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Performance Evaluation of Conventional and Wiper Carbide Tools When Turning 6060 Aluminium Alloy: Analysis of Surface Roughness

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Abstract**—**Wiper inserts are widely used nowadays, particularly in turning and milling operations, due to their unique geometric characteristics that generate superb surface finish and improve productivity. Wiper inserts can produce double the feed rate while preserving comparable surface roughness compared to that produced by conventional cutting tools. This paper reports an experimental investigation of surface quality generated in the precision dry turning of 6060 Aluminium alloy using conventional and wiper inserts at different cutting conditions. The Taguchi L9 array, Analysis of Means (AOM) and variance (ANOVA) were employed in the development of the experimental design and to optimise the process parameter identified: average surface roughness (Ra). The experimental results show that the wiper inserts substantially improved the surface quality of the machined samples by a factor of two compared to those for the conventional insert under all cutting conditions. The ANOVA and AOM analysis showed that the type of insert is the most significant factor affecting surface roughness, with a Percentage Contribution Ratio (PCR) value of 67.41%. Feed rate also significantly affected surface roughness but contributed less to its variation. No significant difference was found between values of Ra using wiper inserts under dry and wet cooling modes when turning 6060 Aluminium alloy.

Keywords**—**6060 Aluminium alloy, conventional and wiper carbide tools, dry turning, average surface roughness.

I. Introduction

THE application of advanced aluminium alloys has become increasingly popular in recent decades, particularly in the aviation, automotive and marine industrial sectors. This is due to their superior mechanical properties such as power-to-weight ratio, tensile strength and stiffness, hardness, and corrosion resistance as well as technological features such as excellent castability and the low-cost of manufacturing processes [1], [2].

Most aluminium alloys can be machined with or without cutting fluids and less cutting power is required. However, some aluminium alloys, and especially those containing magnesium, need to be supplied with cutting fluid during machining since they ignite easily. The contemporary machining industry has made significant advances in cutting tool technology, and new cutting tool materials and designs have been introduced to meet the demands of machining applications. Good surface quality is crucial and one of the key outputs in machining operations due to the increasing demand for higher performance and reliability and longer-lasting machined components. Several factors influence surface quality during a turning operation. The size of the cutting tool's corner radius and feed rate are the two most critical variables. In conventional inserts, the radius of the cutting tool nose is standardised so that there is one radius on the cutting edge. This leaves peaks and pits on machined surfaces and, to overcome this issue, wiper inserts have recently been introduced. These provide a multi-radius geometry which has led to the improved surface quality of machined parts [3]. Wiper inserts have been successfully employed for high-speed turning operations [4] where, as mentioned above, the key factors that influence surface quality are feed rate and the cutting tool's nose radius [5]. It is axiomatic that an insert with a conventional round-nose geometry reduces the productivity of the turning process. This is because the higher limit of feed rates is controlled by the nose geometry, and applying a high feed rate results in poor surface quality [6]. Fig. 1 shows the cutting mechanisms involved when using conventional and wiper inserts.

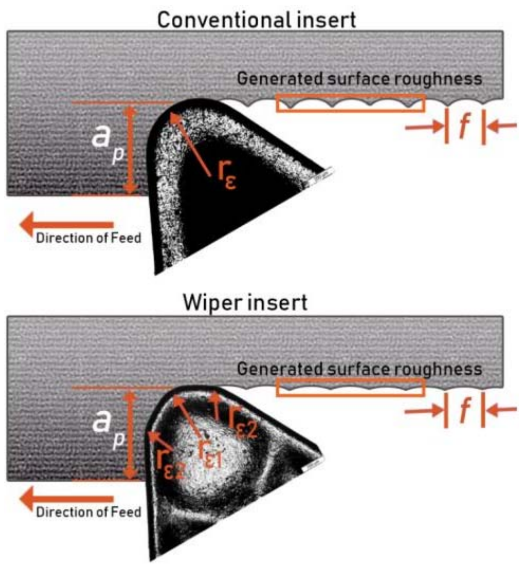

Fig. 1 Cutting mechanisms of conventional and wiper inserts [6]

