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A Comparative Study of the Performance of Uncoated, PVD, CVD and MTCVD Coated Carbide Inserts in Dry Turning of AISI4140 Steel

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Abstract

An experimental study has been carried out to investigate and compare the cutting tool performances represented by insert wear, surface roughness and cutting forces of an uncoated carbide (H13A) and three coated carbides GC2015 ($TiCN/Al_2O_3/TiN$), GC1015 (TiN) and GC4215 ($TiCN/Al_2O_3$) during the dry turning of AISI4140 steel. Turning was carried out during 5 minutes on cylindrical specimens (80 mm diameter and 400 mm cutting length) along with a depth of 0.5 mm, a feed rate of 0.08 mm/rev, and with a cutting speed of 350 m/min. The wear results show the effectiveness of both GC2015 and GC4215 cutting inserts where the flank wear rate of the monolayer insert (GC1015) reaches approximately 2 times that of the bilayer insert (GC4215) and 4-times that of the multilayer insert (GC2015), while insert H13A demonstrated the highest wear. Moreover, SEM analysis shows that abrasion, adhesion and chipping are the dominant wear mechanisms. The surface quality obtained with the coated GC2015 insert is found to be 1.38, 1.63 and 4.63 times better than those obtained with GC4215, GC1015 and H13A inserts respectively. Finally, the coated GC2015 (CVD) cutting insert is identified as the leading material in terms of cutting force as the results found show that the ratios are ($F_{t\text{-GC4215}}/F_{t\text{-GC2015}}$) = 1.05, ($F_{t\text{-GC1015}}/F_{t\text{-GC2015}}$) = 1.13 and ($F_{t\text{-H13A}}/F_{t\text{-GC2015}}$) = 1.77.

Keywords

turning, PVD/CVD/MTCVD coated carbides, AISI4140 steel, surface roughness, cutting forces, flank wear

1 Introduction

Steels Cutting of is a subject of great importance in industrial production whose implementation employs several types of cutting inserts such as cubic boron nitride, ceramic and carbide … etc. [1]. Despite the great development of the inserts, carbide cutting tools are still widely used in a large spectrum in diverse sectors of industry [2]. Several studies related to machining have underlined the importance of output parameters such as the surface roughness, the cutting forces and the tool wear in order to improve the quality of manufactured products and minimize manufacturing costs. Researches on this topic take into account several aspects such as the properties of cutting tools [3] along with the mechanical and chemical properties of the workpiece material [4].

For this purpose, Posti and Nieminen [5] investigated the impact of coating thickness on the lifespan of TiN-coated HSS cutting inserts experimentally. They found out that the thickness of the coating had a significant effect on the tool's performance i.e., the tool's life increased with the coating thickness. Bouchelaghem et al. [6] observed that abrasion was the most remarkable wear mechanism when turning AISI D3 with a CBN tool. Sahoo and Sahoo [7] concluded that the multilayer ($TiN/TiCN/Al_2O_3/TiN$) coated tool performed better, in terms of wear and surface roughness, than its uncoated counterpart and ($TiN/TiCN/Al_2O_3/ZrCN$) coated carbide. Furthermore, abrasion was found to be the main wear mechanism during turning of AISI 4340 tempered steel along with the

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observation of the phenomena of catastrophic failure and chipping when using uncoated carbide. Gaitonde et al. [8] performed an experimental study that investigates both the tool wear and surface roughness along with the cutting force when turning AISI D2 steel (59–61 HRC) using two ceramic cutting inserts (Wiper and conventional). They concluded that wear and surface roughness are reduced when using the wiper cutting insert, and that the conventional ceramic insert is more appropriate for reducing the cutting effort. Fnides et al. [9] examined both the surface roughness and cutting force during hard turning of X38CrMoV5-1 steel and Cakir et al. [10] concluded that the PVD cutting insert leads to lower roughness compared to CVD one in the case of AISI P20 steel (52–54 HRC) turning. Suresh et al. [11] used a multilayer CVD coating ($TiN/TiCN/Al_2O_3$) on a cemented carbide substrate during machining of AISI 4340 (48 HRC) steel. They observed that the main wear mechanism under all machining conditions was represented by abrasion. Elbah et al. [12] evaluated the surface roughness performance of two cutting inserts: (CC6050) ceramic and (CC6050WH) conventional reference wiper when turning AISI 4140 hardened steel (60 HRC). They identified the wiper cutting insert as achieving better surface quality. Yallese et al. [13] observed that the CBN cutting insert exhibits good wear resistance despite the aggressiveness of the 100Cr6 hardened steel. Bensouilah et al. [14] studied the influence of machining conditions on surface quality and cutting force components when turning AISI D3 hardened steel with two mixed ceramic inserts i.e., coated and uncoated. The results showed a better surface quality when using the coated ceramic insert. However, the uncoated insert was found useful in reducing the machining force. Thakur et al. [15] presented an experimental study to examine tool wear, surface roughness and cutting force during the turning of Incoloy 825 using three cutting inserts (CVD with $TiCN/Al_2O_3$, PVD with TiAlN/TiN and an uncoated tool). It was observed that the PVD-coated tool was more efficient than other tools mainly because of the coating properties. Das et al. [16] established the fact that abrasion is the main wear mechanism when using a CVD coated carbide insert ($TiN/TiCN/Al_2O_3/TiN$) during the hard turning of the AISI 4340 (49 HRC). Recently, Kumar et al. [17] examined the effects of three different grades of CBN inserts on cutting forces and surface roughness during hard turning of AISI H13 steel containing different levels of hardness (45 HRC, 50 HRC and 55 HRC). They showed that the surface roughness (R_a) decreases with the increase of the workpiece hardness while the tangential force (F_t) decreases with decreasing workpiece hardness. Laouissi et al. [18] concluded that the coated ceramic tool is better in terms of surface finish, cutting force and wear resistance compared to the uncoated ceramic tool in machining of grey cast iron EN-GJL-250. Keblouti et al. [19] observed that the abrasion and adhesion phenomena are the two main wear mechanisms encountered in turning AISI4140 steel using a coated carbide cutting insert. More recently, Chihaoui et al. [20] studied the performance of a TiN/PVD coated CBN7050 tool when turning grey cast iron EN-GJL250. They found out that the CBN tool proved its high performance by achieving a very good surface finish along with a relatively good wear resistance even when machining at fairly high cutting speeds. Laouissi et al. [21] conducted an experimental study on machining gray cast iron under MQL environment in order to estimate the performance of two cutting tools represented by coated ceramic and coated carbide in terms of surface roughness. The results revealed that the coated ceramic tool performs better than the coated carbide tool in terms of surface roughness whose recorded surface roughness values are less than 0.39 µm. Milan et al. [22] found out that adhesion and abrasion were the main tool wear mechanisms when milling the calcium-treated and untreated AISI P20 mold steel using triple-coated cemented carbide (TiN, TiCN and Al_2O_3). Kuntoğlu et al. [23] employed four optimization methods (Taguchi *S*/*N* ratio, RSM and nature-inspired algorithms, HBA and H-ABC) in order to derive the optimal solutions for both cutting forces and Material Removal Rate (MRR) in turning AISI 5140 steel.

