https://dx.doi.org/10.4314/dujopas.v8i3a.4
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490

Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 8 No. 3a September 2022*

Determination of Cutting Condition for Optimal Tool-Workpiece Interface Temperature in Dry-Turning AISI 1029 Steel with Carbide-Insert Tool by Taguchi's Method

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Abstract

The AISI 1029 steel type is often used in the turning process to manufacture fasteners, studs, and other engineering components under the costly effects of high temperatures. The paper exemplifies the basic use of Taguchi's optimization method in selecting cutting conditions and determining at which condition the optimal tool-workpiece interface temperature occurs in dry-turning the steel type on the lathe with a carbide-insert tool. Turning experiments were performed on an XL 400 lathe with the steel type in accordance with the L-9 Latin squares arrays designed with 0.5, 1, and 1.5 mm-depths of cut; 0.1, 0.2, and 0.3 mm/rev-feed rates; and 125, 250, and 500 m/min-cutting speeds as selected inputs, and measured tool-workpiece interface temperatures as the outputs. The inputs and outputs were analyzed using the Minitab-17 software-generated signal-to-noise ratios, main effect plots, contour and surface plots, and variance analysis by imbibing Taguchi's philosophy of the smaller-the-better. The result showed that the optimal interface temperature within the turning conditions was 29.5°C at 125 m/min cutting speed, 0.1 mm/rev feed rate, and 1.5 mm depth of cut. The variance analysis at a 95% confidence level showed that the cutting speed contributed most to the temperature with an 88.15% value, followed by depth of cut with 5.33%, and feed rate with 33.33%. A validation test at the optimal cutting condition indicated 30.31°C as the optimal interface temperature with an error of only 2.7% relative to the 29.5°C-value obtained with the software's predictive regression equation.

Keywords: Dry turning, AISI 1029 steel, cutting temperatures, Product cost, Optimal condition

INTRODUCTION

Turning is the machining technique of removing extra material from the exterior body of a cylindrical or conical work part held rigidly and rotated in the chuck of a lathe machine with a single point cutting tool to produce an engineering-serviceable component. During turning operation, the cutting tool is held without rotating on the lathe tool post and regulated to cut the work-piece under rotation at selected speeds with selected depths of cut in its transverse and longitudinal directions (Akkus and Yaka, 2018., Krishankant et al, 2012). The maximization of productivity and product quality at the lowest possible cost are goals in turning operations. Cutting tool temperature must be minimized and tool life maximized to reduce turning costs (Farooq and Jahanzaib, 2014). In turning operations, minimizing cutting

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tool temperature as a vital factor that incurs operational costs and poses hazards to adjacent people is a priority. During turning operations, the accompanying heat or temperatures can cause rapid wear of the tool and shortens its lifespan, plastic deformation of the tool's cutting edge if its material of manufacture is not sufficiently hot-hard, thermal flaking and fracturing of the tool's cutting edges, thermal shocks, and built-up edge formation. Other potential negative impacts of cutting temperatures are dimensional inaccuracy of the component being produced due to its thermal expansion and contraction to different dimensions from the ones being targeted to achieve, work surface or subsurface deterioration due to oxidation, high corrosion rate, burning, microcracks, and induction of high residual strain. (Akhil et al, 2016., Bhirud and Gawande, 2017., Pradeep Kumar et al, 2015., Manel and Kumar, 2017). It is therefore essential to keep cutting temperatures as low as possible, but doing so means operating at suboptimal cutting speed, feed rate, depth of cut, and cutting forces for maximum productivity (Akhil et al, 2016., Bhirud and Gawande, 2017) The use of suitable coolants is a standard means of dealing with the generated cutting temperatures. Coolants have benefits and drawbacks. Dry metal cutting is less expensive than wet metal cutting since no coolant or its delivery system, which can add to cutting costs, is required. Dry metal cutting is also more advantageous than wet metal cutting in that it does not expose workers or personnel to significant hazards, is less polluting, and eliminates issues associated with machine tool corrosion. Dry metal cutting is, however, more disadvantageous than its wet counterpart in terms of unsuitability for hard materials, limitation to low cutting inputs, characterization by greater heat generation or attendant temperatures, and ability to oxidize work surfaces or cause them to burn under generated heat with attendant poor work quality (Bedada et al, 2021., Jadav and Dalayi, 2020., Ogedengbe et al, 2019).

