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The Effects of Single Cutting Tool Geometry on Surface Roughness

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ABSTRACT

This paper aims to optimize a new cutter design for turning of AISI 12L14 material with a Titanium Aluminium Nitride (TiAlN) coated tungsten carbide tools. The interaction of the tool geometry and workpiece on a performance characteristics of surface roughness has been investigated, and Taguchi Orthogonal Array (OA) L9 is selected as the technique for the optimization. In this study, results showed that altering the rake angle of -10°, 0° to +10° rake angles will give significant influence on part's surface finishing. However, the minor cutting tool edge, K_{r2} with 3° is found to be the predominant factor in influencing surface roughness, R_y. The experimental results showed the obtained surface roughness (R_y) values were low, i.e. between 6.76μm to 16.18μm, and within a desirable range in manufacturing requirements. The optimum turning operation was obtained at T9 test setting with K_{r1}: 60°, K_{r2}: 3°, rake angle: 0°, and inclination angle: +3°; which provided the smallest surface roughness (R_y) value of 6.76μm. It is suggested that the Taguchi parameter design and Taguchi signal-to-noise (S/N ratio) used for the tool optimization is simple, systematic, reliable, and efficient tools for the optimization process in turning.

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Introduction

All manufacturers presume to have higher productivity in their machining processes, continually improve performance and reduce costs. Therefore, major improvements in the design of cutting tools are needed. Apart from considering the tool life, strict control on the quality of surface finish during turning is extremely important. Surface roughness is significantly depending on the characteristic of work-piece, while the tool life and the chip controllability are often managed by the development of cutting tool technology. Optimizing on turning-interrelated factors in mass production must be considered. Optimization is impossible or otherwise, all the interaction parameters are known. Multiple factors instead of one factor at one time must be considered when conducting the experiment. In the previous research, numerous optimization techniques have been introduced, and Taguchi method is likely to be the most practical and superior design technique widely chosen by many industrial practices and researchers. According to Taguchi method, all factors can be considered at once, as well as it gives a better graphic visualization *via* S/N ratio calculation to obtain an accurate optimum machining condition, and eventually capable of saving time and reducing cost [1].

Turning process is the mechanical actions where a single point cutting tool is used to cut the work-piece by the means of mechanical deformation to produce the desired shapes. Turning involves the use of high-speed rotation of spindle and/or sub-spindle while doing their jobs. Turning with high feeding allowed the increase of manufacturing volume, but other problems will arise; the cutting forces increment and larger metal removal rate, which decrease the cutting tool life significantly. Cutting speed, depth of cut, feed rate, and other machine regimes control parameters contributed to the formed magnitude of forces, temperature, chip formation, which lead to the tool effectiveness and performance [2]. Other factors, e.g. heat, wear and chemical resistant, toughness or difficult to break characteristic are some of the most identical aspects intensively focused by the majority of tool/insert manufacturers in designing and fabricating their tool/insert for the optimum performance. AISI 12L14 offers a naturally good machinability, which enables the production of high-performance with high accuracy parts and to provide the consumers with the compatibility of cost efficiency and high product precision (high function) without the need for additional finishing process. However, the effects of built-up-edge (BUE) formed during cutting process is reportedly to be high in the machining of relatively soft free-cutting steel, which can impair surface roughness of the workpiece being machined [3, 4]. In spite of extensive research on tool geometry design, determining the optimum tool geometry of WC tool for AISI 12L14 free cutting steel (an ‘easy-to-machine’ material yet has sticky characteristic), in industrial setting, is still relies on the operators' skill and also trial-and-error methods. On top of that, their effects on the surface finish of AISI12L14 workpiece in turning are still lacking. Therefore, the aim of this work is to obtain an optimize tool geometry of single cutting tool coated with TiAlN on AISI 12L14, as the function of surface roughness (R_y) based on Taguchi technique. Experiments were carried out to study the effects of major and minor cutting tool angle, rake angle, and inclination angle on workpiece affecting the performance characteristics of surface roughness [5].