A number of researchers have compared the cutting performance of wiper and conventional inserts in terms of surface quality based on experimental work. Raykar et al. [7]

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benchmarked the performance of wiper inserts against conventional ones when hard turning oil-hardening non-shrinking steel. A superior surface finish was obtained when a wiper insert was used at the optimal cutting conditions of 1200 rpm cutting speed, 1.2 mm nose radius, 0.1 mm depth of cut, and 0.08 mm/rev. feed rate. It was found that feed rate was the most significant parameter for surface roughness followed by the depth of cut and type of insert. In a study by Elbah et al. [8], a comparative assessment was performed of the effect of wiper and conventional ceramic tools on surface roughness during the hard-turning of AISI 4140 steel. Wiper inserts achieved a good surface finish at a higher-than-normal feed rate and the surface quality obtained with the wiper ceramic inserts was significantly improved 2.5-fold when compared with conventional ceramic inserts. Davim et al. [9] machined AISI 1045 carbon steel at selected machining conditions and reported the level of surface roughness (Ra) was a function of feed rate and cutting speed for different cutting tool radii (0.4 and 0.8 mm) and insert type (conventional or wiper). It was observed that the values of Ra with wiper inserts were lower compared to those for conventional inserts. A study by Guddat et al. [10] examined surface roughness using a polycrystalline cubic boron nitride (PCBN) wiper insert in the turning of AISI 52100 material. They found that high surface quality could be attained at lower feed rates. Meanwhile, Zhang et al. [11] investigated the cutting performance of wiper and conventional inserts in terms of surface integrity when turning Ti-6Al-4V alloy. The results showed that better surface topography was obtained in finish turning with a wiper insert than that with a conventional insert. The burnishing effect of the wiper insert led to a decrease in Ra by 50%. Grzesik et al. [12] reported that the machined surfaces produced by wiper inserts contain blunt peaks with distinctly smaller slopes when compared to those with conventional inserts when hard turning quenched alloy steel. Davim et al. [13] performed comparative evaluations of conventional and wiper inserts in the turning of AISI D2 steel. The results indicated that the use of wiper inserts at optimal cutting conditions produced lower values of surface roughness ($Ra < 0.5$ μm) compared to those for conventional inserts ($Ra < 0.8$ μm). At the same optimal cutting conditions, high dimensional accuracy ($IT < 7$) was achieved without the necessity for cylindrical grinding. Noordin et al. [14] examined the effect of cutting parameters on surface integrity using wiper-coated carbide inserts when machining stainless steel. They found that the wiper's radius allows the cutting tool to remove more material, leading to the lowering of the peak-to-valley roughness of the machined surface. Another investigation by Horváth et al. [1] studied the impact of wiper and conventional inserts on surface quality when high-speed turning two types of aluminium alloys (AS12 eutectic alloy, and AS17 hyper-eutectic alloy) at different cutting conditions. The use of wiper inserts led to notable decreases in values of surface roughness compared with conventional inserts of 30% in the case of the AS12 and 38% for AS17 aluminium alloys at the optimal cutting condition of 2000 m/min cutting speed, 0.158 mm/rev feed rate and 0.42 mm depth of cut.

According to the aforementioned literature, it is clear that numerous studies have demonstrated the benefits of wiper tools as an alternative to traditional inserts in achieving superior surface quality [6]-[10]. However, insufficient attention has been paid to performance in terms of resulting surface quality under different cutting conditions when using wiper inserts rather than conventional tools to cut aluminium alloys. In this context, the aim of the present work is to investigate the effect of conventional and wiper carbide tools on surface roughness when rough turning 6060 aluminium alloy under dry cooling mode. Following this introduction, the remainder of the paper is organised as follows. The design of experiment (DoE) is explained and then the experimental work is described, including the sample shapes, material and composition, insert geometries, and measurement equipment used. The experimental results are subsequently presented and discussed, followed by the findings of a statistical analysis using AOM and ANOVA to investigate the interaction effects of the process parameters. Finally, conclusions are drawn based on the findings.

II. Design of Experiment

A Taguchi (L9 array) experimental design was used in this study. Table I shows the control factors and corresponding levels. The AOM and ANOVA using Minitab 19 software were performed to determine the influence of the process parameters on the response variable of Ra when turning 6060 Aluminium alloy under dry cooling mode.

