

## **EFFECT OF THE TURNING INSERT SHAPE AND FEED ON THE SURFACE PROFILE**

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**Abstract.** *This study investigates the combined effect of cutting insert geometry and feed rate on surface roughness in turning of 42CrMo4 alloy steel. Controlled experiments were conducted on a CNC lathe using three insert geometries (C, D, and V types) and three feed rates (0.15, 0.25, and 0.35 mm/rev), while maintaining constant cutting speed and depth of cut. Surface characteristics were evaluated through quantitative roughness measurements and qualitative microscopic analysis. The results demonstrate that feed rate is the dominant factor influencing surface roughness, with increasing feed leading to a significant deterioration in surface quality, as reflected by higher  $R_z$  and  $R_t$  values. Insert geometry also plays a critical role: C and D inserts produce consistently lower roughness values, whereas the V insert results in inferior surface quality under identical cutting conditions. Notably, despite identical nose radii, substantial differences were observed between C and V inserts, highlighting the pronounced influence of edge geometry, particularly the end cutting edge angle. The findings indicate that conventional geometric models based solely on feed and nose radius are insufficient to accurately predict surface roughness. Instead, insert shape parameters must also be considered. This study contributes to improved understanding of the interaction between tool geometry and machining parameters and provides practical guidance for optimizing surface quality in turning operations.*

**Keywords:** *surface profile; turning; insert shape; feed; surface roughness; main effect plot.*

### **1. Introduction**

Machining is a process used to create a part or shape with precise dimensions and tolerances [1]. Surface roughness plays a crucial role in determining the quality of the product [2], as it directly impacts the product's performance during use. The quality of the surface significantly enhances properties such as fatigue strength, corrosion resistance, and creep life [3]. With the increasing demand for improved surface quality, especially in industries like automotive, aerospace, and die and mould manufacturing, achieving a smooth surface finish is essential. Surface roughness is typically measured by a specific value, where a higher value indicates a rougher surface and a shorter fatigue life. Therefore, it's important to clearly specify the required surface roughness in designs to ensure the machining process is appropriately adjusted to meet these standards [4].

Achieving an ideal surface finish in machining remains a significant challenge due to the complex and interdependent interactions between the cutting tool, the workpiece material, and the machining environment. Several factors contribute to surface imperfections, including the formation of a built-up edge (BUE) [5], which alters the effective geometry of the cutting tool; surface damage caused by chips curling back and impacting the freshly machined surface; tearing during chip formation in ductile materials; and surface cracks resulting from discontinuous chip formation in brittle materials [8]. Friction between the tool's flank and the workpiece further degrades the surface finish. Beyond these, key machining parameters - such as feed rate, cutting speed, and depth of cut - along with the process kinematics, cutting tool geometry and material, mechanical properties of the workpiece, and dynamic issues like machine vibrations and tool deflection, play crucial roles. The precision, rigidity, and overall condition of the machine tool itself also significantly influence surface quality [6,7].

Surface roughness measurement is essential for evaluating the quality and performance of machined components, as it directly affects factors like friction, wear, fatigue strength, and sealing capability [8]. Depending on the required accuracy, surface type, and application, different measurement techniques are used. Contact methods, such as stylus profilometers, are widely adopted for their reliability and standardized outputs, while non-contact optical methods, like interferometry and confocal microscopy, offer high-resolution analysis without risking surface damage. Advanced techniques like atomic force microscopy enable nanoscale assessments, although they are limited to small areas and specialized applications. Selecting the appropriate method depends on balancing precision needs, surface characteristics, and practical constraints such as speed and cost [9,10].

Predicting surface roughness in machining is critical for ensuring product quality and process optimization. Multiple approaches have been developed, each leveraging different principles, tools, and technologies. Below are five key approaches to surface roughness prediction, along with expanded explanations [11,12]:

- Approaches that are based on machining theory to develop analytical models and computer algorithms to represent the machined surface,
- Approaches that examine the effects of various factors through the execution of experiments and the analysis of the results,
- Approaches that use designed experiments,
- Artificial intelligence (AI) approaches,
- Surface roughness characterization by using image processing.