The above review shows the growing importance of performing various investigations related to manufacturing as they lead to improving both productivity and quality of the needed machined parts. It is within this perspective that the present investigation has been carried out. Furthermore, the literature review accomplished leads to deduce that very few research works related to machining the low alloy steel (AISI 4140) using four carbides with different coatings along with a systematic evaluation of the output technological parameters have been carried out, and this is what essentially represents the originality of the present study. Its aim is to evaluate the performances of four carbide inserts represented by a coated carbide with a monolayer applied by PVD (TiN) along with two multilayers applied by CVD ($TiCN/Al_2O_3/TiN$) and by MTCVD ($TiCN/Al_2O_3$) and finally by an uncoated carbide tool.

The AISI 4140 steel dry turning was carried out following long term tests in order to estimate the output parameters represented by the flank wear (V_B and $V_{B\text{-max}}$), the components of the cutting force (F_a, F_r and F_t) and the surface roughness (R_a, R_z, R_q, and R_t).

2 Materials and methods

A parametric study intended for the comparison of the influence of the different grades of carbide inserts depicted above has been performed. Table 1 presents the cutting conditions for the parametric tests while Fig. 1 and Fig. 2 show the flank wear profile and the experimental procedure respectively.

Table 1 Cutting parameters of parametric tests

Cutting speed V_c (m/min)	350 m/min
Feed rate f (mm/tour)	0.08 mm/rev
Depth of cut a_p (mm)	0.5 mm
Machining time (min)	05 min

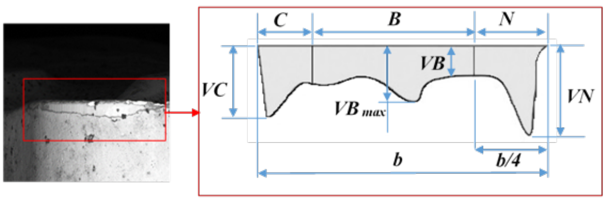


Fig. 1 Flank wear profile according to NF ISO 3685

2.1 Workpiece material

The workpiece material represented in Fig. 3 (a) are represented by 42CrMo4 (AISI 4140) steel round bars of 80 mm in diameter and 400 mm in cutting length. In order to minimize machining vibrations, a mixed mounting was used in the experiments. A Brinell hardness test was performed using the Universal Test Hardness UH930 shown in Fig. 3 (b), and the average value was found to be 284 HB. This material has been selected for its wide applications in automotive, crank shafts, connecting rods, pumps, gear shafts, spindles, tie rods and bolts requiring high strength [24]. The chemical composition of AISI 4140 steel was performed by a Spectrometer Oxford PMI-Master Pro like the one shown in Fig. 3 (c). The chemical composition along with the mechanical and physical properties of the workpiec material are presented in Table 2.

2.2 Cutting tool material/coatings

All the cutting inserts used were manufactured by Sandvik. The four types selected for machining the AISI 4140 steel (cf. Table 3) have identical cutting geometries, but different coating layers performed using different deposition methods. Each cutting insert was attached to the tool holder designated (PSBNR2525M12) whose geometry is described by $\chi r = 75°$, $\alpha = 6°$, $\gamma = -6°$ and $\lambda = -6°$.