Without the application of optimization methods, minimizing the attendant tool temperature in turning operations is difficult by the trial-and-error approaches that are commonly used due to the combined variable extents of several input control parameters (Abdallah et al, 2019., Krishan Prasad, 2013). Although experience, the use of handbook manuals, or the use of formulae are often employed to predict the desired cutting parameters, such approaches are generally less accurate than the use of optimization methods (Gunjal et al, 2015). Many optimization methods, such as artificial neural networks, finite elements, Taguchi, genetic algorithms, and design of experiments, have apparently been successfully employed to handle complicated experimental and production challenges (Ayalew et al, 2019., Dede et al. 2019, Tsai et al. 2013). Due to its simplicity in formulating the experimental layout with the required variable control parameters, analyzing the influence of each parameter by statistical analysis of variance (ANOVA), and determining the optimal combination of parameters for the best activity condition, Taguchi's method has common applications in many human activities, including engineering. The method can be used for optimizing production objectives by establishing the optimal process level or control parameters for creating robust products (Ghani et al, 2013). The optimal process level of control factors, depending on the situation, is the one that maximizes or minimizes signal-to-noise ratios. Signal-to-noise ratios are determined as log functions of the desired output characteristics. Experiments to find out the optimal control levels use orthogonal arrays that are balanced in relation to all of the control parameters while being small in number. As a result, the amount of material and time needed for the tests is likewise modest (Wakjira et al, 2019). If the quality of the input signal directly determines the output, Taguchi's optimization approach involves determining the control factor levels for which the input/output signal ratio is closest to the desired features of the product quality being optimized. The optimization method is extensively used in product design and development to reduce faults and failures of manufactured items (Krishankant et al, 2012).

The AISI 1029 steel is a carbon steel type with a percentage carbon content that ranges across the boundary between low and medium carbon steel types. It is an inexpensive steel that has outstanding fabrication qualities for producing high-strength structural components or systems for engineering applications It is frequently turned according to specifications to produce fasteners, studs, and other components for engineering applications (AZO Materials, 2021., Guma and Onoja, 2021). Cutting conditions in turning carbon steel types including AISI 1029 type can vary from 5 to 200 m/s cutting speed, 0.1 to more than 10 mm depth of cut, and 0.05 to more than 5 mm/rev feed rate with unacceptable high tool-work interface temperatures (Guma and Onoja, 2021). Turning of carbon steel often necessitates a trade-off in cost-cutting aims by optimizing tool-work interface temperature under specific cutting conditions (Elsadek et al, 2020). Machineability varies greatly among steel kinds. The hardness, chemical composition, strength level, and microstructure of a steel type determine how easily it can be machined (Polishetty et al, 2016., Zheng and Liu, 2013). The ease with which a steel type can be machined is also influenced by the machine tool, cutting coolant quality, feed rates, cutting speeds, and cut depths used (Zheng and Liu, 2013). This wide variability in cutting conditions makes it difficult or impossible to achieve all the essential goals in turning a carbon steel type with a cutting tool type and other diverse cutting circumstances on a lathe machine type. Minimizing tool-work interface temperature is a typical goal in turning operation. There is therefore a need to provide a data base on optimal conditions from the wide sets of selectable cutting conditions for easy optimization of tool-interface temperature in dry-turning of AISI 1029 steel using different cutting tools, but such a data base is presently unavailable for engineers and machinists to use.

The goal of this research paper is to demonstrate the applicable use of Taguchi's optimization method in determining which of some selectable conditions of cutting speeds, depths of cut, and feed rates in the dry-turning of AISI 1029 carbon steel on the lathe machine with a carbide-insert tool provides the optimal tool-work piece interface temperature as a way towards providing the data base.

MATERIALS AND METHODS

Material

The material used in carrying out this research work was AISI 1029 steel, sourced from Hartzog Nig. limited in the Kakuri business area of Kaduna metropolis, with words from the company's sellers that the material was the steel type.

The following machines at the Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna, Nigeria were used.:

i. Inserts of ISO–CNMG 12 04 08-QM specification for tungsten carbide cutting tools.
ii. An XL 400 lathe machine.
iii. A surface roughness tester, type CVR-135.
iv. A digital pocket infrared thermometer with a temperature reading range of -35^{o}C to +230^{o}C, a reading accuracy of 20°C, and a 3V lithium button cell battery.

Methods of Experimentation

Ascertainment analysis of the procured AISI 1029 steel

To approve or reject the acquired steel as an AISI 1029 material, its nominal chemical composition was determined using a handheld S1 TITAN 500 Alloy Analyzer at Ahmadu Bello University Zaria's metallurgy lab.

Taguchi design of experiments

Tool cutting speed, feed rate, and depth were chosen as the three variable input parameters in turning operations with the AISI 1029 steel. As indicated in Table 1, each parameter was established with three levels, denoted L1, L 2, and L3. In addition, temperatures at the tool-work-piece interfaces were chosen as response factors. The Taguchi method was used to create the L9 orthogonal arrays for the experiments (Akkus and Yaka, 2018., Nalbant et al, 2007). The arrays offered the required number of experiments to be performed. In a series of experiments with the arrays, the link between the orthogonal turning parameters of the AISI 1029 steel and the response factors was investigated using the Taguchi method.

Table 1: Levels of cutting parameters for the turning experiments

Cutting variable	Levels		
	L1	L2	L3
Cutting Speed (mm/min)	125	250	500
Feed Rate (mm/rev)	0.1	0.2	0.3
Depth of Cut (mm)	0.5	1.0	1.5

Table 2: Coded and actual process design variables using Taguchi's L9 design with 3 levels and 3 factors

Experiment	Coded process level			Actual process variable		
No	Cutting speed	Feed rate	Depth of cut	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
1	1	1	1	250	0.1	0.5
2	1	2	2	125	0.2	1.0
3	1	3	3	125	0.3	1.5
4	2	1	2	250	0.1	1.0
5	2	2	3	250	0.2	1.5
6	2	3	1	250	0.3	0.5
7	3	1	3	500	0.1	1.5
8	3	2	1	500	0.2	0.5
9	3	3	2	500	0.3	1.0

Work-piece Specifications

Nine solid rod samples, each 40mm in diameter and 400mm in length, were sawn out of the acquired and certified AISI-1029 steel rod for the turning experiments.