TABLE I
Control Factors and Corresponding Levels

Factor	Level 1	Level 2	Level 3	Level 4
Cutting speed (rpm)	1000	1200		
Feed rate (mm/rev)	0.1	0.15	0.2	0.25
Depth of cut (mm)	0.5	1.0		
Tool or insert type	Conventional	Wiper		

III. Experimental Work

All experiments were conducted on a Computer Numerical Control (CNC) turning machining centre (Pinacho MUSTANG 225) equipped with the GE Fanuc 21i-T series controller and a spindle power and speed of 12 kW and 3000 rpm respectively. Samples of 6060 Aluminium alloy were 35 mm in diameter, 150 mm long, and mounted between the spindle chuck and centre as shown in Fig. 2. The chemical composition of the 6060 Aluminium alloy is shown in Table II. Each test had a cutting length of 120 mm and a new tool insert was used. WALTER conventional (MP5 WPP20S) and wiper (FW5 WPP20S) coated chemical vapour deposition (CVD) TiCN + Al_2O_3 + (TiCN) carbide tools were used in this work. Both conventional and wiper inserts have a similar rhombic shape, and ISO designation (CNMG120408). All tools had the following cutting tip oblique geometries; nose radius $r\varepsilon = 0.8$ mm, rake angle $\gamma = -6°$, cutting edge angle $Kr = 95°$, clearance angle $\alpha = 0$, an inclination (oblique) angle $\lambda s = -6°$, and tool point (included) angle $\varepsilon = 80°$. The inserts were mounted on a Sandvik tool holder with the ISO designation DCLNR 2020M12. Fig. 3 shows images of the conventional and wiper inserts used in the trials, while Fig. 4 shows the machined 6060 Aluminium alloy.

TABLE II
CHEMICAL COMPOSITION OF SUPPLIED 6060 ALUMINIUM ALLOY

Weight (%)	Al	Fe	Si	Mg	Mn	Zn	Cu	Ti
Min	97.9	0.1	0.3	0.35	0.0	0.0	0.0	0.0
Max	99.3	0.3	0.6	0.6	0.1	0.15	0.1	0.1

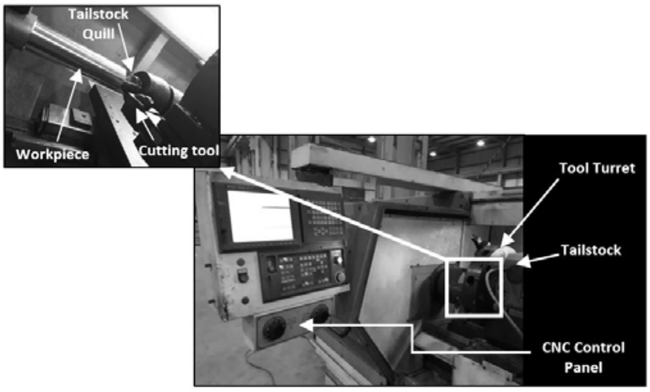

Fig. 2 Experimental set-up for 6060 Aluminium alloy turning trials

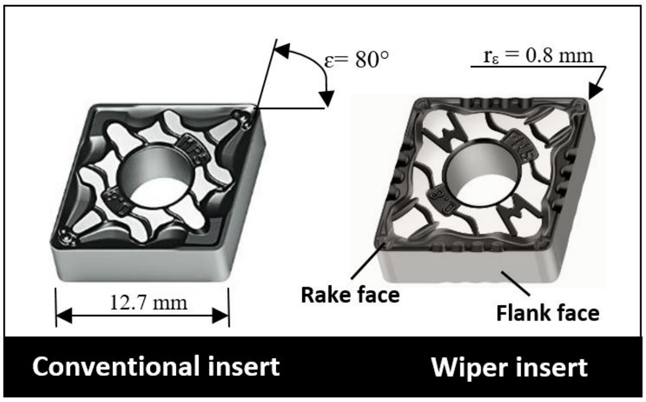

Fig. 3 Images of wiper and conventional tools used in the trials [15]