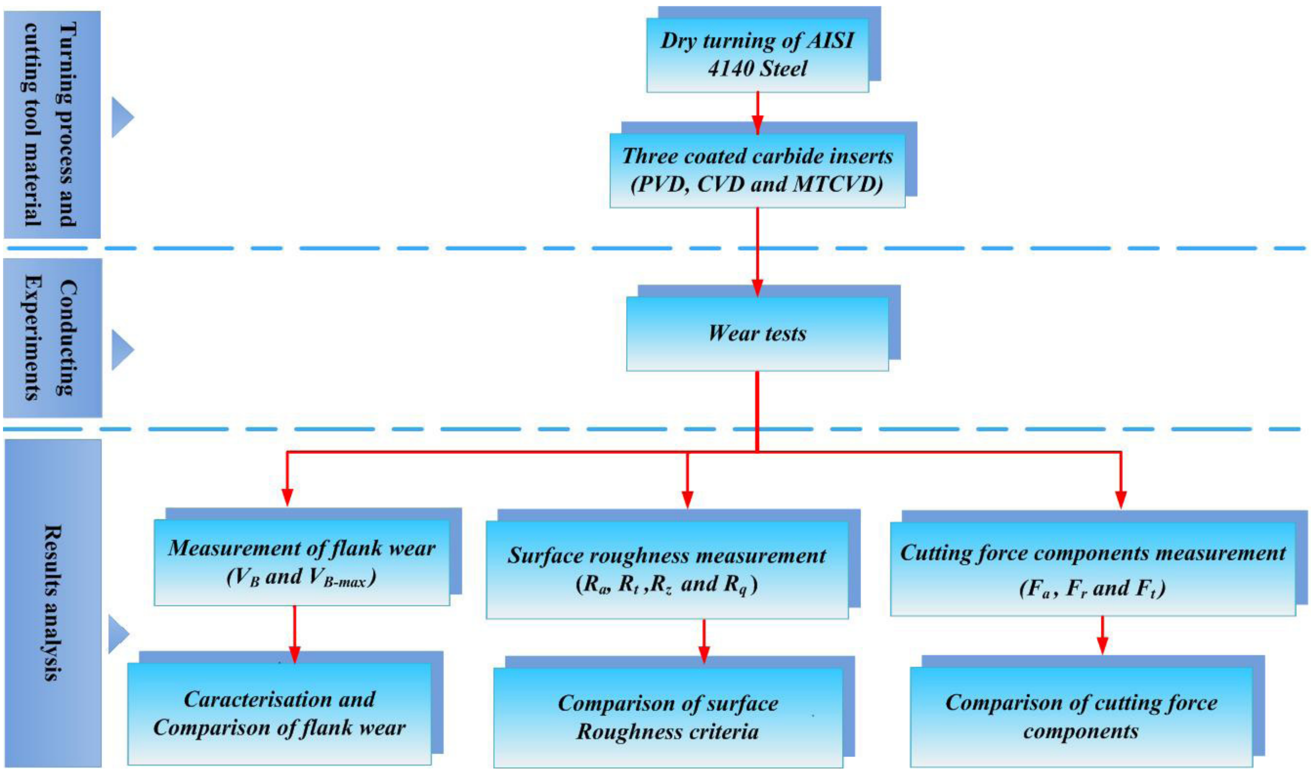


Fig. 2 Flow chart of the experimental procedure and data analysis

(a) (b) (c)

Fig. 3 (a) Specimens used, (b) Universal test hardness (UH930), (c) PMI master pro

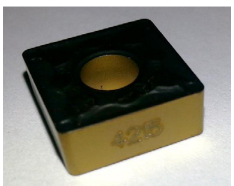
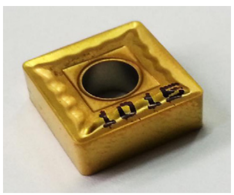
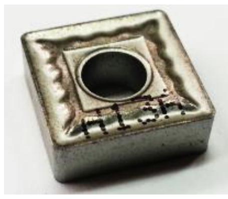
Table 2 Chemical composition and properties of the workpiece material

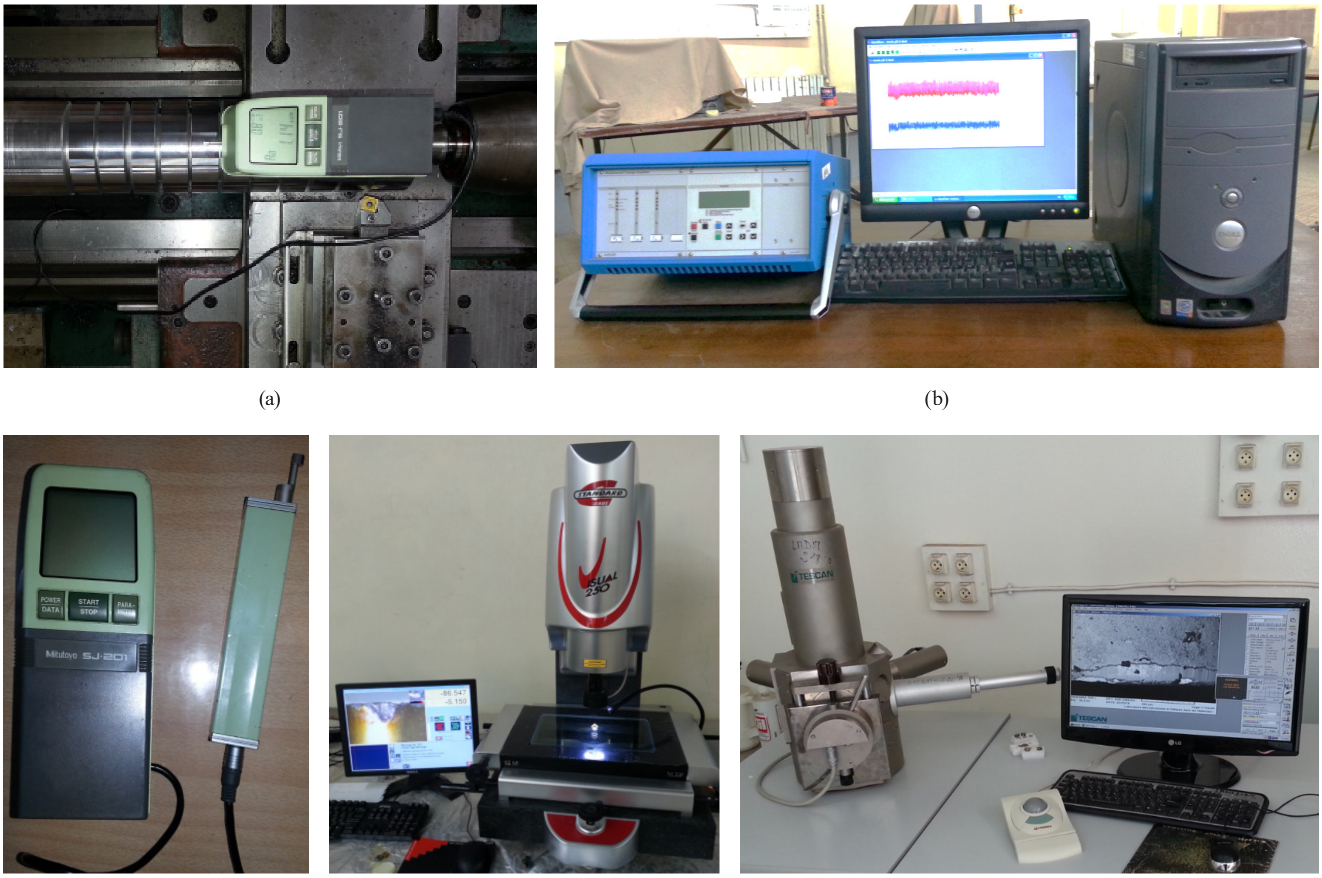
Properties	Specification					
Tensile strength	655 MPa					
Yield strength	415 MPa					
Density	7.85 g/cm^3					
Melting point	1416 °C					
Chemical composition	C	0.424	Mo	0.196	Cu	0.0377
	W	0.002	Si	0.297	Ti	0.0027
	Zr	0.006	Mn	0.841	Al	0.0151
	Pb	0.0166	Nb	0.003	Cr	0.997
	Co	0.0042	V	0.0020	Fe	rest