Cutting tool Specifications

Carbide inserts of ISO-CNMG 12 04 08-QM were used in the turning experiments with the AISI 1029 steel. The following were the cutting tool specifications:

i. The diameter of the inscribed circle (IC) = 12.7 mm.
ii. The effective length of the cutting edge (LE) = 12.7 mm.
iii. Radius of curvature (RE) = 0.794 mm.
iv. 4.763mm insert thickness.
v. 25th grade.
vi. The angle of clearance = 0 degrees.

The Turning Experimentations

The tungsten carbide cutting tool was used for the experimental turning of the prepared AISI 1029 steel samples in the Production Workshop of NDA, Kaduna, on the XL 400 lathe. The cutting tool had four cutting edges with the CNMG 12 04 08-QM 425 carbide inserts. The workpieces measured 400 mm in length and 79.6 mm in diameter. In each turning experiment, one end of the workpiece was tightly held in the lathe's chuck, whilst the tail stock supported the other end. The cutting tool shank was firmly clamped to its holder. The lathe was set to the selected set of cutting conditions according to the experimental design arrays shown in Table 2. In each experimental case, the workpiece was initially faced and prepared for a length accuracy of 250 mm, and its turn length was 200 mm. Temperatures at the tool-workpiece interface were measured three times at two-minute intervals from the commencement of an experimental turning operation with a digital infrared thermometer by switching it on and directing it towards the work-piece-tool interface. Average value of the three temperatures was used as the tool-workpiece interface temperatures for each experimental array shown in Table 2.

To guarantee uniformity in the cutting settings, one insert cutting edge was used for each turning experiment, and it was replaced once all four insert edges had been used. The cutting speed was calculated using equation 1 (Guma and Onoja, 2020), which is as follows:

$$v = \frac{\pi DN}{1000} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where D was the workpiece diameter in millimeters (79.6 mm) and R denoted the spindle speed in revolutions per minute (rpm). Cutting speeds of 125, 250, and 500m/min were used in the experiments as shown in Table 2, with spindle speeds of 500, 1000, and 2000 rpm, respectively.

The average measured tool-workpiece interface temperatures in the separate experimental cases were used to generated Signal-to-Noise ratio in terms of the main effect plots, contour plots, surface plots, and analysis of variance using the Minitab-17 software. The input cutting variables and the response tool-interface temperature Signal-to-Noise ratio (S/N) values obtained from the turning experiments were analyzed by imbibing Taguchi's concept of the 'Smaller-the-Better' according to equation 2 (Krishankant et al, 2012., Wakjira et al, 2019).

$$S/N = -10log_{10}\left[\frac{1}{n}\sum\frac{1}{y^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where y was the measured value of the tool-workpiece interface temperature, and n was the number of measurements.

The relative importance of each turning variable was also given in the order of its percentage contribution in the turning process by analysis of variance (ANOVA) using the Minitab-17 software at a level of significance of = 0.5, that is at a 95% confidence level. After data analysis to determine the optimum cutting condition for tool-workpiece interface temperature, a confirmation experiment was carried out using the set of cutting variables for the optimum temperature obtained from the analysis. Results obtained from the Minitab-17 generated regression equation using the Minitab-17 software were also compared with the results obtained from the confirmation experiment.

RESULTS AND DISCUSSION

Results

Table 3 shows the result of the nominal composition analysis of the AISI 1029 steel used in the investigation. Table 4 shows the results of the three temperature readings, T1, T2, and T3, at distinct moments of tool-workpiece interface with the digital infrared thermometer during each experimental turning investigation with the AISI 1029 steel and their corresponding average (T) values. Results of the signal-to-noise ratios of the tool-workpiece interface temperature responses generated with the Minitab-17 software are shown in Table 5. The generated main effect plot of the signal-to-noise ratios of temperatures at the tool work-piece interface with the Minitab-17 software is shown in Fig 1. Figs 2, 3, and 4 respectively depict the contour plots generated with the Minitab-17 software for temperatures at the tool-work interface for the cutting speed (m/min) vs. depth of cut (mm), feed rate (mm/rev) vs depth of cut (mm), and cutting speed (m/min) vs feed rate (mm/rev). On the other hand, Figs 5, 6, and 7 respectively depict the Minitab-17-generated surface plots of temperatures at the tool-work interface for cutting speed (m/min) vs feed rate (mm/re), cutting speed (m/min) vs depth of cut (mm), and depth (mm) of cut vs feed (mm/rev). Table 6 shows the ANOVA of the too-workpiece interface temperatures result, while Table 7 shows the confirmation test result.