Numerous roughness parameters have been developed to describe surface textures. These parameters describe different characteristics of surface roughness, so

we can choose the parameter most suitable for describing the surface, knowing the purpose under investigation [13]. Whitehouse proposed an approximation technique to estimate the maximum peak-to-valley roughness ( $R_t$ ) and the arithmetic average roughness ( $R_a$ ) for surfaces generated using a circular tool nose. Similarly, Vajpayee provided an approximation for estimating  $R_t$  for surfaces created with a circular tool nose. Qu and Shih formulated mathematical models to predict  $R_t$ ,  $R_a$ , and root-mean-square roughness ( $R_q$ ) for ideal tool nose shapes composed of elliptical and circular arcs, using both implicit and approximation methods. Their work is further analysed and compared to the digital simulation method introduced in this study [14].

The aim of this research is to investigate the influence of insert geometry and feed rate on surface roughness during the turning process. The study focuses on analysing how different insert shapes affect the quality of the machined surface under three different feed conditions.

## **2. Material and methods**

The experiment was carried out using a CNC turning on a Euroturn 12B CNC turning machine. The workpiece material used was 42CrMo4 (1.7225) alloy steel, which is commonly used for high-strength mechanical components and an often used reference test material in cutting experiments.

Each test was performed under the same machining conditions except for the feed rate, allowing a comparison of the machining behaviour and surface characteristics produced during the CNC turning process. Three specimens were machined with three tools, and each test part contain 3 separate surfaces (Figure 1). The cylindrical workpiece had a diameter ( $D$ ) of 34 mm and a length ( $L$ ) of 30 mm. During the turning operation, a constant cutting speed ( $v_c$ ) of 120 m/min and a depth of cut ( $a_p$ ) of 0.5 mm were maintained throughout the experiment. To investigate the influence of feed rate on the machining process, three different feed values were applied: 0.15 mm/rev, 0.25 mm/rev, and 0.35 mm/rev.



Figure 1 - Turned specimens.

Three different cutting insert and tool-holder combinations were used during the CNC turning experiments to evaluate their influence on the machining

performance and surface quality of the workpiece. The inserts were manufactured by Sandvik Coromant and TaeguTec (Table 1, Figure 1), which are widely recognized suppliers of cutting tools for metal machining applications.

Table 1. Data of three turning tools.

Insert	KAPR	SIG	ECEA	RE
CCMT 09T304-PM4225 (Sandvik)	95	80	5	0.4
DCMT 11T308 FG TT8125 (TaeguTec)	93	55	32	0.8
VBMT 110204-UF4315 (Sandvik)	93	35	52	0.4

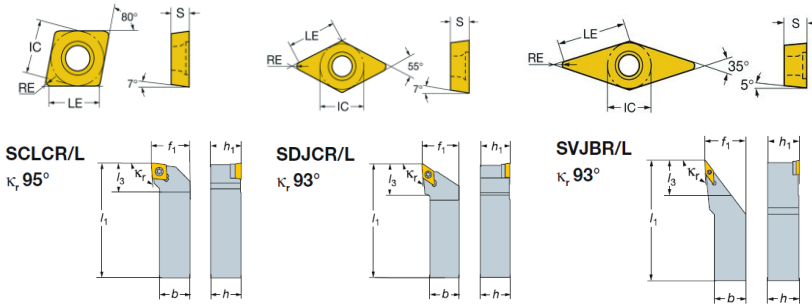


Figure 2 - Cutting insert geometries and tool holder configurations.

The first cutting tool used was the CCMT 09T304-PM4225 insert mounted on an SCLCR 1616 H9 tool holder (Figure 2). This tool configuration has a tool cutting edge angle (KAPR) of 95°, a clearance angle (SIG) of 80°, an end cutting edge angle (ECEA) of 5°, and a nose radius (RE) of 0.4 mm. This geometry is typically used for stable turning operations and is suitable for medium machining conditions due to its balanced cutting forces and good chip control.

The second tool consisted of a DCMT 11T308 FG TT8125 insert mounted on an SDJCR 1616 H11 tool holder, produced by TaeguTec. This configuration has a KAPR of 93°, SIG of 55°, ECEA of 32°, and a nose radius of 0.8 mm. The larger nose radius can improve surface finish and distribute cutting loads more evenly, which may reduce tool wear during machining.

The third tool used in the experiment was the VBMT 110204-UF4315 insert mounted on an SVJBR 1616 H11 tool holder, produced by Sandvik. This tool also has a KAPR of 93°, but with SIG of 35°, ECEA of 52°, and a nose radius of 0.4 mm. The sharper geometry and smaller nose radius make this insert suitable for finishing operations and precision machining where lower cutting forces and improved surface quality are required. The larger end cutting edge angle (ECEA) ensures turning a steep undercutted feature.