2.3 Machine tool and analysis equipment used

The experiments were carried out under dry conditions on a SN40C universal lathe machine that develops a spindle power of 6.6 kW and a maximum spindle speed of 2000 rpm. The surface roughness criteria (R_a, R_z, R_q and R_t) were measured at the completion of each test (after 05 minutes of machining) by a Mitutoyo Surftest-201 roughness meter along a length of 4 mm and a basic span of 0.8 mm. In order to achieve more accuracy, all the measurements were obtained directly on the machine i.e., without dismantling the workpiece from the lathe. The average value of three measurement results performed at equidistant locations at 120° around the circumference of the testes piece was used (Fig. 4 (c)). The cutting force components (F_a, F_r and F_t) were measured during the machining operations by a (Kistler 9257B) standard quartz dynamometer (Fig. 4 (a)) that supports measurements from −5 kN to 5 kN. The measurement setup includes a charge amplifier (Kistler 5019B130), a data acquisition system (A/D 2855A3) and a graphical programming facility (Dynoware 2825A1-1) for data analysis and visualization (Fig. 4 (b)). The acquired force signal was analyzed for a cutting time of 5 seconds and an acquisition speed of 500 Hz. At the end of each test, the used inserts are removed from the tool holder and examined with a microscope (Visual Gage 250) in order to measure the generated draft wear, this

Table 3 Characteristics of the cutting inserts used

Cutting tools	Coated carbide	Coated carbide	Coated carbide	Uncoated carbide
Manufacturer and code	Sandvik GC2015 (*T*1)	Sandvik GC4215 (*T*2)	Sandvik GC1015 (*T*3)	Sandvik H13A (*T*4)
Cutting insert photo				
Coating method	CVD	MTCVD	PVD	None
Coating material	TiN/Al_2O_3/TiCN	Al_2O_3/TiCN	TiN	None



(a) (b) (c) (d) (e)

Fig. 4 (a) Standard quartz dynamometer (Kistler 9257B), (b) Charge amplifier (Kistler 5019B130) and data acquisition system, (c) Mitutoyo Surftest-201, (d) Visual Gage 250, (e) SEM Tescan Vega TS-5130MM

microscope has a resolution of 752 × 582 pixels and a magnification starting at 0.7× and up to 4.5× (cf. Fig. 4 (d)). Finally, and as illustrated in Fig. 4 (e), the wear mechanisms of the worn inserts were examined using a Tescan Vega TS-5130MM Scanning Electron Microscope (SEM).

3 Results and discussion

3.1 Tool wear analysis

Various parameters are involved in the determination of he manufacturing costs of mechanical parts. Among them, the flank wear may be considered as the primary criterion affecting the lifespan of a cutting tool [25]. This led the authors to carry out a detailed analysis of the different morphologies of wear along with its rate wear mechanisms endured by the different inserts used.

Table 4 shows the experimental results in terms of surface roughness criteria (R_a, R_z, R_q and R_t), flank wear (V_B) along with its optimum ($V_{B\text{-max}}$) and finally the cutting force components (F_a, F_r and F_t) for the four cutting inserts used ($T1$), ($T2$), ($T3$) and the uncoated carbide ($T4$). The results were achieved at the completion of the experiments that lasted 5 minutes of turning time with a cutting speed of V_c = 350 m/min, a feed rate of f = 0.08 mm/rev and a depth of cut of a_p = 0.5 mm.