Experimental Setup

Experimental Workpiece

The workpieces used in the experiments were free cutting steel AISI 12L14. The AISI 12L14 consists of (in wt. %): carbon (C) 0.15 max, Manganese (Mn) 0.85 - 1.15, Phosphorus (P) 0.04 - 0.09, Sulphur (S) 0.26 - 0.35 and Lead (Pb) 0.15 - 0.35 and the rest is Iron (Japan Industrial Specification, 1994). Initially, raw material was purchased in the form of bar (Total length: 2500mm and diameter: ∅40mm). The raw material workpiece was then cut into 230mm length and machined according to Figure 1. To minimize the interruption of cutting operation and the consistency of measurement (due to machine-workpiece run-out), workpiece outer diameter was turned to 30mm diameter as a pre-machine, in order to remove the outer layer surface due to the previous operation (bar drawn process) before conducting the turning experiments [6]-[8].

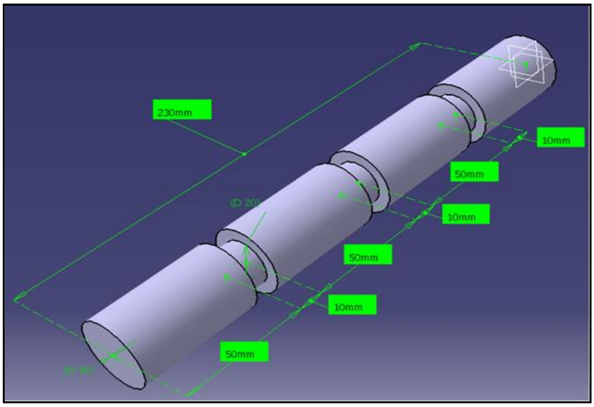

Figure 1: The workpiece dimension for testing (units in mm).

Tool Selection and Tool's Preparation

Tungsten carbide (WC) material was selected for the experiments. Initially, a blank (brazed tool) was purchased and then grinded into the designated geometry. There were four main geometry variables; (1) major cutting tool edge angle (K_{r1}), (2) minor cutting tool edge (K_{r2}), (3) rake angle (γ), and (4) inclination angle (λ) prepared for the tests. The example of tool's geometry design used in this test with K_{r1}: 90°, K_{r2}: 3°, γ: -10°, and λ of -3° is depicted in Figure 2. Grinded tools were coated with TiAlN using physical vapor deposition (PVD) technology.

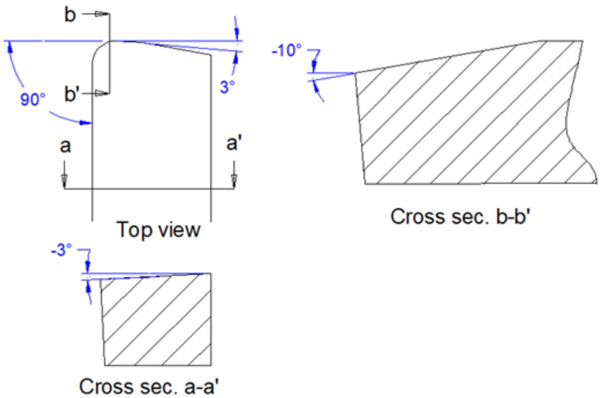

Figure 2: Example of tool geometry used for the 3rd experiment (Table 1)

Three levels and four parameters (L9) Taguchi orthogonal array (OA) design was used to determine the relationships of tool geometries on the machined surface roughness. A total of nine experiments were conducted. Table 1 shows the L9 Taguchi orthogonal array was used for the four factors (major tool cutting edge angle, minor tool cutting edge angle, rake angle and inclination angle) considered at three levels, respectively. Three major cutting parameters; cutting speed (V_c) 100m/min, depth of cut (a_p) 2.0mm, and feed rate (f_r) 0.3mm/rev., were fixed during the experiments.