The use of these three different tool geometries allowed the investigation of how insert shape, cutting edge angle, and nose radius affect the machining process, tool performance, and the resulting surface characteristics of the turned specimen.

Surface roughness of the machined surfaces were measured after the turning process. Surface roughness measurements were carried out using a Mitutoyo SJ-301 Surface Roughness Tester (Figure 3). The instrument was used to determine the roughness parameters of the machined surfaces. Each surface was measured ten times, so the analysis was performed based on 90 data sets.

Three surface roughness parameters were analysed:

- $R_z$  – Average Maximum Height of the Profile is the average of the successive values of  $R_{ti}$ .
- $R_t$  – Maximum Height of the Profile is the vertical distance between the highest and lowest points of the profile.
- $R_{sm}$  – Mean Spacing of Profile Irregularities is the mean value of the spacing between profile irregularities.

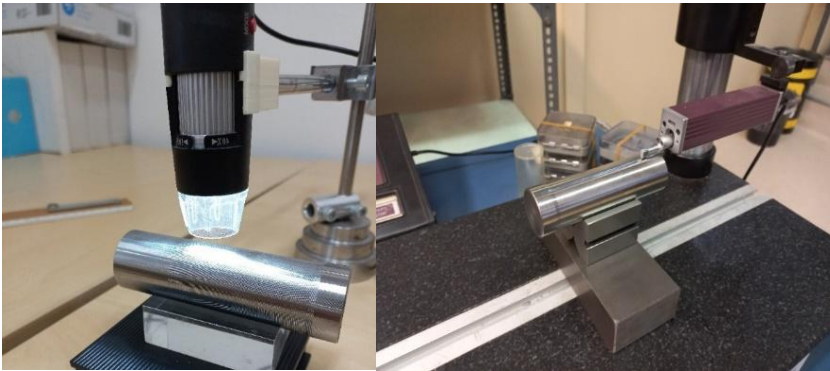


Figure 3 - Measurement and testing of the three machined specimens for surface roughness analysis: a) Digital microscope b) Mitutoyo SJ-301.

For the qualitative roughness measurements, the surface topography of the specimens was examined using a digital microscope (Figure 3). The microscope images allowed a detailed observation of the surface texture, feed marks, and machining patterns generated during the turning operation. The combination of the roughness measurements obtained from the surface tester and the visual analysis from the digital microscope provided a more precise evaluation of the surface quality of the machined specimens.

The data analysis was performed with Jamovi v2.6.44 and Minitab v22 software.

### 3. Results

The most significant results of the surface roughness measurements under different machining conditions are presented below. Figure 4 shows that at a feed rate of 0.15 mm/rev, the surface profiles exhibit low amplitude with shallow valleys, indicating smoother surfaces. At 0.25 mm/rev feed rate, the peaks become more noticeable and regularly spaced, showing a moderate increase in roughness. At 0.35 mm/rev feed rate, the profiles display high, sharp peaks and deeper valleys, indicating a significantly rougher surface. It can be observed that the surface profile produced with inserts C and D is similar for all three feeds.

This similarity can also be seen in the microscopic images (Figure 5). However, the V insert shows a significantly different profile and image. In case of small feed, the V insert produced more regular profile, than C and D.

Table 2 shows the mean values of the measured  $R_z$ ,  $R_t$  and  $R_{Sm}$  values as a function of the insert shape and feed. The values of  $R_z$  and  $R_t$  are almost the same. The V insert shows a substantially stronger sensitivity to feed rate, with  $R_z$  increasing by up to 254%, compared to 159–168% for C and D inserts. The values of  $R_{Sm}$  increased by 99%, 53% and 116% for the feed. The  $R_{Sm}$  mean value is highly correlated with the feed, no clear dependence on insert geometry can be identified.