Fig. 5 represents the wear (V_B and $V_{B\text{-max}}$) for the four cutting tools investigated. It is clear that the two cutting

Table 4 Experimental results for (F_a, F_r and F_t), (R_a, R_z, R_q and R_t) and (V_B and $V_{B\text{-max}}$)

Tool materials	Machining forces			Surface roughness criteria				Flank wear	
	F_a (N)	F_r (N)	F_t (N)	R_a (µm)	R_z (µm)	R_q (µm)	R_t (µm)	V_B (mm)	$V_{B\text{-max}}$ (mm)
$T1$	85.76	124.44	135.24	0.44	3.04	0.57	3.19	0.069	0.105
$T2$	95.84	138.74	141.48	0.61	3.79	0.74	4.03	0.140	0.167
$T3$	106.8	151.12	152.83	0.72	4.41	0.89	5.51	0.306	0.378
$T4$	152.02	194.36	239.04	2.04	8.19	2.36	8.68	0.524	2.818

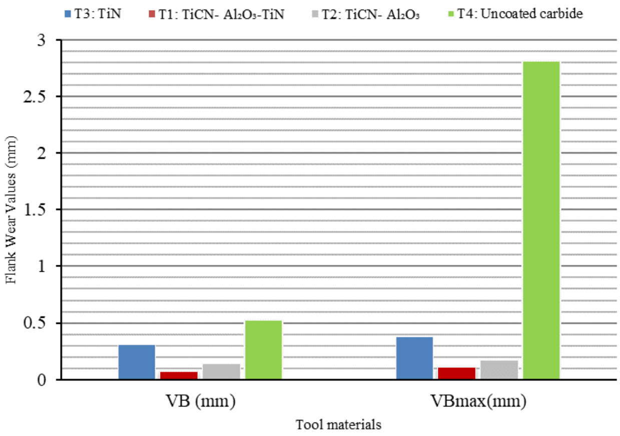
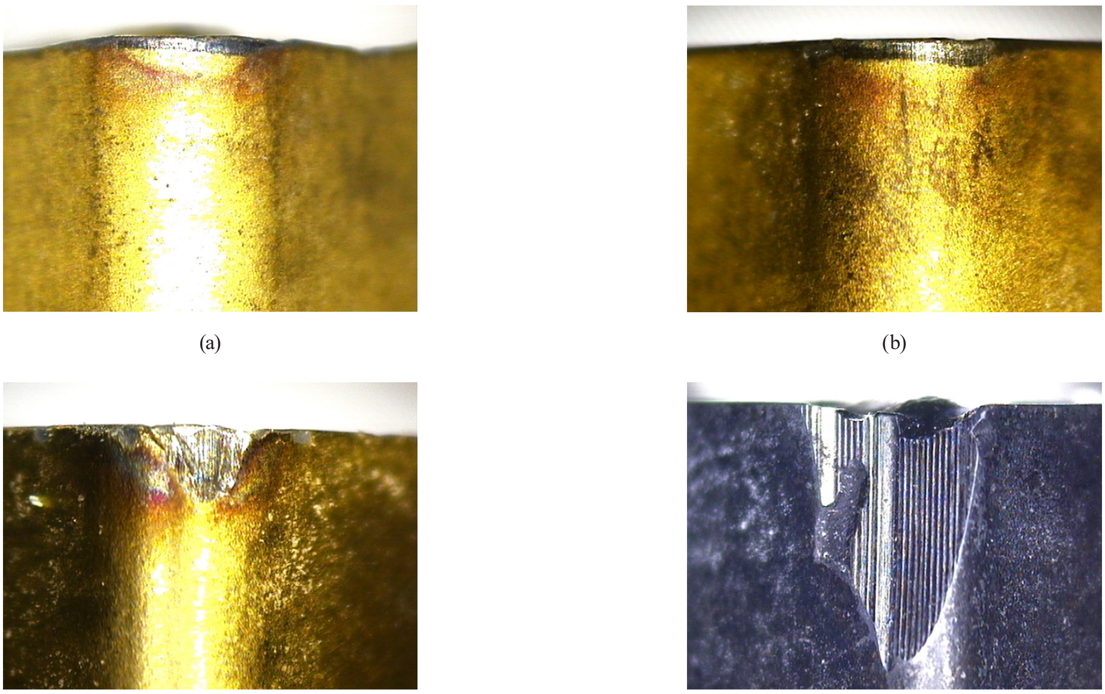


Fig. 5 Comparison between different inserts in terms of flank wear at $V_c = 350$ m/min, $f = 0.08$ mm/rev, $a_p = 0.5$ mm, after 5 min of turning

inserts ($T1$) and ($T2$) exhibit lower wear compared to inserts ($T3$) and ($T4$). The CVD insert ($T1$) demonstrates minimal wear. This difference is mainly due to the physical properties of the used coating materials, the presence of the (Al_2O_3) coating layer resulting in maximum protection against heat diffusion to the substrate. It also offers a maximum protection against wear by reducing the temperature in the cutting area [26, 27]. The bilayer coated (TiCN-Al_2O_3) insert shows a relatively lower wear resistance than the multilayer coated (TiN/Al_2O_3/TiCN) insert, the reason being the presence of the coating layer (TiCN). This coating applied by CVD technique employs medium deposition temperature and subsequently offers a better resistance to mechanical wear as well as a good adhesion to the substrate. The flank wear rate of the monolayer insert ($T3$) reaches approximately 2-times that of the bilayer insert ($T2$) and 4-times that of the multilayer insert ($T1$). This is attributed to the thermal properties of the (TiN) coating layer which facilitates heat diffusion to tool substrate and thus decreases the hardness of the (TiN) coating layer leading to an increased tool wear. The uncoated cutting insert ($T4$) exhibits the highest rate of flank face wear. This situation can be explained by the absence of protection as all the remaining inserts were coated.