Table 1: Taguchi orthogonal array (L9) design

Test	Major tool cutting edge angle (K_{r1}°)	Minor tool cutting edge angle (K_{r2}°)	Rake angle (γ°)	Inclination angle (λ°)
1	90	7	+10	+3
2	90	5	0	0
3	90	3	-10	-3

4	70	7	0	-3
5	70	5	-10	+3
6	70	3	+10	0
7	60	7	-10	0
8	60	5	+10	-3
9	60	3	0	+3

The experiments were conducted on a rigid conventional lathe machine Wasino. The workpiece bars were held in the machine with a three-jaw chuck clamping with supported by tailstock center to minimize run-out and maximize rigidity as depicted in Figure 3. The cutting tool was firmly mounted on a tool holder. The tool overhang was kept at 48mm for each in order to obtain accurate readings of the surface roughness. The turning operation was closely monitored to ensure that there were no anomalous issues such as built up edges or tool failure.

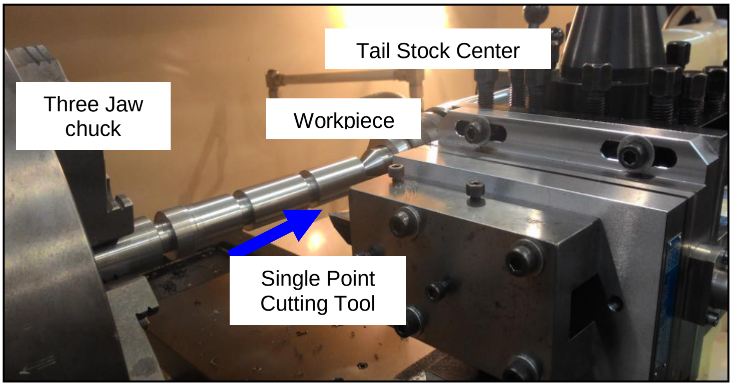

Figure 3: Experimental setup: Cutting tool-work piece-clamping.

After all tests were completed, the surface roughness of the workpieces was measured and recorded. The measurement of maximum height of surface roughness, R_y (R_y: JIS B 0601:2001) was obtained using Mitutoyo Surftest SV-400 using cut-off length and traverse lengths of 0.8 and 4.0mm, respectively. Maximum peak-to-valley roughness (R_y) is one of the various simple surface roughness amplitude parameters used in industry. Three measurements values were obtained from each test and mean values of the measurement results were recorded for further statistical analysis. Figure 4a shows the overview of Mitutoyo Surftest SV-400 connected with data acquisition. Meanwhile Figure 4b shows how the workpiece were secured and measurement were conducted for all samples. The ANOVA was performed on all values using MINITAB 17, mean comparison analysis was carried using the Tukey method at $p < 0.05$.

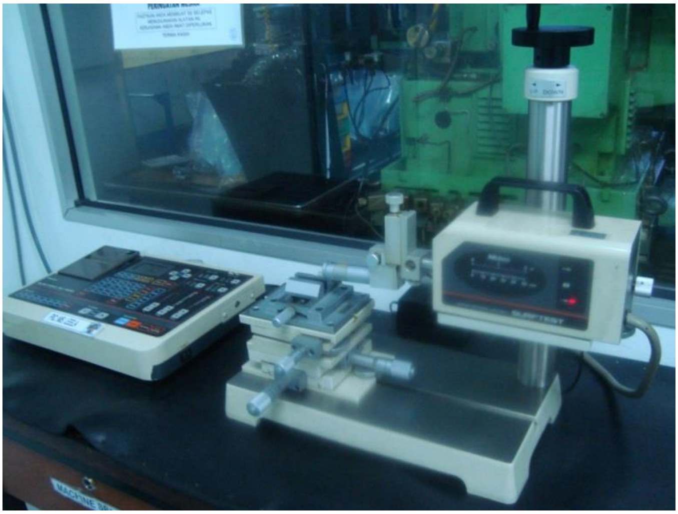

Figure 4: (a) Overview of surface roughness tester Mitutoyo Surftest SV-400 using for surface roughness measurement.

