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Coated Tungsten Carbide Inserts: Effects on Machinability in Turning of AISI 1020 Steel

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Abstract: ***How the different types of cutting inserts coatings influence on surface roughness and tool wear, taking these two factors as machinability criteria, in turning carbon steel bars AISI 1020 was investigated. Specimens of 36 mm in diameter and 200 mm in length tested were made. Uncoated inserts and coated WC tungsten carbide inserts with: TiN; TiN / Al_2O_3 and TiC / Al2O3 / TiN, were use. The tests were carried out on automatic parallel lathe, using the cutting parameters: 1500 rpm; a= 0,25 mm/rev; p= 0,4 mm; therefore, the cutting speed was Vc= 170 m/min. Roughness was measured in the roughness meter: Mitutoyo, Surftest-211, and a high resolution optical microscope was used to measure the flank wear, complementing with SEM electron microscopy. It was found that the lowest roughness Ra is obtained using Triple inserts showing a variation Ra = 2µm. The maximum flank wear V_B = 300µm was taken as machinability criterion, to later determine the tool life for each insert. The uncoated insert life was 8 mim, and TiN coated insert life was 14.5 min, while the bilayer and trilayer coating inserts did not exhaust their life for 12,000 mm length machining. Uncoated and TiN-coated inserts showed strong wear and workpiece material build-up (BUE). The double and triple layer inserts did not show this phenomenon due to the Al_20_3 compound which is chemically inert at high temperatures. The most prevalent mechanisms in the inserts wear was adhesion and abrasion. No direct or inverse relationship was found between wear and roughness.***

Keywords: ***coating inserts, flank wear, machinability, roughness,***

I. INTRODUCTION

The growth of economies based on manufacturing can be described largely by the development of the various machining operations; This requires that operations must be increasingly efficient and cutting conditions optimized according to the needs of users. This objective is achieved by carrying out the cutting processes with good machinability; which means "easing of machining" **[1].** The general criteria for evaluating machinability are many ones, among which are: 1) Tool life, 2) Surface roughness, 3) Surface integrity, 4) magnitude of cutting forces or energy consumption, 5) material removal capacity, and so on. The criteria being so diverse; any criteria must be chosen, depending on the requirements of a particular operation; reason for which it becomes difficult to have a unified criterion regarding how to quantify machinability. According to M.E. Merchant [2], F.W. Taylor in 1906, asked three questions related to machinability: What tool should I use? What cutting speed should I use? What feed speed should I use? Since then many attempts have been made to accurately answer these questions. It is established that the best tool is one that has been carefully chosen to get the machining to be done, efficient and economical **[3], [4].** The first machinability criterion is determined by the "tool life"; which is defined as the cutting time during wich, this tool can be used. In other words, the tool life consists of allowing its operation until a catastrophic failure occurs. Consequently, the tool life is to allow it to operate until a catastrophic failure occurs. This failure criterion is closely related to tool wear. Then, to quantify the life of a tool, it is common practice to establish a measure of maximum wear allowed (normalized), and the life is estimated as the time taken to reach that limit condition. Flank wear or crater wear is generally taken as the limit value. However, in most cases the failure is largely the result of a number of different types of progressive wear occurring simultaneously, such as: nose wear, notch wear, and chipped edge **[5].** The second machinability criterion is determined by the surface roughness produced on the machined surfaces. The surface finish has a fundamental influence on the most important functional properties; such as, wear resistance, fatigue resistance, corrosion resistance and energy losses due to friction. A poor surface finish will lead to a rapid breakdown of the peaks of the micro-irregularities, causing decisive wear on the friction surfaces, both material and tool. Reason for wich, finishing processes are used in machining to obtain parts with a minimum degree of surface roughness **[6],** since the current precision requirements the for machined parts increase continuously **[7].**

In actual machining there are many factors that affect surface roughness; such as, cutting conditions, tool and workpiece conditions. The power consumed that is largely converted into resulting heat **[8],** which brings about high temperatures that directly influence the wear of the tool, inducing thermal damage to the machined surface **[9].** All of these difficulties lead to high tool wear, low material removed rate (MRR), and poor surface finish [10]. In conclusion, it is very difficult to take into account all the parameters that control the roughness of the surface in any machining process **[11]** and nor can a unified machinability criterion be taken in this context.