Table 3: Analysed nominal composition of the AISI 1029 steel used for the experimental turning investigations

Element	C	Si	Mn	P	S	Fe
Wt. (%)	0.300	0.10	0.790	0.040	0.050	98.72

Table 4: Temperature readings at tool-work-piece interface

Run	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Temperature (^{O}C)			
				T1	T2	T3	T
1	125	0.1	0.5	36	37	41	38
2	125	0.2	1.0	40	43	46	43
3	125	0.3	1.5	51	55	62	56
4	250	0.1	1.0	45	43	44	44
5	250	0.2	1.5	43	41	39	41
6	250	0.3	0.5	58	60	59	59
7	500	0.1	1.5	41	40	42	41
8	500	0.2	0.5	42	50	52	48
9	500	0.3	1.0	64	58	81	67

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Table 5: Signal-to-noise ratios for the tool-workpiece interface temperatures.

Run	Temperature (^{o}C)	Signal-to-noise ratio
1	38	-31.5957
2	43	-32.6694
3	56	-34.9638
4	44	-32.8691
5	41	-32.2557
6	59	-35.4170
7	41	-32.2557
8	48	-33.6248
9	61	-35.7066

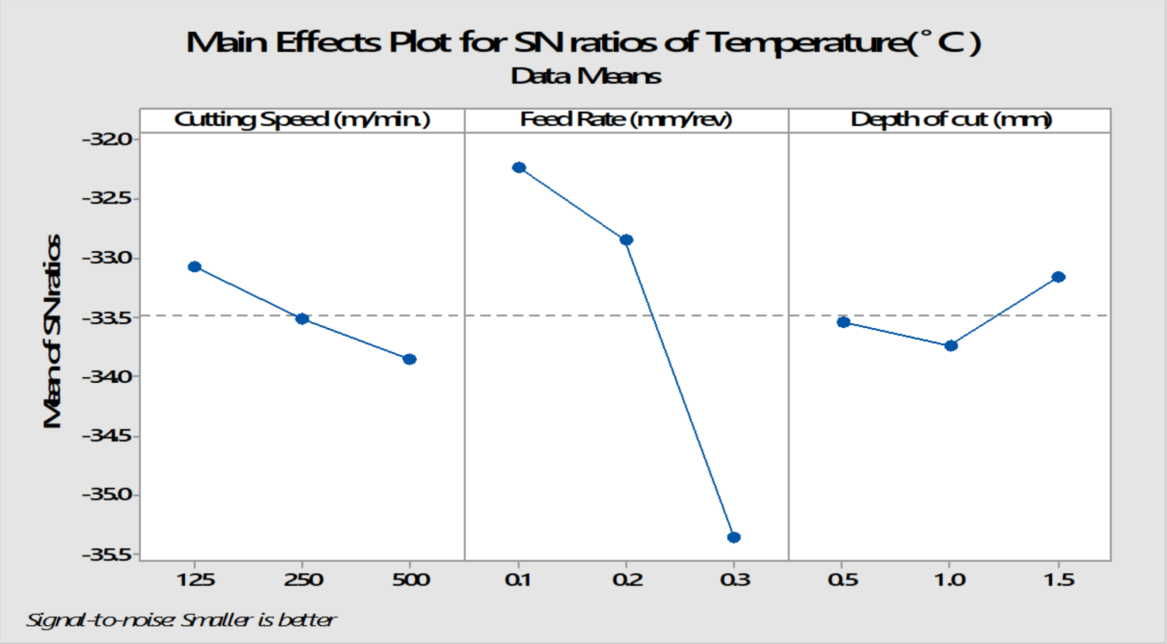

Fig 1: Main effect plot of temperature for cutting speed, feed rate, and depth of cut