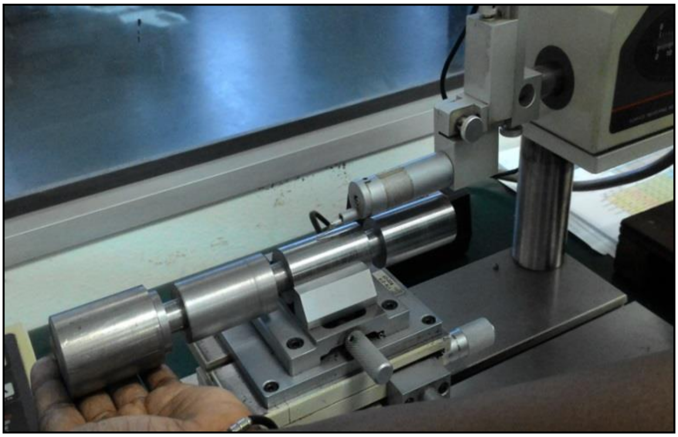

Figure 4: (b) Measurement of workpiece using surface roughness tester Mitutoyo Surftest SV-400 for surface roughness measurements.

Results and Discussion

The effect of tool geometries on performance characteristics of workpiece surface roughness were investigated via Taguchi method. In Taguchi method, the process parameters which influence the product can be separated into two categories: control factors which are used to select the best condition for stability in manufacturing, whereas noise factors represent all factors that cause variance. In this research, the controllable factors (major and minor tool cutting edges, rake and inclination angles) and response factors (surface roughness) relationship was examined, hence, the optimal control factors combination that produce the lowest surface roughness values will be obtained. In addition, it is expected that the optimized parameter values are insensitive to the variation of environmental conditions and other noise factors (i.e. machine and setup vibration, electrical noise). The characteristic performance of smaller-the-better was applied to calculate the S/N ratio of surface roughness (R_y).

Quality characteristic for smaller-the-better were applied to assess the surface roughness (R_y) [9]. The smaller values are always preferred and it indicates that the high accuracy parts were produced. The experimental results (Table 2) showed the obtained surface roughness (R_y) values were low i.e. between 6.76μm to 16.18μm, and within desirable range in manufacturing requirements. The optimum turning operation was obtained at T9 test setting with K_{r1}: 60°, K_{r2}: 3°, rake angle: 0°, and inclination angle: +3°; which provided the smallest surface roughness (R_y) value of 6.76μm.

Table 2: Experimental result for R_y using four tool geometry (K_{r1}: major cutting tool edge angle, K_{r2}: minor cutting tool edge, γ: rake angle, and λ: inclination angle) for nine tests (N°).

Test	**Major tool cutting edge angle (K_{r1}°)**	**Minor tool cutting edge angle (K_{r2}°)**	**Rake angle (γ°)**	**Inclination angle (λ°)**
1	90	7	+10	+3
2	90	5	0	0
3	90	3	-10	-3
4	70	7	0	-3
5	70	5	-10	+3
6	70	3	+10	0
7	60	7	-10	0
8	60	5	+10	-3
9	60	3	0	+3

Furthermore, the analysis of S/N ratio for surface roughness in Table 3 shows that Kr2 gave the highest delta value of 5.83, followed by rake angle, Kr1, and inclination angle with the respective delta value of 2.74, 1.73, and 0.25. A high delta indicates a strong effect of tool geometry on the resultant surface roughness, R_y. This indicated that K_{r2} has a major influence on surface finish of workpiece. The effects of K_{r2} which is having 3° of extended surface area are larger than other geometry tools, it provided as an extended tool cutting edge length engagement between tool and machined surface compared to other cutting tools, which causes a better surface roughness. As K_{r2} extended angle increased to 5° and 7°, poor surface quality was obtained. A similar observation was found by others [10].