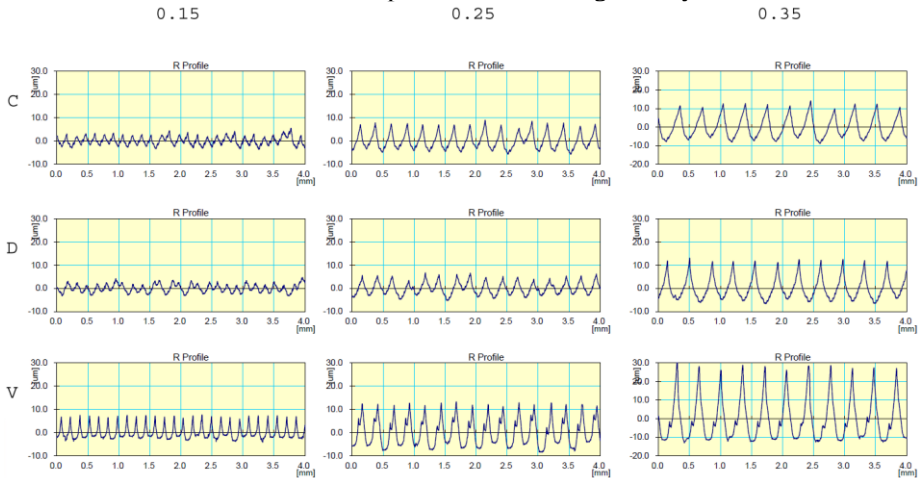


Figure 4 - One measurement results of surface profile.

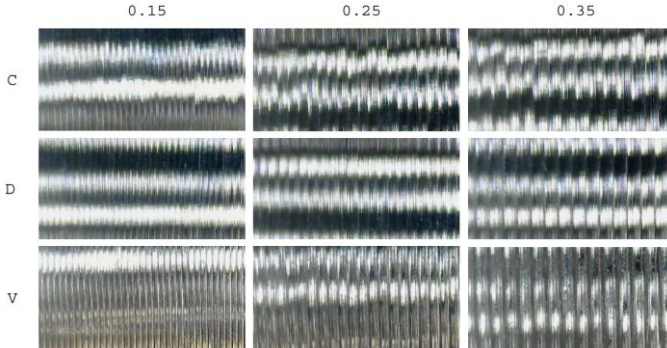


Figure 5 - Images of three inserts taken with a digital microscope.

Table 2. Mean value of  $R_z$ ,  $R_t$  and  $R_{Sm}$  parameters.

Insert	$f$	$R_z$	$R_t$	$R_{Sm}$
C	0.15	7.57	9.16	0.175
	0.25	14.20	15.60	0.269
	0.35	20.30	21.70	0.349
D	0.15	7.06	8.16	0.228
	0.25	10.50	11.70	0.277
	0.35	18.30	19.30	0.348
V	0.15	11.60	12.90	0.164
	0.25	21.00	22.90	0.262
	0.35	41.10	42.80	0.355

#### 4. Discussion

Three surface roughness parameters were selected from the results, because several of the parameters show high correlation. Based on the measured results presented in Figure 6, it can be concluded that both insert geometry and feed rate have influence on surface roughness parameters ( $R_z$ ,  $R_t$ , and  $R_{sm}$ ) during the turning process. The distributions clearly demonstrate that variations in feed rate (0.15, 0.25, and 0.35 mm/rev) lead to noticeable changes in roughness values across all insert types (C, D, and V).

As the feed rate increases, there is a general trend of increasing roughness values, particularly evident in  $R_z$  and  $R_t$  parameters, indicating a deterioration in surface quality. Lower feed rates produce more concentrated and stable distributions with smaller roughness values, which suggests better surface finish. In contrast, higher feed rates result in wider distributions and higher peaks, reflecting increased variability and roughness.

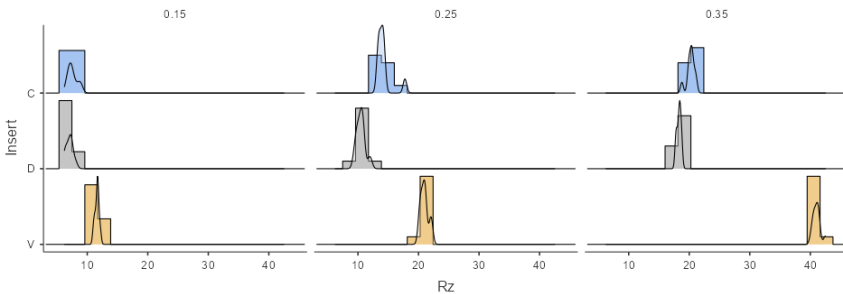
The effect of insert shape is also prominent. The V insert geometry tends to produce higher roughness values under similar cutting conditions, while C and D demonstrate more stable and lower roughness profiles. This indicates that insert geometry plays a crucial role in controlling surface characteristics.

Additionally, the  $R_{sm}$  parameter shows sensitivity to both feed rate and insert type, reflecting changes in the spacing of surface irregularities. This suggests that not only the height but also the pattern of surface texture is influenced by machining conditions.