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Many articles have been published in this regard, based on experiments to study the effect of cutting parameters on surface roughness, tool wear, cutting forces, energy consumption, material removal rate **[12] - [15].** Therefore, it is necessary to select the most suitable machining configuration, in order to improve cutting efficiency.

Likewise, numerous tools have been developed to improve their use in cutting processes, to increase its machinability. Carbon steel tools were developed a century ago **[16].**

Cemented carbides were first introduced around 1926, and they remain the most popular of the cutting tool materials available today **[17].** Increased productivity in manufacturing processes requires acceleration of the design and evolution of improved cutting tools with respect to obtaining better tribological performance and wear resistance **[18].** Thus we have the studies of J.A. Ghani et al **[19]** who investigated the wear mechanism of two cutting tools, one of them used uncoated cemented carbide inserts and the other used TiN coated cemented carbide, for various combinations of cutting speed, feed rate and depth in turning H13 steel. It was observed that the tools life with coated carbide inserts was greater than uncoated carbide tools, especially in the combinations of high cutting speed, feed rate and depth; but, In the combinations: low cutting speed, low feed rate and depth, the uncoated carbide tools exhibited more uniform and gradual wear on the flank face than coated carbide inserts. E. Aslan et al., (2007**) [20]** carried out an optimization study of turning on hardened AISI 4140 (63HRC) steel using ceramic inserts coated with Al2O3 + TiCN. The study determined that ceramic inserts coated with Al_2O_3 are required to achieve tools for efficient machining in hard steels with good wear resistance and high hardness. Flank wear (V_B) and surface roughness were chosen as the machinability criteria. As a result, it was seen V_B decrease as cutting speed and depth of cut increased; Surface roughness increased as the feed rate increased. Y. Morales et all. **[21]** studied the flank wear behavior in high speed dry turning of AISI 316L stainless steel using Sandvik coated carbide inserts: GC1115-M15 and CVD GC2015-M15. The inserts machined at 400 m / min showed wear by abrasion, adhesion and diffusion. For the speed of 450 m/min, the insert GC1115 (1) shows excessive wear revealing abrasion, adhesion, diffusion, plastic deformation and fracture of the cutting edge, while the GC2015 (2) showed abrasion, adhesion, diffusion and plastic deformation. The objective of this research work is to quantify machinability in turning AISI 1020 steel, taking as machinability criteria: tool wear and surface finish on the workpiece.

II. MATERIALS AND METHODS

A. Work Material

SAE / AISI 1020 steel is a low carbon steel (o,21%); In the state of supply it has an average hardness of 111 HB with good machinability. Its chemical composition is observed in table I.

Table I. Chemical composition of the work material (wt %) AISI 1020 steel

C	Mn	P	S	Si
0,21	0,40	0,03	0,04	0,25

B. Cutting Tools: Inserts

Both the tool holder and the inserts were acquired from the company: *Sandvik- Coromant* **[22]**, according to the recommendations indicated in their manufacturer catalogs. In accordance with the cutting conditions to be used, the tool holder was selected: MDJNR - 12 - 4B (see Fig. 1), on which four (4) types of tunsgsten carbide (WC) inserts were rigidly mounted: 1) Uncoated WC inserts. 2) WC inserts with a coating layer of TiN (Titanium nitride); 3) WC inserts with two layers of TiN /Al_2O_3 coating (Titanium Nitrite / Alumina); 4) WC inserts with three layers: TiC / Al_2O_3 / TiN (Titanium Carbide / Alumina / Titanium Nitride). Todos los insertos tienen idéntica geometría designada por la norma (ANSI) designados con las siglas DNMG – 432, y grado C6 (See Fig.1). All of them are adhered to the substrate through the process (CVD), forming a film on cooling, with thicknesses of: 2-4μm.