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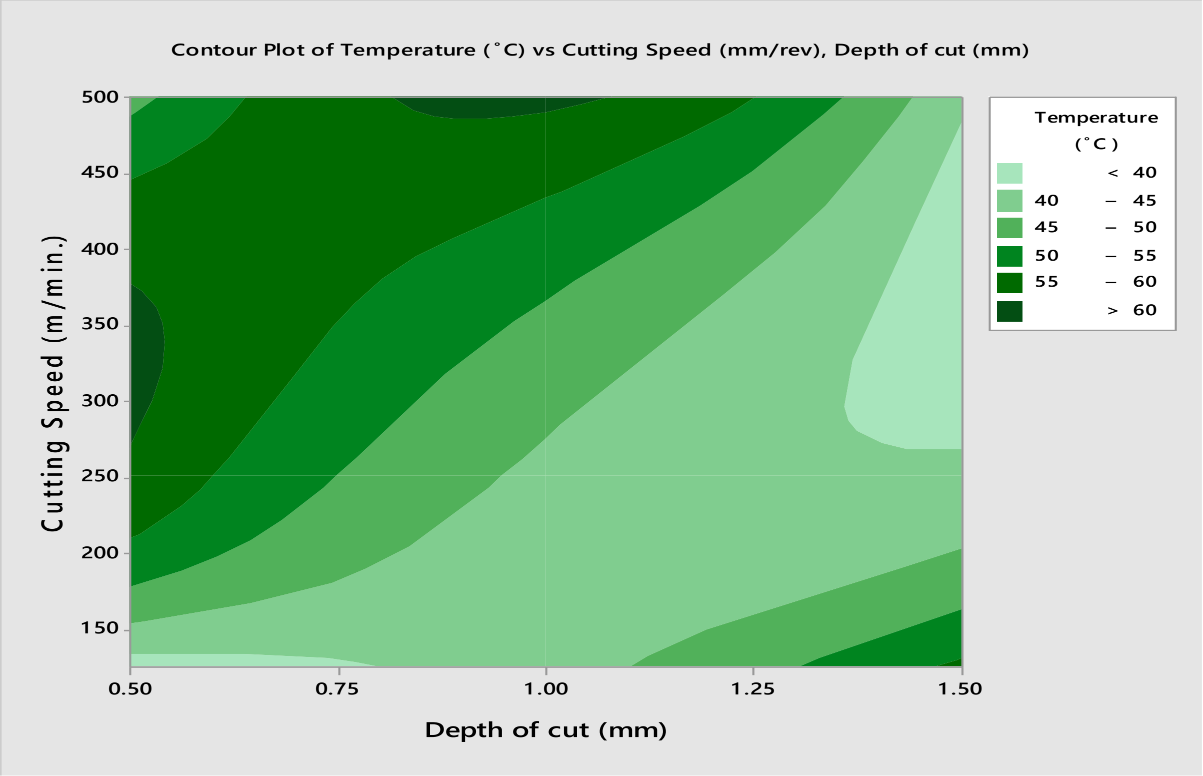

Fig. 2: Contour plots of temperature (° C) for cutting speed (m/min) vs depth of cut (mm)

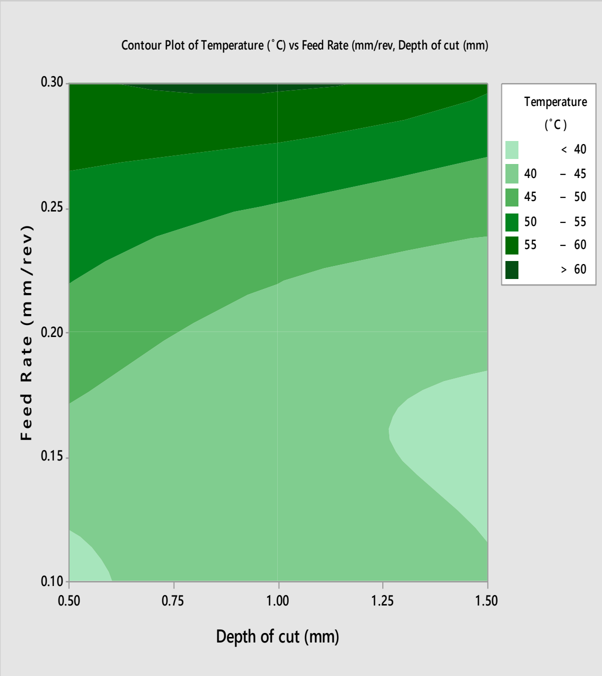

Fig. 3: Contour plots of temperature (ᵒC) for feed rate (mm/rev) vs depth of cut (mm)

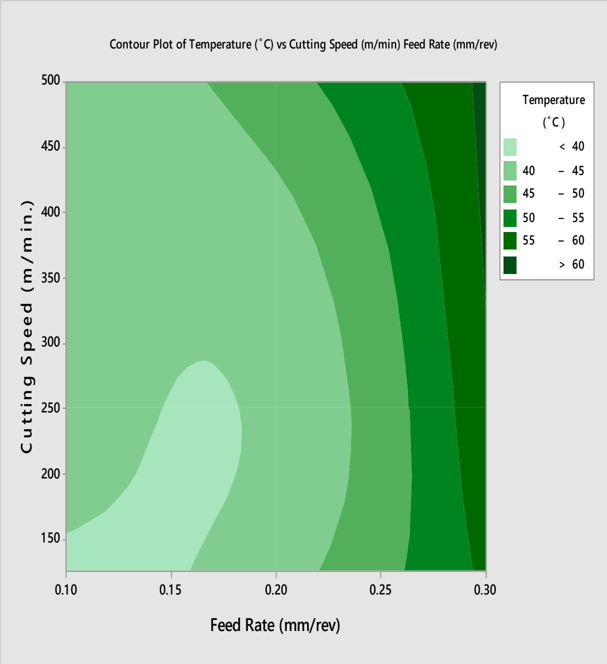

Fig 4: Contour plots of temperature (ᵒC) for cutting speed (m/min) vs feed rate (mm/rev) for 0.3mm depth of cut

