generated during turning of workpiece with produced cutting tools with different rake angles. It is clear from Table that cutting forces increased with increasing depths of cut. This trend is similar to the one obtained by Kaya, *et al.* [12], Dai, *et al.* [13]. Qiao, *et al.* [14] explained that the reason why cutting forces increased with an increasing depth of cut is due to the fact that an increase in the chip load increases the cutting forces need to remove the material. It was observed in Table 9 that depth of cut of 0.1mm gave a cutting force of 2.5N while depth of cut 0.5mm gave cutting force of 12.58N for treated tool having rake angle of 8° in the 2nd and 7th run respectively. The cutting force value of 12.58N at depth of cut 0.5mm was better than that of 41.28N obtained at the same depth of cut for standard tool.

Variation of cutting force with speed was also noticed in Table 2. There was decrease in cutting as the cutting speed increased during machining with the cutting tools produced. This is due to high friction in the tool-chip interface and extreme pressure in the cutting zone. The

heat generation rate is more at higher spindle speed. So, the material becomes soft at cutting zone. Hence, lower cutting forces are required for machining the material at higher spindle speeds. The chips carry away most of the heat while machining at higher spindle speed. The chip gets thinner and cutting force value decreases with increasing spindle speed. This is due to reduction in tool - work contact area and partly by reduction in shear strength in the cutting zone [15]. In the 2nd and 7th run of experiment as shown in Table 2 having the same feed rate and depth of cut gave cutting force of 2.52N at a cutting speed of 150 m/min while cutting force value of 2.41N was observed at a cutting speed of 200 m/min.

From Table 4, the models developed for all three tools, fit in for linear model. The values of R² are: R² = 0.7357, adjusted = 0.6791 and predicted = 0.5258. Whereas, for the quadratic model has values of R² = 0.9806, adjusted = 0.9341 and the predicted = 0.2803 respectively. Considering the above information, the linear model was chosen, as it will minimize the variation the actual value of cutting force and the predicted results (R² = 0.7357 and R² predicted = 0.5258), are more reliable than the other models..

According to Table 3, the linear model generated: the model have F-value 12.99 and P-value less than 0.0001, this makes it significant; cutting speed, have F-value 0.5622 and P-value = 0.4596, this makes it not significant; the federate have F-value of 28.02 and P-value is less than 0.0001, which makes it significant. While, the depth of cut have F-value = 48.08 and P value less than 0.0001 is significant. While rake angle and tools have F-values of 0.0676 and 0.3176 respectively, with all their P-values greater than 0.0001. This makes them not significant.

From Table 5, the Adeq precision of 13.2342 is greater than the standard value of 4.00. As any signal to noise ratio greater than 4, is adequate signal for the modeling process. From Table 6, the modeled equations for the cutting force in terms of actual factors showed that the tools showed comparable performances. The scrapped mating ring of face seals have been studied and performed satisfactorily as single point turning tools (SPTTs). The strengthened tool has a better performance than the rest tools. It exhibited lower cutting force to achieve better surface finish.

4. Conclusion

The turning operation models for the cutting forces of all three SPTTs under consideration showed excellent correlation. The statistical analysis showed that cutting force, the model, depth of cut and feed rate are significant. But the cutting speed, rake angle and tool have no significant impact on cutting force at 95% confidence level.

The strengthening of the scrapped mating ring of face seals used to produce SPTT produced lower cutting research, will provide the machine tools' shop with more durable SPTTs. and resistant to cutting stresses. Again, it will enhance reliability; minimize downtimes and accidents in machining processes. It will ensure better surface finish, durability and longer life span of SPTTs. The mechanical properties shown by strengthened- scrapped mating ring,

suggests it can be used for other applications in the machine tools' shop.

References

- [1]. Sousa, V. F. and Silva, F. J., (2020). Recent advances in turning processes using coated tools: A comprehensive review. *Metals*, 10(2), 170-184.
- [2]. Musavi, S. H., Adibi, H. and Rezaei, S. M., (2022). Development of an Innovative Grinding Process for Producing Functional Surfaces, *Tribology International*, 173, 107652.
- [3]. Afolalu, S. A., Abioye, A. A., Idirisu, J. and Okokpujie, I. P. (2018). Abrasion Wear of Cutting Tool Developed from Recycled Steel using Palm Kernel Shell as Carbon Additive, *Progress in Industrial Ecology – An International Journal*, 12(1/2), 206- 218.
- [4]. Kishawy, H. A., and Hosseini, A., (2019). Machining difficult-to-cut, *Materials Forming, Machining and Tribology*, 10, 973-978.
- [5]. Oshuoha, I. C., (2010). Performance evaluation of single point turning tools produced from mating ring scraps of mechanical face seal. PG Research Thesis. Department of Mechanical Engineering, University of Agriculture Makurdi, Nigeria. 122pp.
- [6]. Oshuoha, I. C., (2024). Evaluation of Single Point Turning Tools from Scrapped Mating Rings of Face Seals. Ph.d Research Thesis. Department of Mechanical Engineering, Joseph SarwuanTarka University, Makurdi, Nigeria. 123pp.
- [7]. Giordano, C., Erpen, C., Yao, W., Milke, B. and Antonietti, M., (2009). Metal nitride and metal carbide nanoparticles by a soft urea pathway. Chemistry of materials; American Chemical Society, Washington D.C.
- [8]. Oshuoha, I. C., Tuleun, L. T. and Oseni, M. I., (2015). Recycling of scrapped mating rings of mechanical face seals, *American Journal of Engineering Research (AJER)*, 4(1), 138-142.
- [9]. Ipilakyaa, T. D., Tuleun, L. T. and Gundu, D. T., (2014). Predictive force models for orthogonal cutting incorporating tool flank wear, *International Journal of Engineering and Technology*, 4(7), 435-443.
- [10]. Korkmaz, M. E., Yaşar, N. and Günay, M., (2020). Numerical and Experimental Investigation of Cutting Forces in Turning of Nimonic 80A Superalloy, *Engineering Science and Technology, an International Journal*, 23(3), 664-673.
- [11]. Mia, M., Anwar, S. and Yang, X., (2023). Development of interactive friction model for machining considering the instantaneous interfacial characteristics, *Journal of Materials Processing Technology*, 322, 118203.
- [12]. Kaya, S., Aydin, G. and Karakurt, I., (2023). An experimental study on the cutting depth produced by abrasive waterjet: how do abrasive and rock properties affect the cutting process?, *The International Journal of Advanced Manufacturing Technology*, 125(9), 4811-4823.
- [13]. Dai, X., Huang, Z., Shi, H., Wu, X. and Xiong, C., (2021). Cutting force as an index to identify the ductile-brittle failure modes in rock cutting, *International Journal of Rock Mechanics and Mining Sciences*, 146, 104834.
- [14]. Qiao, S., Feng, C., Wang, G., Liu, T. and Singh, J., (2025). Two-Dimensional Finite Element Analysis and Cutting Force Model for the Cutting of Circular Steel Bars Using Negative Rake Angle Cutters: Accounting for Chip Accumulation Effects, *Materials*, 18(6), 1339 -1357.
- [15]. Kuntoğlu, M., Aslan, A., Pimenov, D. Y., Usca, Ü. A., Salur, E., Gupta, M. K. and Sharma, S., (2020). A review of indirect tool condition monitoring systems and decision-making methods in turning: Critical analysis and trends, *Sensors*, 21(1), 108-124.