B1. Features and Geometry

All inserts are C6 grade, suitable for machining steels at high cutting speed and high feed rates. They also all have identical geometry designated by the American National Standard Institute (ANSI) as DNMG - 432, where:

D: Rhombus-shaped insert: 55°

N: Clearence angle: 0°

M: Tolerance of the inscribed circle and thickness of ± .002 and ± .005 respectively.

G: Insert with one hole and chip breaker on both sides.

Sintered tungsten carbide cutting tools are highly resistant to abrasion and can also withstand higher temperatures than high speed steel tools. Carbide cutting surfaces are often used for machining materials such as carbon steel or stainless steel. Because these carbide tools hold the sharp cutting edge better than other tools, and generally produce a very good quality surface finish.

The material of these inserts is composed of a metallic cobalt matrix, where tungsten carbide particles are added to the matrix. Due to its high hardness and low ductility, pieces of this material are made in powder form, adding between 6 and 10% cobalt. The grains of tungsten carbide used in the process typically have diameters of about 0.5 to 1 microns. Uncoated WC tungsten carbide can resist high temperatures and is extremely hard ~ 85 HRC. **[23]**

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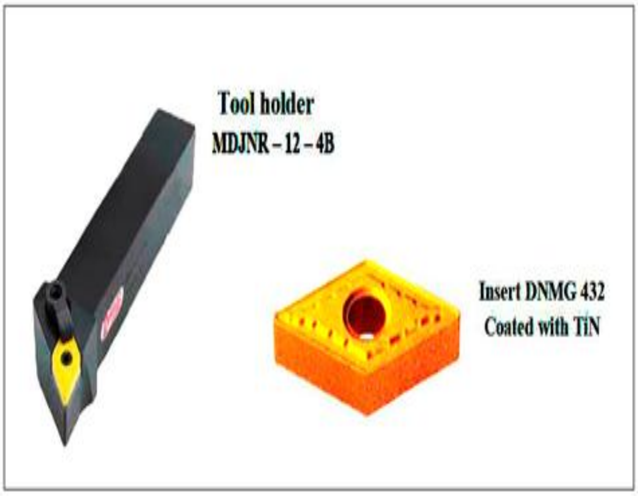

Figure 1. Photographs taken from the Sandvik Turning Catalog, showing the tool holder used and a TiN coated insert. Ref. [22]

C. Experimental Process.

C1. Samples.

The specimens were made from round bars of 38 mm in diameter and 6 m long, which were cut into pieces of 300 mm in length and then each bar was machined with a test length of 200 mm in length and 36 mm in diameter, being ready for the tests, as shown in Fig. 2, and its respective diagram. These measurements of the specimens were selected in order to meet the requirements of standard ISO 3685 **[24],** where it specifies the ratio (length/diameter) of the workpiece material used for these cases, must be less than 10 during testing to prevent vibrations that can occur in the machining.

C2. Machining Parameters.

The cutting parameters were selected taking into account selected inserts, according to the technical references of the Sanvick-Coromat for the use of these inserts in finishing processes. With these recommendations the following parameters were selected: n = 1500 rpm; a = 0.25 mm / rev; p = 0.4 mm, being the cutting speed used was 170 m/min. These parameters remained constant for all the tests, the same happened with the types of inserts with respect to their coating geometry and so on; Since, what is sought is how WC coatings influence the roughness of the cut material and the tool wear, for certain pre-established machining conditions.

C3. Wear Measurement

To better understand the procedure to be followed in the insert wear test, we will define the meaning of the term cut and cut numbers that appear in the tables and graphs of the results.

A cut is defined, as the finished turning of the bars, along its entire test length (200mm), with the stipulated cutting conditions (Fig. 2).

The machinability criterion was taken: flank wear of the tool; Therefore, what measured was: the depth of wear in that zone (V_B), and the tool life was determined when V_B = 300µm.