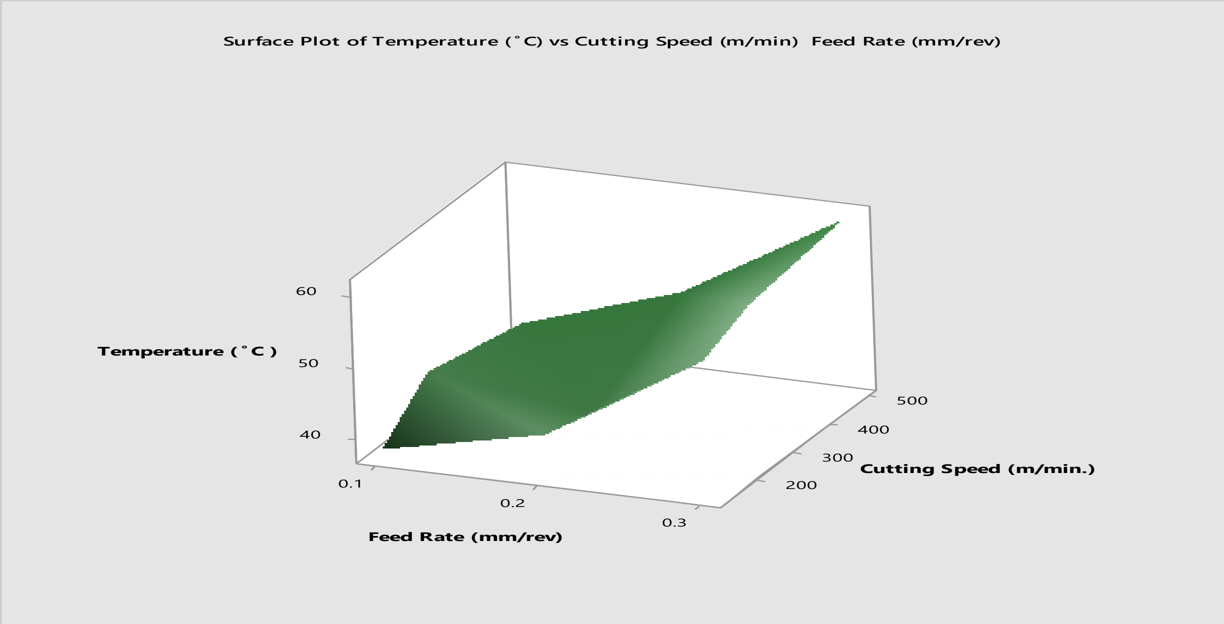

Fig. 5: surface plot of temperature (ᵒC) for cutting speed (m/min) vs feed rate (mm/rev)

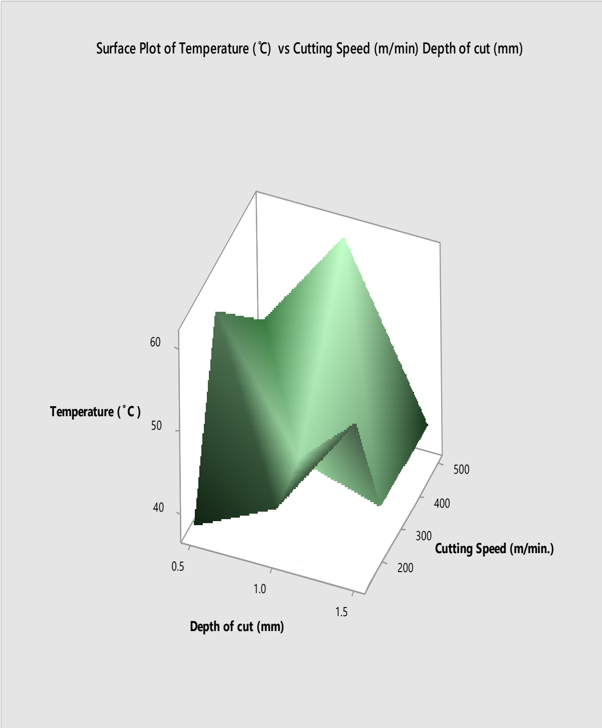

Fig. 6: Surface plot of temperature (° C) for cutting speed (m/min) vs depth of cut (mm)

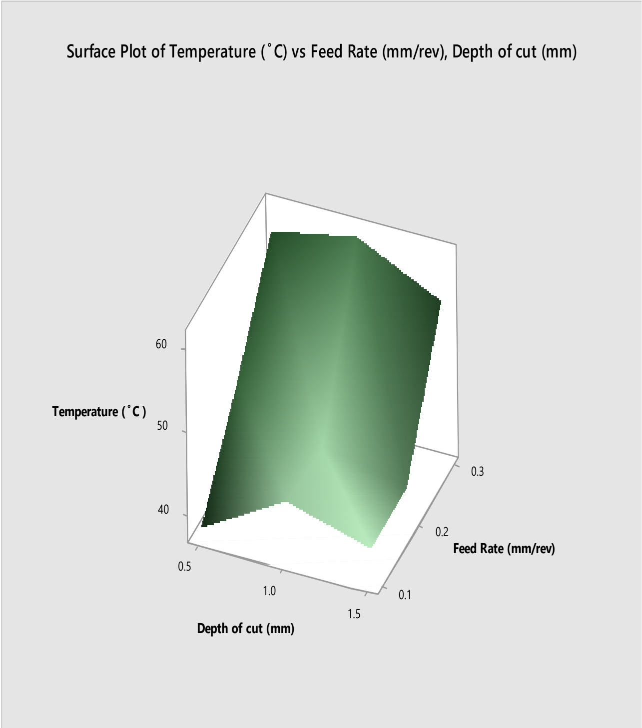

Fig. 7: Surface plot of temperature (° C) for depth of cut (mm) vs feed rate (mm/rev)