Based on the geometric model of the theoretical surface roughness of the turning, the nose radius (RE) and the feed ( $f$ ) have influence on the surface roughness. Based on it, the C and V insert should be produces similar profile and surface roughness parameters because of the same RE. However, the more favorable ECEA angle of insert C in terms of surface roughness compensates for the unfavorable nose radius. Thus, the roughness of the surfaces created by inserts C and D is similar, while insert V with a large ECEA angle and a small tip radius shows much higher roughness results.

The statistical analyses of the measured data by Main Effect Plot (Figure 7) shows that feed rate has the strongest influence on surface roughness, which meet with the theory. As the feed rate increases,  $R_z$  and  $R_t$  values rise, leading to poorer surface quality, while lower feed rates ensure a smoother finish.

Insert geometry also plays an important role: C and D inserts produce lower roughness, whereas the V insert results in higher values. The analysis confirms the effect of the insert shape on the surface roughness, the average roughnesses for inserts C and D are almost the same, while the values for insert V are significantly higher. It can also be observed that the effect of the shape of insert C does not completely eliminate the difference, insert D with a larger nose radius provides better surface roughness.



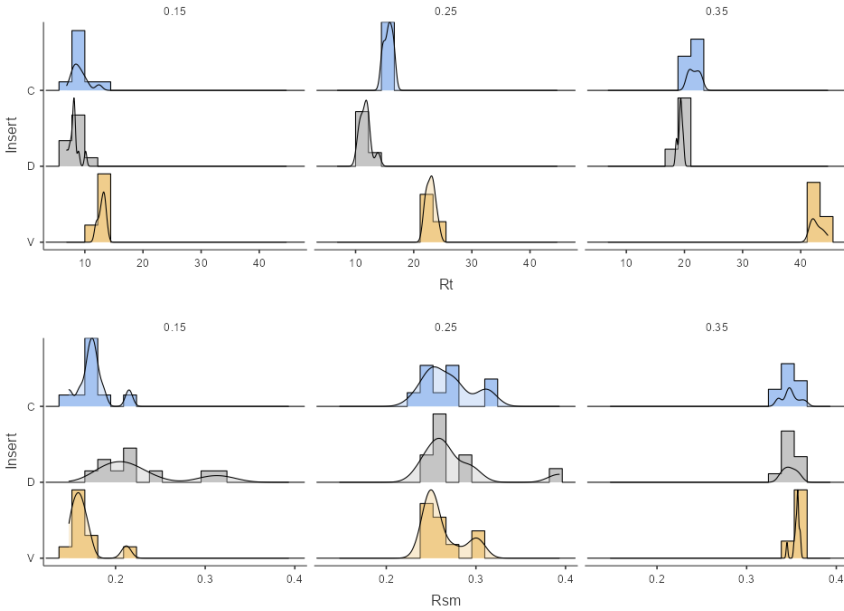
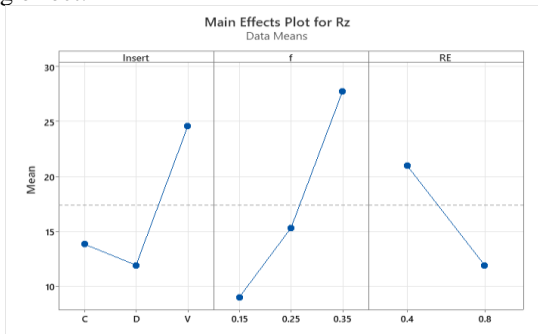


Figure 6 - The results of the measure.

The  $R_{sm}$  parameter in the feed direction shows a different pattern. Based on the measured data (Figure 6), the C and V inserts show a similar pattern, while the D insert has a significantly higher variance, especially at low feed rates.

The main effects plot shows the ratio of  $R_{sm}$  to feed, which is ideally 1. At higher feed rates, the  $R_{sm}$  parameter approaches the feed rate value. As can be seen, the C and V inserts with the same radius resulted in almost the same average value, which is also shown by the radius effect. In this case, the shape of the C insert has no compensating effect.