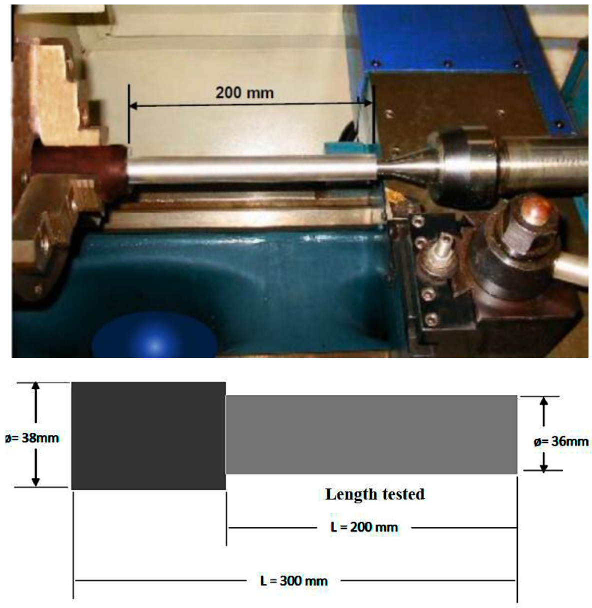

Figure 2. Specimens machining on the lathe according to sketch in the attached figure.

To measure the wear performance of each insert, 60 cuts were made for each one, which represented a total test length of 12,000 mm per insert. Wear was measured after every three (3) cuts, resulting in 20 measurements per insert, as seen in table V. The depth measured in flank wear was made using Karl Zeizz 2000 optical microscope with precision: 0.005 mm. Moreover, SEM JEOL Scanning Electron Microscope, JSM-IT500 was used to observe wear details on some representative zones.

C4. Roughness Measurement.

All tests were carried out using a Mitutoyo digital roughness meter, model Surftest-211. A full essay length sweep of 200mm was made for each cut. Then the corresponding average was taken to represent the roughness per cut, taking the arithmetic mean (Ra) for each stretch.

These average values in µm, were taken for the 50 cuts per insert. Three measurements were made per test and with their averages the tables and graphs were constructed as shown in table II and Fig. 3.

III. RESULT AND DISCUSSION

A) Surface Roughness.

The results can be seen in table II and all the trend graphs are in Fig. 3. The table successively indicates that 50 cuts have been made, with the respective roughness values in µm being found at the bottom. side

Table II. Average roughness measurements (Ra) using coated and uncoated inserts as a function of the number of cuts or passes through the test length

Insert	Cuts number / roughness- R_a (µm)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
uncoated	2,2	2,4	2,6	3,0	3,0	3,9	3,7	4,0	3,8	4,0
monolayer	3,8	3,9	3,75	4,1	3,75	4,1	3,9	3,9	3,9	3,8
bilayer	3,0	3,2	3,,6	4,0	3,85	4,15	4,2	4,6	4,6	4,8
three-layer	2,65	2,6	2,8	2,8	2,5	2,7	2,55	2,7	2,7	2,75
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
uncoated	4,3	4,5	4,1	4,0	4,15	4,15	4,15	4,07	3,9	4,15
monolayer	3,75	4,1	3,6	4,0	4.1	4,2	4,5	3,6	4,3	5,0
bilayer	4,94	5,0	4,7	4,7	4,9	4,7	4,5	5,1	5,2	5,0
three-layer	2,6	2,48	2,1	2,5	2,45	2,45	2,25	2,25	1,75	2,0
	21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
uncoated	3,85	4,06	4,1	4,4	4,6	4,5	4,4	4,7	5,0	3,9
monolayer	4,0	4,15	4,2	3,9	4,2	3,5	3,4	3,2	3,1	3.05
bilayer	5,1	5,5	5,1	5,6	5,5	5,3	5,2	5,2	5,4	5,3
three-layer	2,0	2,1	2,0	1,9	2,45	2,7	2,38	2,5	3,2	3,4
	31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
uncoated	4,0	4,2	4,2	4,3	4,4	4,4	4,2	4,7	4,8	4,0
monolayer	3,3	3,45	3,35	3,35	3,8	4,1	3,7	3,6	3,95	4,8
bilayer	4,8	5,0	5,0	5,3	5,3	5,2	4,98	5,4	5,7	5,4
three-layer	2,7	3,15	3,15	2,8	2,9	2,75	3,0	3,0	2,75	2,5
	41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
uncoated	4,15	4,0	4,8	4,8	4,6	4,2	4,3	5,1	4,8	4,9
monolayer	3,8	3,95	3,9	3,9	4,0	3,6	3,9	3,8	3,55	3,95
bilayer	6,0	5,4	5,4	4,5	4,7	5,2	5,8	5,5	4,9	5,2
three-layer	2,95	2,75	2,8	3,1	3,8	3,3	3,0	2,25	2,1	2,2