Fig. 4 Images of machined 6060 Aluminium alloy samples

IV. MEASUREMENT EQUIPMENT

The average surface roughness (Ra) of the machined bars was measured using a portable SRT- 6120 surface roughness tester as shown in Fig. 5. All Ra tests were conducted according to ISO 4287 and ISO 4288 and using a 0.8 mm cut-off and an evaluation length of 4 mm. Nine surface roughness readings were recorded for every sample at three different points and positions (120 degrees between each point at the beginning, middle and end of the cut). The Ra values presented in Table III are the averages of these 9 measurements. Images of the machined surfaces were captured using the B011 Supereyes digital optical microscope with a maximum magnification factor of 2000X.

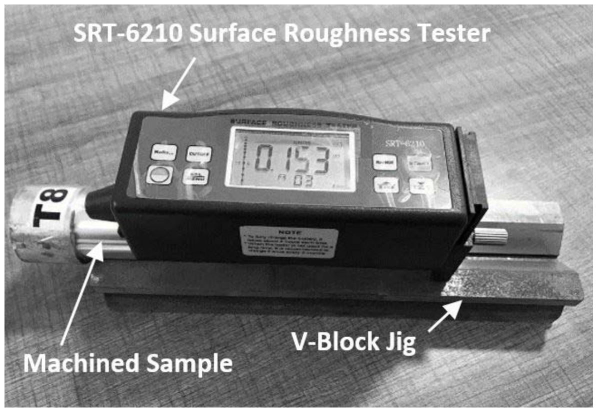

Fig. 5 Image of Ra measurement set-up used for the 6060 machined bars

V. RESULTS AND DISCUSSION

Table III presents the measured surface roughness (Ra) values for all the trials. In general, Ra values are in the range of 1.02-1.18 µm for wiper and 1.52-2.73 µm for conventional tools. Obviously, wiper inserts outperformed conventional tools in all machining trials, where the Ra values obtained by wiper inserts are almost 50% less than conventional tools. This could be attributed to the unique insert tip geometry of the wiper tool that helps to improve the surface quality of the machined samples. These findings coincide with those of a recent study by Horváth et al. [1] when turning AS12 and AS 17 aluminium alloys using wiper inserts. Additionally, the range of surface roughness values attained through standard machining operations on aluminium alloys for critical engineering applications such for the aerospace and automotive sectors is ≤ 1.6 µm, and all of the measured values using wiper inserts are within these limits [2]. Fig. 6 shows the AOM for the Ra results. According to AOM, the optimal surface finish can be achieved at a cutting speed of 1200 rpm, feed rate of 0.1 rev/mm, and depth of cut of 1 mm with a wiper cutting tool. It is clear that the values of Ra for the machined bars decrease with increased cutting speed. This is due to the fact that a higher spindle speed is associated with a higher cutting temperature which increases the softening of the workpiece material and then reduces the cutting forces; hence leading to a better surface finish. On other hand, values of Ra declined in an irregular pattern with lower feed rates, and this is in accordance with the theory that Ra is directly proportional to the square of the feed per revolution [16]. In addition, according to the ANOVA analysis shown in Table IV, the main factor contributing to Ra is cutting tool type, which has a high PCR value of 67.41%, followed by feed rate (12.13%). This confirms that tool type is the most significant factor affecting the surface finish, whereas cutting speed and depth of cut have a lower impact on Ra when turning 6060 Aluminium alloy. An error level of approximately 16.61% associated with the Ra evaluation was recorded, which is within acceptable error levels of up to 20%. This suggests that all of the important variables had been considered and the measurements were accurately performed. Fig. 7 shows optical images of the machined surfaces obtained for conventional and wiper inserts at a cutting speed of 1000 rpm and 0.5 mm depth of cut.