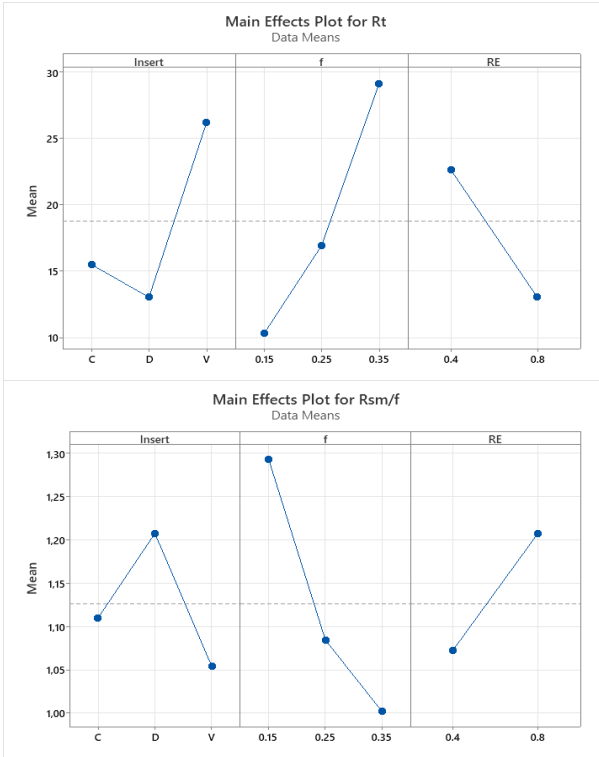


Figure 7 – Main effects plots for  $R_z$ ,  $R_t$  and  $R_{sm}$ .

Overall, the results confirm that optimal surface quality can be achieved by selecting appropriate insert geometry and maintaining lower feed rates. These findings provide a useful basis for improving machining performance, enhancing product quality, and optimizing cutting parameters in turning operations.

### 5. Summary

This study investigates the surface profile and roughness values of turned surfaces as a function of feed and insert geometry for 42CrMo4 steel alloy. Three insert geometries (C, D, V) were compared. Feed rate was found to be the dominant factor in terms of surface roughness of the turned surface, but edge geometry variations resulting from insert shape have significant secondary influence on surface roughness.

The future work of the research is to develop a roughness prediction model based on a geometric-kinematic model. The model, supplemented with statistical

elements, creates an equivalent replacement profile (ERP), which allows for the joint estimation of several roughness parameters. Based on the current results presented in the article, when designing the statistical model, not only the classical feed and nose radius parameters should be taken into account, but also the shape of the insert.

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## ВПЛИВ ФОРМИ РІЗАЛЬНОЇ ВСТАВКИ ТА ПОДАЧІ НА ПРОФІЛЬ ОБРОБЛЕНОЇ ПОВЕРХНІ

**Анотація.** Це дослідження вивчає сукупний вплив геометрії різальної вставки та величини подачі на шорсткість поверхні при токарній обробці легированої сталі 42CrMo4. Контрольовані експерименти проводилися на верстаті з ЧПУ з використанням трьох геометрій вставок (типи C, D і V) і трьох швидкостей подачі (0,15, 0,25 і 0,35 мм/оберт), зберігаючи постійну швидкість

різання та глибину різь. Характеристики поверхні оцінювалися за допомогою кількісних вимірювань шорсткості та якісного мікроскопічного аналізу. Результати показують, що швидкість подачі є домінуючим фактором, що впливає на шорсткість поверхні, а збільшення подачі призводить до значного погіршення якості поверхні, що відображається у вищих значеннях  $R_z$  і  $R_p$ . Геометрія вставки також відіграє критичну роль: вставки C і D дають стабільно нижчі значення шорсткості, тоді як V-вставка призводить до гіршої якості поверхні за однакових умов різання. Варто зазначити, що, незважаючи на ідентичні радіуси вершини, спостерігалися суттєві відмінності між вставками C і V, що підкреслює виражений вплив геометрії країв, особливо кута ріжучої крайки вершини. Результати свідчать, що звичайні геометричні моделі, засновані виключно на подачі та радіусі при вершині, недостатні для точного прогнозування шорсткості поверхні. Натомість слід враховувати параметри форми вставки. Це дослідження сприяє кращому розумінню взаємодії між геометрією інструмента та параметрами обробки та надає практичні рекомендації для оптимізації якості поверхні в токарних операціях. Майбутня робота дослідження полягає у розробці моделі прогнозування шорсткості на основі геометрично-кінематичної моделі. Модель, доповнена статистичними елементами, створює еквівалентний профіль заміни (ERP), що дозволяє спільно оцінювати кілька параметрів шорсткості. Виходячи з поточних результатів, представлених у статті, при розробці статистичної моделі слід враховувати не лише класичні параметри подачі та радіусу при вершині, а й форму вставки.

**Ключові слова:** профіль поверхні; точіння; форма вставки; подача; шорсткість поверхні; графік основного ефекту.