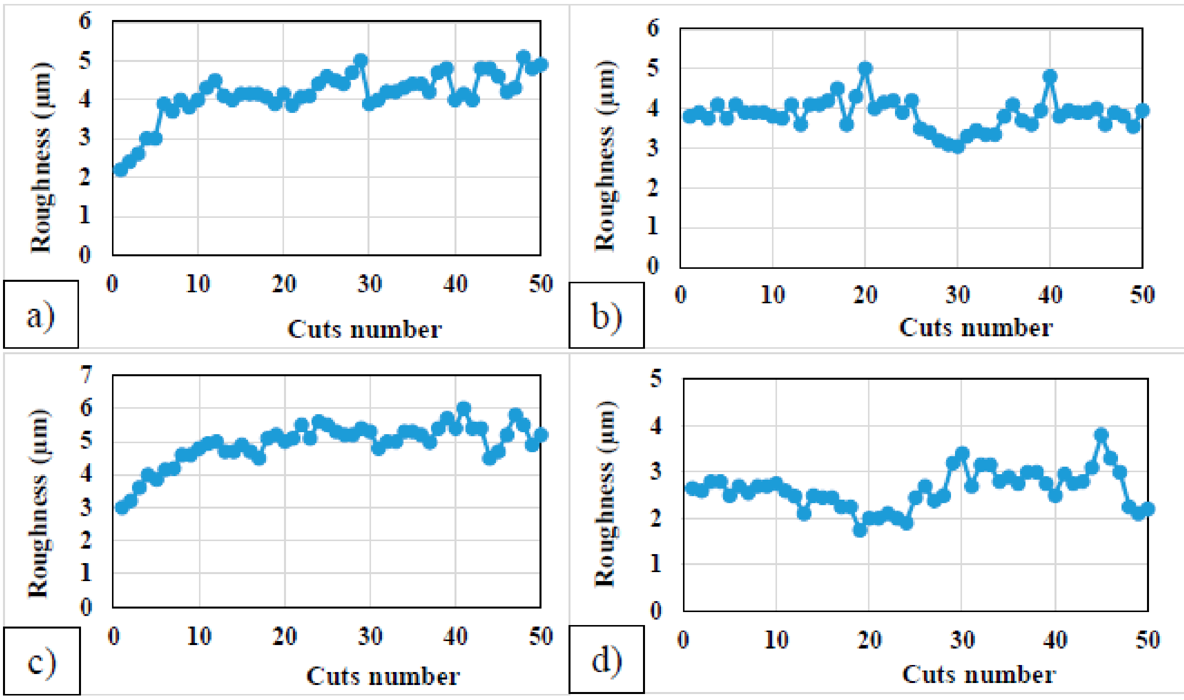

Figure 3. Roughness graphs as a function of the cuts number and WC Tungsten carbide inserts types: a) uncoated; b) monolayer; c) bilayer; d) three-layer

After looking at Table II and its graphs in Fig. 3, these results are described and discussed below.

Fig.3(a) corresponds to the uncoated inserts, where an irregular curve with an increasing trend is observed, whose values oscillate in the range of [2-5 µm]. This increase is due to the time of use of the tool. A notable increase is observed in the first 10 cuts followed by an oscillating behavior. In general, the curve fits the data very well in the first 20 cuts and from there until the end the data dispersion increases.

Fig.3(b) corresponds to the TiN-coated monolayer inserts. The graph shows an irregular curve with a fluctuating trend, whose values oscillate in the interval of [3-5µm]. The results present almost constant values of 4µm in the first 10 cuts and in the last 10 cuts, showing a greater dispersion in the intermediate cuts.

Fig.3(c) corresponds to the TiN/Al_2O_3 coated bilayer inserts. The graph shows an irregular curve with a fluctuating trend, whose values oscillate in the range of [3-6µm]. An increasing trend is observed until cut 20 with an almost constant permanence until cut 40 and then continue with an irregular trend until the end.