TABLE III
CONTROL FACTORS WITH MEASURED VALUES OF THE Ra

RUN	Feed rate (f) rev/min	Speed (N), rpm	Tool Type	DOC (a_p) mm	Ra (μm)
1	0.25	1000	Conventional	0. 5	2.73
2	0.25	1200	Wiper	1	1.04
3	0.2	1000	Conventional	1	1.52
4	0.2	1200	Wiper	0. 5	1.11
5	0.15	1000	Wiper	0. 5	1.02
6	0.15	1200	Conventional	1	2.07
7	0.1	1000	Wiper	1	1.18
8	0.1	1200	Conventional	0. 5	1.81
9	0.1	1200	Wiper	0.5	0.92

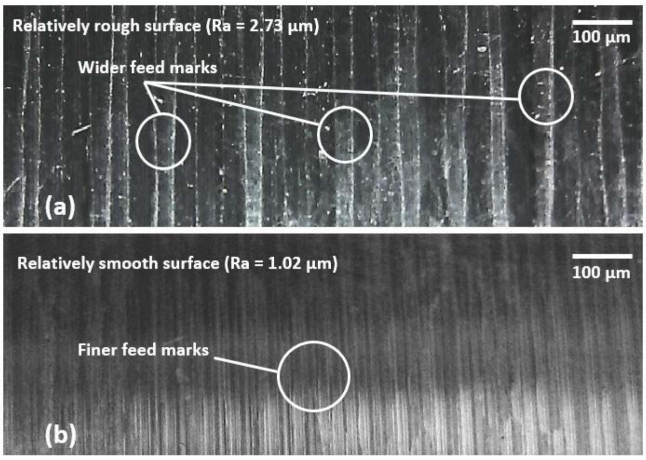

Fig. 7 Images of machined surface obtained at 1000 rpm cutting speed and 0.5 mm depth of cut for: (a) conventional insert (b) wiper insert

Fig. 8 shows the interaction effects on Ra of all factors evaluated. It can be seen that there are noticeable mutual interactions among all of the factors investigated, particularly cutting speed, feed rate and depth of cut. However, those factors have a low degree of interaction with insert type, especially when using a wiper insert. In addition, the parallel trends of the lines also suggest that there is no interaction between insert type and the other factors of cutting speed, feed rate and depth of cut. This is in line with the AOM results, which indicate that the insert type has a higher effect on Ra than other factors.

Table V shows the values of Ra recorded at the optimal cutting conditions of a cutting speed of 1200 rpm, feed rate of 0.1 mm/rev and 1 mm depth of cut using wiper inserts under dry and wet cooling modes. It was noted that there are no substantial differences in Ra values between the two cooling modes. This could be attributed to the better cutting performance of the wiper insert owing to its superior coating characteristics with TiCN, Al_2O_3 and TiCN. These multi-layered coatings have lower friction coefficients, which help to hinder friction during the cutting process, even without cooling, producing better surface quality.

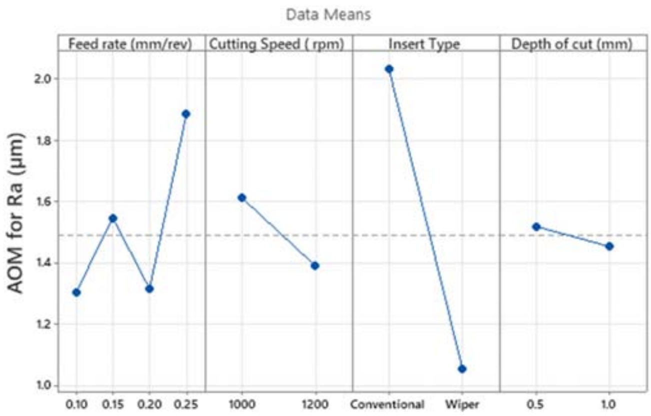

Fig. 6 AOM for average surface roughness (Ra)

TABLE IV
ANOVA RESULTS FOR AVERAGE SURFACE ROUGHNESS (Ra)

Source	DF	SS	MSS	F	P	PCR
Feed rate (mm/rev)	3	0.35997	0.11999	0.64	0.657	12.13%
Cutting speed (rpm)	1	0.0340	0.03402	0.18	0.711	1.14 %
Insert type	1	1.9996	1.99962	10.68	0.082*	67.41%
Depth of cut (mm)	1	0.0806	0.08065	0.43	0.579	2.71%
Error	2	0.37448	0.18724			16.61%
Total	8	2.96609				
S= 0.4327 R-Sq = 87.37% R-Sq (adj) = 49.50%						