Table 3: Response table for surface roughness S/N ratio.

Level	**K_{r1} (°)**	**K_{r2} (°)**	**γ (°)**	**λ (°)**
1	-19.93	-23.35	-19.01	-20.34
2	-21.26	-19.85	-19.95	-20.28
3	-19.53	-17.52	-21.75	-20.09
Delta	1.73	5.83	2.74	0.25
Rank	3	1	2	4

The machined surface were captured using optical microscope (mag. x70) as depicted in Figure 4(a, b, c), it's can be observed that tool T7 with K_{r2}: 7° , tool T8 with K_{r2}: 5° and tool T9 with K_{r2}: 3° have a very uniform turn marked/appearance. Merely a slightly different of surface finish can be observed through the optical microscope. This could be due to the fact that x70 magnifying resolution is inadequate to seize the details of surface roughness.

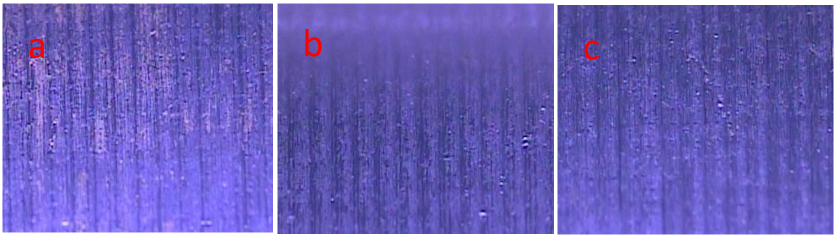

Figure 4: Snap pictures of surface roughness of (a) Tool T7 with K_{r2}: 7°. (b) Tool T8 with K_{r2}: 5°. (c) Tool T9 with K_{r2}: 3°.

Furthermore, the effect of K_{r2} on surface roughness was also observed through the measurement of true profile using the surface roughness as depicted in Figure 4(a, b, c). As illustrated, reducing K_{r2} angles from 7° to 3° caused modifications on the surface profile (peak and valley height) and gave smaller surface roughness, R_y as well as lowering the overall surface roughness.

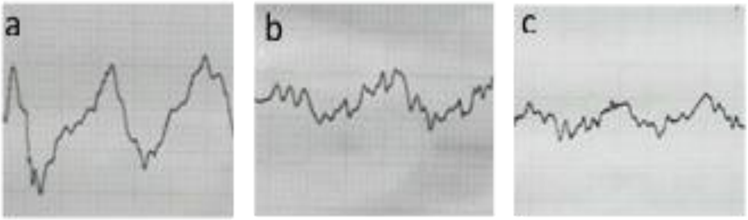

Figure 4: Real surface roughness profile measurement by Mitutoyo Surftest SV-400 (cut-off length: 0.8mm, traverse length: 4mm, mag. 10μm/cm). (a) Tool T7 with K_{r2}: 7°. (b) Tool T8 with K_{r2}: 5°. (c) Tool T9 with K_{r2}: 3°.

Conclusion

In this study, rough cutting condition of cutting speed 100m/mm, depth of cut 2.0mm and feed rate of 0.3mm/rev. were selected as machine setting conditions. By employing Taguchi S/N ratio for the optimization, the optimum tool geometry on surface roughness was obtained at K_{r2}: 3°, and rake angle +10°. In general, minor cutting tool edge, K_{r2} with 3° having an extended contact length between cutting edge and machined surface was found to be predominant factor in influencing surface roughness (R_y). Altering negative to positive rake angles significantly lowered the surface roughness (R_y). It is suggested that the Taguchi parameter design and Taguchi signal-to-noise (S/N ratio) used for the tool optimization is a simple, systematic, reliable, and efficient tools for the optimization process in turning.

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