For triple-layer inserts with coating: TiC/Al_2O_3/TiN, the trend of results can be observed in Fig. 3(d). The graph shows an irregular curve with a fluctuating trend, whose values oscillate in the interval of [2-4µm], being the narrowest interval that all the inserts present; Moreover, a slightly oscillating trend curve is observed. The graph shows an almost constant trend in the first 20 cuts, where all its points are in the interval [2-3µm] and then follow an increasing trend until cut 30, then showing a fluctuating trend until the end. This small range of roughness shown highlights the great influence of the triple layer coating. From the previous analysis we can extract Table III.

Table III. Range of roughness measurements obtained for each type of insert used in the experiment

Insert	Roughness range
uncoated	[2-5µm]. Δ= 3µm
coating layer: TiN	[3-6µm]. Δ= 3µm
coating layer: TiN/Al_2O_3	[3-6µm]. Δ= 3µm
coating layer: TiC/Al_2O_3/TiN	[2-4µm]. Δ= 2µm

From table III. It can be seen that the smallest roughness ranges are obtained using the inserts with triple coating: TiC /Al2O3/TiN. At beginning of the first cuts the inserts without coating present less roughness than the coatings with a single layer, and then these values are reversed. We can also infer that using inserts with a higher coating will guarantee a better surface finish. In a sense it would be the right thing to do, but we must bear in mind that the roughness or surface finish depends on many factors, apart from the cutting regime and properties of the tool, as considered in this study.

Benardos and Vosniakos **[25],** classify the factors that affect surface roughness such as: cutting regime, properties of the cutting tool, properties of the piece to be cut, vibrations, variations in cutting forces, and so on. These multiple factors are likely to be interfering more significantly than those being considered. What does not happen with the tool wear, as we will see later.

DIN 4769 standard, for greater and ease specification, and control of roughness, divides the different values of Ra into degrees as shown in table IV.

Table IV. Grades of roughness "Ra" according to DIN 4769.

Ra [µm]	N° Roughness Degree
50	N12
25	N11
12,5	N10
6,3	N9
3,2	N8
1,6	N7
0,8	N6
0,4	N5
0,2	N4
0,1	N3
0,05	N2
0,025	N1

According to the ranges obtained, we are within the roughness grades **N8 and N9**, and within the requirements established for the design. According to the standards we find a medium requirement in surface quality [2.5-4-6] µm. Thus; If the machinability criterion had been established between these two degrees, we would be within the established performance; that is, we would be within control; But if the machinability criterion had been established within the lower or higher grades, we would be out of control.

If almost all the factors that affect roughness have remained constant; The difference in results can be explained by the difference in thermal conductivity of the inserts, which changes the cutting temperature, and this change affects the roughness in many ways, including accumulated edge formation (BUE). Also, non-metallic inclusions such as sulfides generate microcavities, which significantly affect machinability **[26].**

B) Tool Wear.

The results can be seen in table V and all trend graphs are in Fig. 4. The table successively indicates that 60 cuts have been made, the respective wear values for each type of insert being found at the bottom. The maximum wear (495µm) was found using the uncoated insert and the minimum (65µm) was found for the triple-layer coated insert. These results are in agreement with those obtained by surface finish, with regard to the performance of the inserts.

The measurements have been made after every 3 cuts, which is why the graphs and ranges take the third cut as the starting point of reference.

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Table V. Average wear measurements using coated and uncoated inserts as a function of the number of cuts or passes through the test length

Insert	Cuts number / flank wear (µm)									
	3	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**
uncoated	150	200	250	280	300	315	325	335	350	360
monolayer	205	220	240	250	265	270	290	297	310	315
bilayer	0	50	72	90	110	118	123	126	130	135
three-layer	0	2	3	3	5	5	5	6	6	6
	33	**36**	**39**	**42**	**45**	**48**	**51**	**54**	**57**	**60**
uncoated	370	385	400	410	430	450	470	480	485	495
monolayer	325	340	350	350	355	358	360	370	375	380
bilayer	140	143	145	148	150	152	153	158	158	162
three-layer	7	7	8	8	8	38	40	50	60	65