The comparison in terms of wear ratio (V_B) clearly illustrates the quantitative difference between the inserts tested. The ratio (V_{B-T2}/V_{B-T1}) was found to reach 2.02 while the ratios (V_{B-T3}/V_{B-T1}) and (V_{B-T4}/V_{B-T1}) reach 4.43 and 7.59 respectively. Therefore, and on the basis of the above results, it may be concluded that the CVD insert ($T1$) is the most suitable for machining AISI 4140 steel in terms of wear, and that the triple coating (TiCN/Al_2O_3/TiN) CVD proved its efficiency in terms of protection of the insert against wear compared to the other coatings (TiCN/Al_2O_3-MTCVD and TiN-PVD) under the cutting conditions applied.

Fig. 6 shows the morphology of wear on the stripped surface of the inserts used. The wears of both ($T1$) and ($T2$) CVD inserts are illustrated in Fig. 6 (a) and (b). It may be observed that the wear is regular manifesting itself by the appearance of a ribbed bright strip that is parallel to the



(a) (b) (c) (d)

Fig. 6 Wear morphologies for the cutting inserts used, (a) $T1$: TiCN/Al_2O_3/TiN, (b) $T2$: TiCN/Al_2O_3, (c) $T3$: TiN, (d) $T4$: Uncoated carbide cutting edge. Fig. 6 (c) exhibits the flank wear of the PVD insert (*T*3). A small collapse of the tool tip is observed along with small grooves on the flank face of the insert leading to conclude that abrasive wear is present. Finally, the uncoated insert (*T*4) presents high abrasive wear on its flank face that leads to the collapse of the nose and precipitates a catastrophic failure of the cutting edge along with a loss of dimensional accuracy (Fig. 6 (d)).

In order to better understand the behavior and the wear mechanisms that accompany the machining operations, SEM micrographs with the same magnification were captured after 5 minutes of machining for the different cutting inserts used. They are represented in Figs. 7–10. They reveal both the cutter and the clearance surfaces along with the cutting edge of the three regions where the wear occurs. For both (*T*1) and (*T*2) inserts shown in Figs. 7 and 8, wear is found to be regular, and abrasion is the main wear mechanism observed. This is essentially the result of the presence of grooves along the entire length of the wear strip (V_B). These grooves are mainly produced by the hard particles within the structure of the workpiece material used [6]. They are not as deep as the ones observed in other cutting inserts and this is the result of the presence of coating layers that act as protection against abrasive wear. Adhesive wear is also observed for both inserts (*T*1) and (*T*2) and this was confirmed by the traces of work material sticking at the surface of the tool (c.f. the SEM pics of the cutting inserts (*T*1) and (*T*2) of Figs. 7 and 8. This is the consequence of the high temperatures produced during machining along with the physico-mechanical characteristics of the material to be machined.

Fig. 9 shows the SEM illustration of the wear of the PVD cutting insert (*T*3). Numerous abrasive grooves are clearly observed on the flank face of the tool, confirming that the abrasive wear is the predominant wear mechanism. Adhesive wear is also present on the tool surfaces and chipping on the tip of the insert, probably due to high stresses, is also observed.

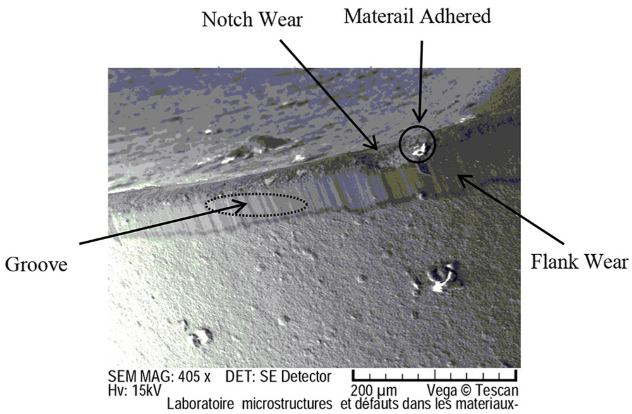


Fig. 7 SEM micrograph of the flank wear for the CVD insert (*T*1) at V_c = 350 m/min, f = 0.08 mm/rev, a_p = 0.5 mm, t = 5 min

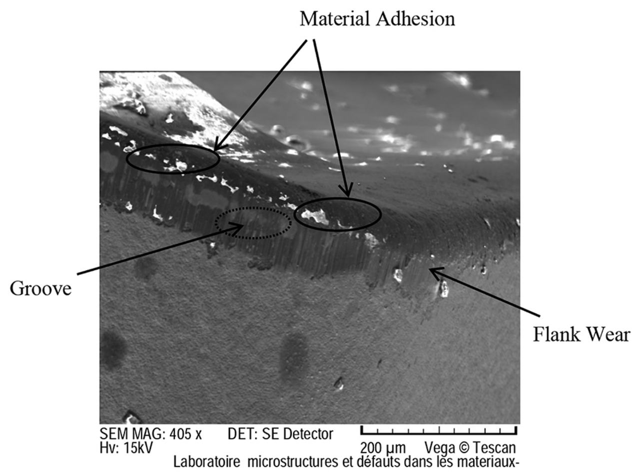


Fig. 8 SEM micrograph of the flank wear for the MTCVD insert (*T*2) at V_c = 350 m/min, f = 0.08 mm/rev, a_p = 0.5 mm, t = 5 min