DF = Degrees of freedom; SS = Sum of squares; F = F-test value; * Significant at the 5% level with a confidence level of 95%; P = Probability

TABLE V
RA RESULTS AT OPTIMAL CONDITIONS UNDER DRY AND WET COOLING MODES

Cooling mode	Ra (μm)
Dry cooling (without coolant)	0.92
Wet cooling (with coolant)	0.90

VI. CONCLUSION

From the experimental findings, the following major conclusions can be summarised as follows:

1) Wiper inserts produced better surface quality compared with conventional inserts, with a dramatic drop in Ra values by 50% when dry turning 6060 Aluminium alloy.
2) Cutting tool or insert type was the most significant factor affecting Ra, with a PCR value of 67.41%, followed by feed rate at 12.31%.
3) Optimal cutting conditions were achieved using wiper inserts at a cutting speed of 1200 rpm, feed rate of 0.1 rev/mm and a depth of cut of 1 mm.
4) A noticeable mutual interaction was observed between all of the factors investigated (cutting speed, feed rate and depth of cut) except for the type of cutting tool used.
5) No significant difference was found between Ra values using wiper inserts under dry and wet cooling modes, and

this will be very beneficial to manufacturers since they can use the wiper inserts without cutting fluid when machining 6060 Aluminium alloy.

The present work will certainly be helpful for researchers, manufacturers, and academics in promoting machining research work on wiper tools, particularly when cutting aluminium, hard metals and super alloys or using it instead of a grinding process. Furthermore, the current work may be extended to consider the analysis of tool wear, cutting temperature and chip morphology when rough turning 6060 Aluminium alloy using wiper inserts under dry cooling mode.

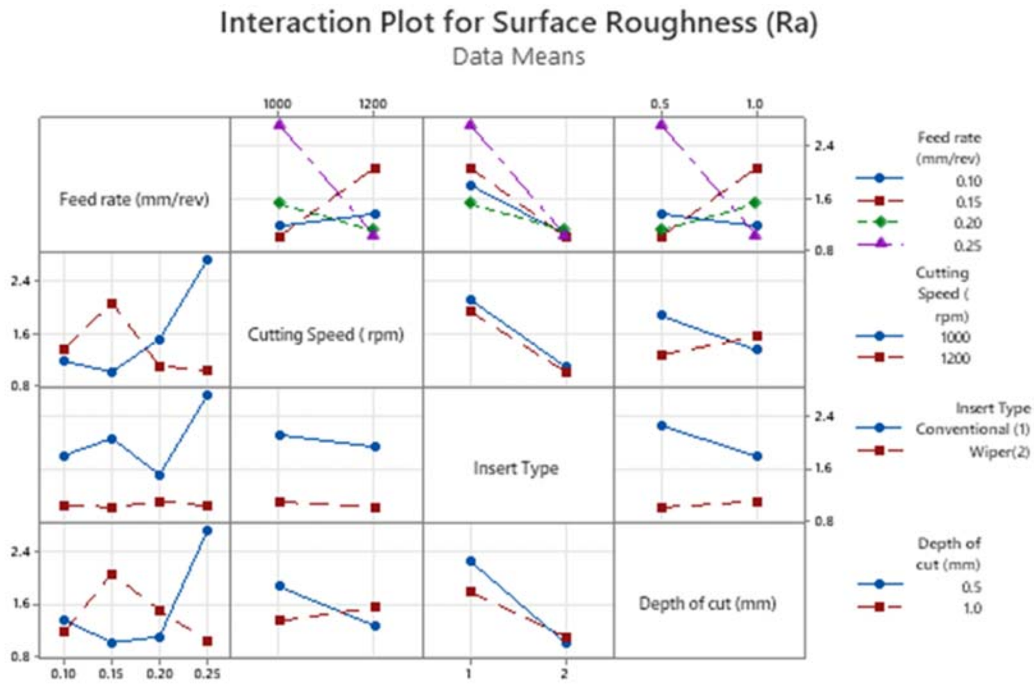

Fig. 8 Interaction effects of process parameters on average surface roughness (Ra)

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