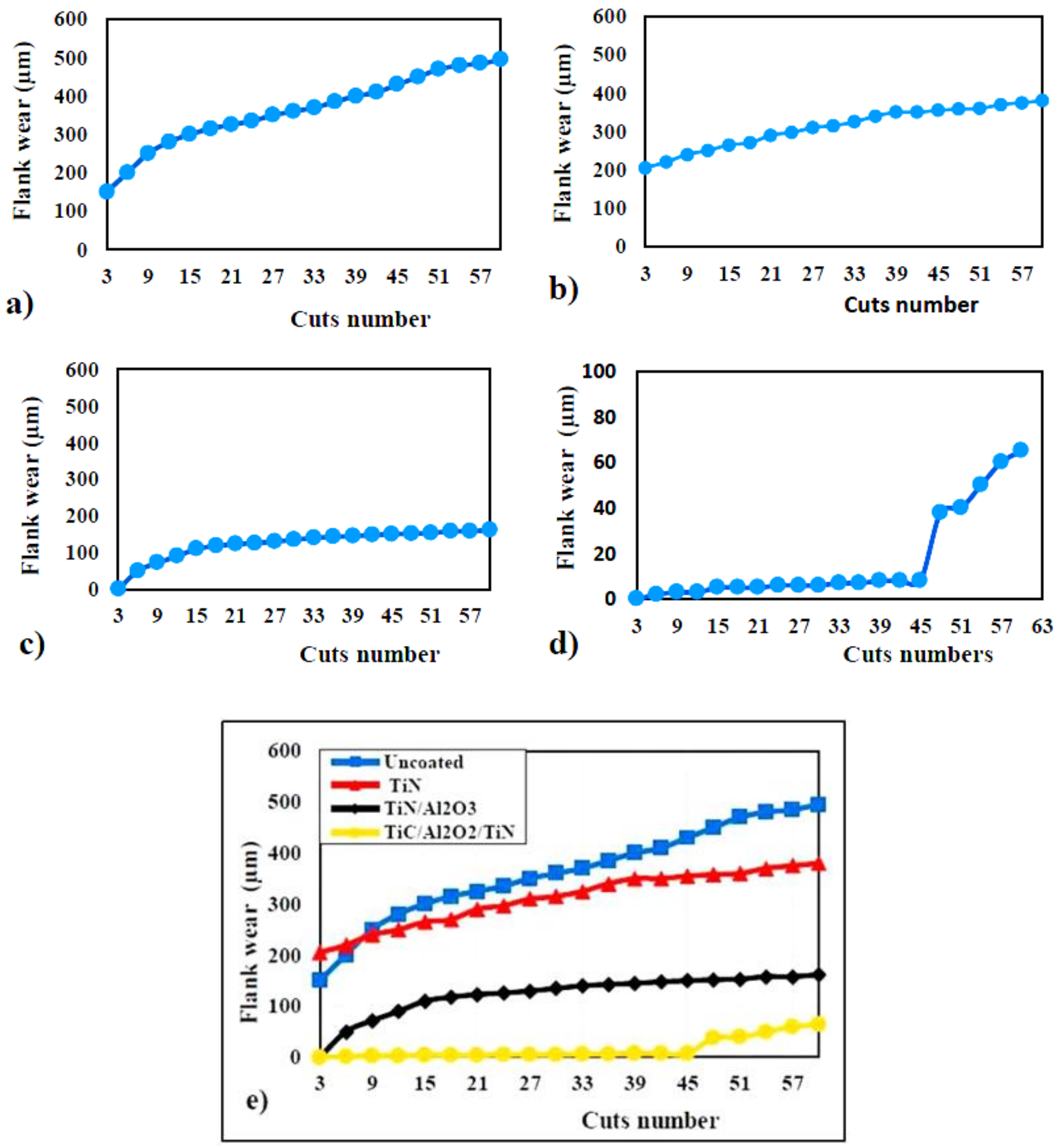

Figure 4. Insert wear graphs as a function of the number of cuts and types of WC Tungsten carbide inserts, a) uncoated; b) monolayer; c) bilayer; d) three-layer e) consolidated graphics.