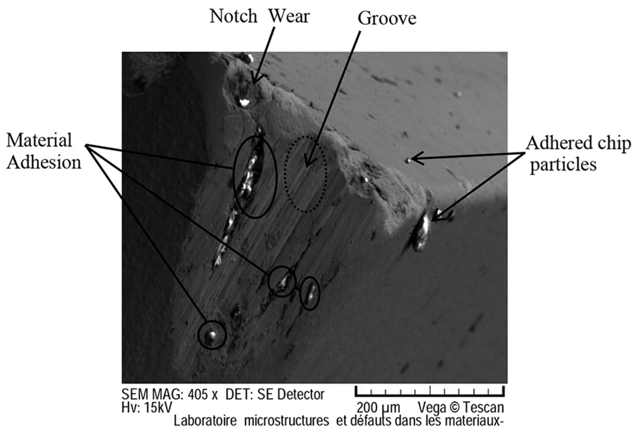


Fig. 9 SEM micrograph of the flank wear for the PVD insert (*T*3) at V_c = 350 m/min, f = 0.08 mm/rev, a_p = 0.5 mm, t = 5 min

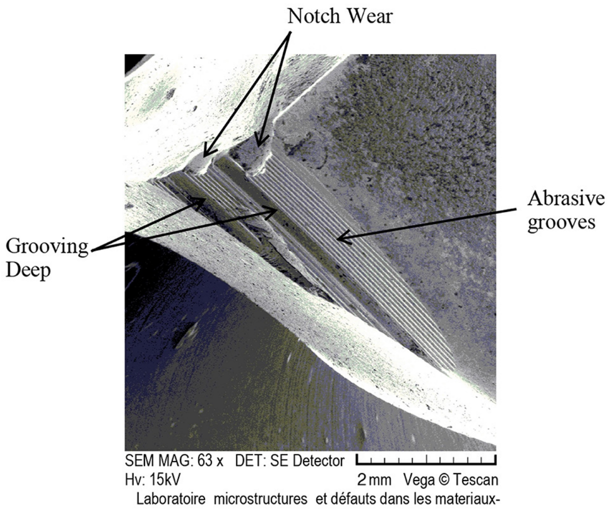


Fig. 10 SEM micrograph of the flank wear for the uncoated insert (*T*4) at V_c = 350 m/min, f = 0.08 mm/rev, a_p = 0.5 mm, t = 5 min

In Fig. 10, high abrasive wear is clearly observed on the flank face of the uncoated insert ($T4$). It is mainly the result of the absence of coating. Chipping is also observed on its cutting edge and is the consequence of the low hardness of the insert. A disastrous failure of the tool tip is produced at the end of the machining time. It is probably the consequence of mechanical fatigue that is generated by the increased tangential cutting force and high temperatures on the tool tip.

The analysis of the wear micrographs shown in Figs. 7–10, lead to conclude that the main wear mechanisms are represented abrasion, adhesion and chipping.

3.2 Cutting force analysis

The results in terms of the three components of the cutting force noted (F_a, F_r and F_t) are represented in Fig. 11 for the four cutting inserts tested. It is clear that the tangential cutting force develops the maximum value compared to both components (F_a and F_r) while the CVD insert ($T1$) produces the lowest tangential force (F_t).

The comparison between the four cutting materials in terms of the tangential cutting force ratios clearly illustrates the difference between them. The ratio (F_{t-T2}/F_{t-T1}) is found equal to 1.05 while that of (F_{t-T3}/F_{t-T1}) reaches 1.13 and finally (F_{t-T4}/F_{t-T1}) takes the maximum value of 1.77. Consequently, and in terms of the cutting force, the CVD cutting insert ($T1$) proves to be the most suitable for machining AISI 4140 steel. However, the cutting forces for the four coated inserts were generally close to each other as the cutting cross-section is the same. Therefore, the coating makes the difference in terms of the cutting forces for the different inserts tested. The evolution of flank wear leads to an increase in the contact surface between the tool and the part. The consequence is the increase in friction forces and consequently the cutting forces.

3.3 Surface finish analysis

Fig. 12 compares the four cutting inserts investigated in terms of the four surface roughness criteria (R_a, R_t, R_q and R_z). It clearly indicates that machining with the CVD coated insert ($T1$) leads to lower surface roughness for the four criteria cited above. In terms of (R_a), the ratio (R_{a-T2}/R_{a-T1}) is found to be 1.38 while (R_{a-T3}/R_{a-T1}) reaches 1.64 and (R_{a-T4}/R_{a-T1}) attains a maximum of 4.63. In reality, the surface roughness is a function of several factors on top of the cutting parameters and the cutting geometry of the inserts such as the tool wear that has a considerable influence on the surface roughness. Since the used cutting inserts have an identical cutting geometry and they were tested in the same cutting parameters, their effects will not be studied.

According to the comparison made earlier of the flank wear of the four used inserts, it may be clearly seen that there is a difference in the level of flank wear between the first two inserts ($T1$) and ($T2$) compared to the third and fourth cutting inserts ($T3$) and ($T4$). The flank wear of the insert ($T3$) attains approximately 2-times that of the insert ($T2$) and 4-times the insert ($T1$) while the insert ($T4$) attains the highest wear. This difference corresponds to a surface roughness (R_a) with the value of (0.069 μm) for the insert ($T1$), the value of (0.140 μm) for the insert ($T2$),