Table 6: ANOVA for Temperature

Factor	DOF	SS	MS	F	P
Cutting speed	2	26.698	26.698	1.49	88.15
Feed rate	2	468.167	468.167	26.05	3.20
Depth of cut	2	8.167	8.167	0.45	5.33
Error	2	89.857	17.971	0.00	3.32
Total	8	592.889	521.023	0.00	100

Table 7: Confirmation test

Parameter	Estimated value	Experimental value	Percentage error (%)
Temperature (° C)	29.05	30.31	2.7

Discussion of Results

Table 3 shows that the AISI 1029 employed for the experimental turning investigations had a nominal chemical makeup of six elements. By comparing the test steel composition to the AISI norm of 0.25-0.31 percent C, 98.7-99.15 percent Fe, 0.07-0.6 percent Si, 0.6-0.9 percent Mn, and less than 0.05 percent S, it is clear that the steel utilized for the studies was correct AISI steel.

Table 4 shows that as the cutting speed increased in the experimental investigations from 125 to 500 m/min, the depth of cut increased from 0.5 to 1.5mm, and the feed rate increased from 0.1 to 0.3mm/rev, the average temperature at the tool-work-piece interface increased from 38 to 67°C, with a minimum value of 38°C at 125 m/min, 0.1 mm/rev, and 0.5mm cut depth condition. This pattern of variation was similarly observed by Farooq and Jahanzaib (2014), in which as the cutting speed increased from 90 to 150 m/min, average tool-work interface temperatures increased from 297.8 to 305.2°C in the optimization of process parameters for temperature distribution in orthogonal cutting of AISI 1018 steel on the lathe with a high-speed steel as the cutting tool, in accordance with Taguchi's method based on orthogonal arrays formed cutting speeds of 90, 120, and 150 m/min; cut depths of 0.3, 0.45, and 0.6mm; and feed rates of 0.09, 0.12, and 0.15 mm/rev. The wide differences in their temperature values and the values presented in this paper are however attributable to the ability of carbide inserts to superior higher temperature resistance than the high-speed steel cutter. It is also attributable to the possibility of more ductile and longer chip formation with greater contact time with the tool in the AISI 1018 steel which has lower carbon content than the AISI 1029 steel.

Table 5 shows that the ideal tool-work-piece interface temperature is 38^{o}C, based on the smaller-the-better signal-to-noise ratio. The signal-to-noise ratio corresponding to this is -31.557, while the cutting variables corresponding to this signal-to-noise ratio are 125-mm/min cutting speed, 0.1-mm/rev feed rate, and 0.5-mm depth of cut. However, according to the main effect plot shown in Fig.1, the least tool-workpiece interface temperature occurred at the smaller-the-better signal-to-noise ratio values for the cutting speed, feed rate, and depth of cut. The optimal turning condition for these signal-to-noise ratio values occurred at about -331 for the cutting speed of 125 mm/min, -322 for the feed rate of 0.1 mm/rev, and -330 for the depth of cut of 1.5 mm, as can be observed from Fig 1. Fig. 1 also shows that the cutting speed had the greatest effect on the condition, followed by depth of cut, and lastly, feed rate, because of the lowest to highest variabilities in signal-to-noise ratios of the three cutting parameters, respectively, within their bands. The regression equation for the tool-workpiece interface temperature (TIT) in the turning experimental investigations generated with the Minitab-17 software is given by equation 3.

$$\mathrm{TIT} = 29.33 + 0.001105\mathrm{CS} + 88.3\mathrm{FR} - 2.33\mathrm{DOC} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where CS was the cutting speed, FR was the feed rate, and DOC was the depth of cut.
Substituting the values CS = 125 m/s, FR = 0.1 mm/rev, and DOC = 1.5 mm/rev as obtained for optimal cutting temperature from the main effect plot for the optimum TIT into equation 3, we got TIT = 29.33 + 0.001105 (125) + 88.3 (0.1) – 2.33 (1.5) = 29.05^{o}C.
Thus, the optimal temperature value at the tool-workpiece interface in the experiments was 29.05 ^{o}C. This value contrasts with the values of 298.06 ^{o}C at 0.6-mm cut depth, 90-rpm cutting speed, and 0.09 mm/rev-feed rate obtained by Farooq and Jahanzaib (2014) and 2.55 ^{o}C at 0.5-mm cut depth, 2000-rpm spindle speed, and 100-mm/min feed rate obtained by Bhirud and Gawande (2017) in predictive optimal equations in Taguchi's optimization method tests. The differences in all the results were due to differences in the measured temperatures due to differences in experimental variables such as workpieces, cutting variables, arrays, and tools used.