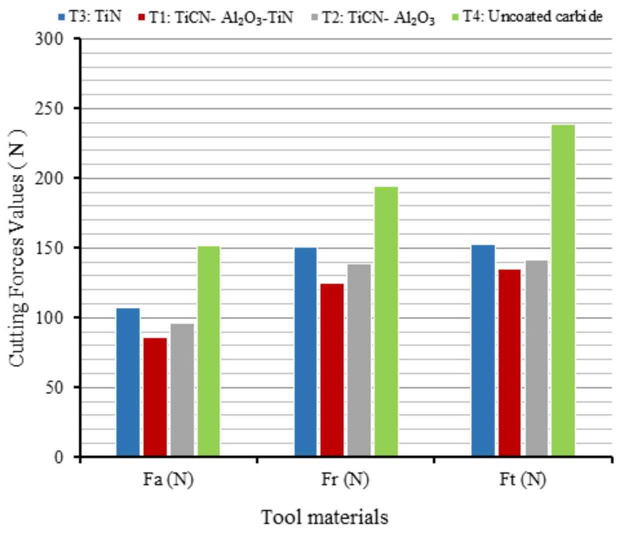


Fig. 11 Comparison of the different inserts in terms of cutting force components (F_a, F_r and F_t) at V_c = 350 m/min, f = 0.08 mm/rev, a_p = 0.5 mm, after 5 min of turning

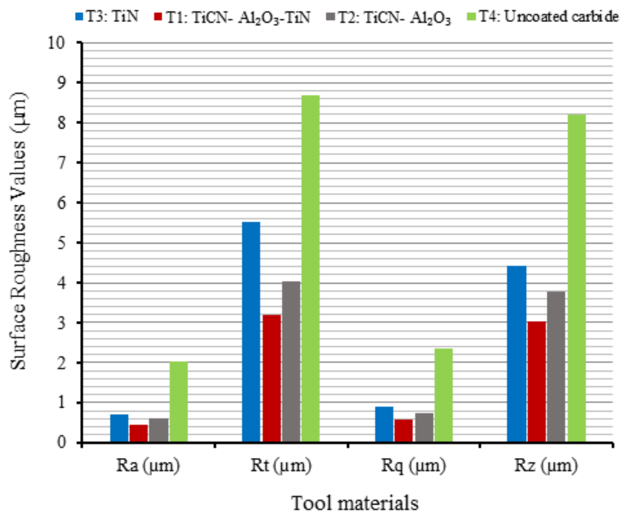


Fig. 12 Comparison between different inserts on surface roughness criteria (R_a, R_t, R_q and R_z), at V_c = 350 m/min, f = 0.08 mm/rev, a_p = 0.5 mm, after 5 min of turning

the value of (0.72 μm) for the insert (*T*3) and the value of (2.04 μm) for the insert (*T*4). The increase of the flank wear (V_B) leads to an increase in the contact zone between the tool and the workpiece that destabilizes the machining process leading to a deterioration in the surface roughness. This result leads to say that the follow-up of the flank wear is essential in the machining as its evolution deteriorates the surface condition.

4 Conclusions

In this study, parametric tests were carried out to investigate the influence of four grades of carbide inserts represented by a monolayer applied by PVD (TiN), multilayer applied by CVD ($TiCN/Al_2O_3/TiN$) and multilayer applied by MTCVD ($TiCN/Al_2O_3$) as well as an uncoated carbide tool in the turning of AISI 4140 steel. The measurements carried out in terms of surface quality (R_a, R_q, R_t and R_z), cutting force (F_a, F_r and F_t), and clearance wear (V_B) showed that:

- The present parametric study provides very useful results allowing the rigorous choice of the best cutting tool that satisfies the best quality/price ratio.
- The CVD cutting insert (*T*1) produces lower wear while the maximum value of (V_B) is displayed by the uncoated insert (*T*4).
- The effectiveness of the CVD cutting insert (*T*1) in terms of wear has been proved with a ratio (V_{B-T2}/V_{B-T1}) = 2.03 while (V_{B-T3}/V_{B-T1}) = 4.43 and (V_{B-T4}/V_{B-T1}) = 7.59.
- From the analysis of SEM, it can be concluded that abrasion, adhesion and chipping are the dominant wear mechanisms observed for the three coated cutting inserts (*T*1), (*T*2) and (*T*3) while only abrasion and chipping are the dominating ones observed for the case of the uncoated insert (*T*4).
- The lowest value for surface roughness was achieved by the CVD cutting insert (*T*1) while the highest was produced by the uncoated insert (*T*4). Therefore, it can be concluded that the CVD coated cutting insert (TiCN-Al_2O_3-TiN) outperforms its three counterparts in terms of surface roughness.
- The lowest cutting force is generated by using the CVD insert (*T*1) while the highest is generated by using the uncoated insert (*T*4). Therefore, and in terms of cutting forces, the CVD coated cutting insert (*T*1) is identified as the leading material.

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Nomenclature

V_c	Cutting speed (m/min)
a_p	Depth of cut (mm)
f	Feed rate (mm/rev)
R_a	Arithmetic mean roughness (μm)
R_t	Total roughness (μm)
R_q	Root mean square roughness (μm)
R_z	Mean depth of profile (μm)
F_a	Axial force (N)
F_r	Radial force (N)
F_t	Tangential force (N)
V_B	Flank wear (mm)
$V_{B\text{-max}}$	Maximum flank wear (mm)
t	Cutting time
HB	Brinell Hardness
α	Clearance angle (°)
χr	Major cutting edge angle (°)
γ	Rake angle (°)
λ	Cutting edge inclination angle (°)
Al_2O_3	Aluminum oxide
TiAlN	Titanium aluminum nitride
TiCN	Titanium carbo-nitride
TiN	Titanium nitride
ZrCN	Zirconium carbon nitride

Abbreviations

AISI	American Iron and Steel Institute
SEM	Scanning Electron Microscope
PVD	Physical Vapor Deposition
CVD	Chemical Vapor Deposition
MTCVD	Medium Temperature Chemical Vapor Deposition
HRC	Hardness Rockwell C

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