From the contour plots of cutting tool-workpiece interface temperatures shown in Fig 2, it can be observed that the minimum tool-workpiece interface temperature was less than 40^{o}C when the depth of cut ranged from about 1.3 mm to 1.5 mm and the cutting speed ranged from about 250 to 500 m/min. In Fig 3, the minimum tool-workpiece interface temperature was less than 40^{o}C when the depth of cut ranged from about 1.25 mm to 1.5 mm, and the feed rate ranged from about 0.12 mm/rev to about 0.18 mm/rev. From Fig 4, it can be observed that the minimum tool-workpiece interface temperature was less than 40^{o}C when the feed rate ranged from about 0.1 mm/rev to about 0.185 mm/rev and the cutting speed ranged from about 0 to about 290 m/min. From these, it can be seen that the TIT results from the Minitab-17 generated predictive equation and optimal cutting conditions obtained from the main effects plot shown in Fig 1 are all within the results band obtained from the analyses of the three contour plots.

Fig 5 shows that a combination of 0.1-mm/rev feed rate and 200-m/min cutting speed produced the lowest tool-workpiece interface temperature, as can be observed from the lowest depression on the surface plot of the interface temperature shown in Fig 5. On the other hand, Fig. 6 shows that the combination values for the optimum temperature occurred at about 200 m/min cutting speed and 0.5 mm depth, as can also be observed from the surface plot of Fig. 6. Fig. 7 shows that the lowest point on the surface plot, which corresponds with the lowest temperature at the tool work-piece interface, occurred at a 1.5-mm depth of cut and about a 0.1-mm/rev feed rate. It is thus clear that the optimal temperature result from the surface plots of the tool-workpiece interface temperatures points to the same optimal cutting condition of 125 m/min cutting speed, 0.1 mm/rev feed rate, and 1.5 mm cut depth as those of the main effect plot, TIT, and contour plots.

From the results of ANOVA with Minitab 17 for tool-work interface temperature presented in Table 6, it is evident that the cutting speed had the highest effect on the tool-work interface temperature. Cutting speed, together with feed rate and depth of cut, had a significant effect on tool-work interface temperature. At a 95% confidence level, the percentage contributions of cutting speed, feed rate, and depth of cut to the interface temperature were 88.15%, 3.33%, and 5.33%, respectively. On the contrast, Bhirud and Gawande, (2017) found that the found that the percentage contributions of depth of cut, cutting speed and feed rate were 86.217, 9.8944, and 1.7894 respectively during the dry end milling operation of Al 6063 with a HSS cutter.in accordance with Taguchi method for experimentation and L18 orthogonal array with spindle speeds of 2000, 3000, and 4000 rpm; feed rates of 20, 60, and 100mm/min; and depths of cut of 0.5, 1.5, and 2.5mm. Also, Sekulić et al, (2011) found that the percentage contributions of cutting speed, feed rate, and cut depth were 50.178, 28.933, and 20.889, respectively, on chip-tool interface temperature in turning Č1730 (EN C60) steel bars of 180 mm in diameter and 600 mm in length using cemented carbide inserts ("Sintal" type P25) under dry cutting conditions in optimizing the process cutting variables using Taguchi's method with L-9 orthogonal arrays formed with cutting speeds of 85, 113, and 150m/min; feed rates of 0.16, 0.249, and 0.392mm/rev; and cut depths of 1.5, 2.1, and 3mm.

From the confirmation test results shown in Table 7, the experimental tool-workpiece interface temperature was 30.31^{o}C, compared to the Minitab-17 generated predictive regression value of 29.05^{o}C. This shows the experimental temperature value was off by only 2.7%. This negligible confirmation test error agrees with results by Bhirud and Gawande (2017) that their measured optimum temperature was well within the 95% confidence level in the Taguchi method optimization of tool-interface temperature in the milling of aluminium.

CONCLUSION

The study has reaffirmed that high metal cutting temperatures add significantly to the total costs of turning processes, so they should be kept at optimal levels within the machining settings. Taguchi's optimization method has been used to exemplify which of the selectable conditions of cutting settings within the cutting speeds of 125, 250, and 500 m/min, feed rates of 0.1, 0.2, and 0.3 mm/rev, and cut depths of 0.5, 1, and 1.5 mm in dry-turning of AISI 1029 steel on a lathe machine with a carbide-insert tool can yield the optimal tool-workpiece interface temperature. Results showed that the optimum tool-work interface temperature in the investigations was 29.5oC at 125 m/min cutting speed, 0.1 mm/rev feed rate, and 1.5 mm depth of cut. An ANOVA at a 95% confidence level revealed that the cutting speed contributed 88.15% to the interface temperature, followed by the depth of cut (5.33%) and the feed rate (3.33%). Confirmation test at the optimal cutting condition yielded a 30.31oC-optimal interface temperature with an error of only 2.7% against the value of 29.5oC obtained with the Minitab-17-generated regression equation. The method can be similarly used to provide optimal cutting condition data base for of wide sets of cutting variables for the turning of AISI 1029 steel as an important material that is widely used for turning fasteners and other engineering-serviceable components.

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