C) Inserts Wear.

For the uncoated inserts, the results can be seen in table V and figure 4a). The wear values are in the range of [150-500µm], showing an increasing trend with the number of cuts.

For TiN coated inserts; wear values are in the range of [205-380µm]. This interval is narrower than the previous one and the tool wears less due to the coating.

For TiN/Al_2O_3 coated inserts, wear values are in the range of [0-162µm]; in the same way with narrower ranges due to the double layer. It can also be observed that in the first 15 cuts the insert undergoes a sudden rate of increase in wear and then appreciably decreases that rate and then maintains an almost constant value until the end point.

For inserts with triple layer coating: TiC /Al_2O_3/TiN, the wear values are in the range [0-65µm]. It is observed that in the first 45 cuts, wear is almost negligible; and then, present a slight increase until reaching to 65 µm. This increase is the narrowest of all tests, and presents the lowest wear values. In this way, the triple layer insert shows its high wear resistance compared to other coatings types.

Figure 4e) shows the consolidated graph of all wear curves using all inserts. The graph also shows that up to the 9th cut, the single-layer insert has greater wear resistance than the double-layer insert, this small section being the only exception. Currently there are no antecedents or references that can explain this phenomenon. Previously, it can be concluded: the greater the number of coating layers, the greater the resistance to wear, which does not happen with the roughness of the cut material. Furthermore, it is known that the wear resistance of the inserts is closely related to the structure and chemical composition they present.

From the previous discussion, table VI is extracted. The effect of the coating on wear is seen more clearly in it. Taking into account the Fig. 4e), the double-layer coatings begin to wear from the third cut, while the triple-layer coating from 45th cut; that is: The higher the number of layers, the lower the wear.

Table VI. Variation on inserts wear, for cylindrical finishing turning of AISI 1020 Steel

Regime: [n= 1500 r.p.m; a= 0,25 mm/rev; d= 0,4 mm]

Insert	Flank wear variation
uncoated	[0-500µm]
coating layer: TiN	[0-380µm].
coating layer: TiN/Al_2O_3	[0- 162µm].
coating layer: TiC/Al_2O_3/TiN	[0- 65µm].

D) Tool Life

Tool life is determined by drawing a horizontal line that indicates the maximum allowable wear (300µm) as shown in Fig.4. The intersections indicate the number of cuts or total distance traveled "L" to reach that wear. The time will be: L/ A; (A = advance speed).

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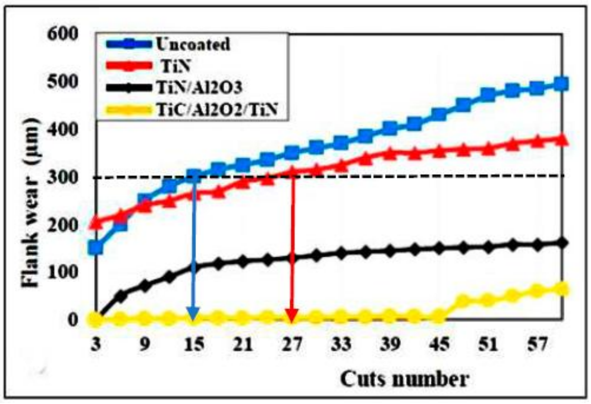

Figure 5. Wear graphs that determine the life of the tool taking as a criterion a flank wear limit of 300µm. [ANSI / ASME B94.55M 1985 standard]

According to the ANSI / ASME B94.55M 1985 standard for tool life testing for turning, there are several criteria for determining tool wear. Subsection 7.1.2 of this standard establishes that a cutting tool is declared non-serviceable when the flank wear reaches a value of 0.3 mm (300µm) under uniform wear conditions. In the graph of Fig. 5, the horizontal dashed line establishes this limit. It can be seen that for the entire experiment the inserts that exhaust their life are the uncoated inserts and the TiN-coated monolayer insert. The first ends its life at 18 cuts (8 min) and the second at 30 cuts (14.5 min), the other two inserts have an indefinite life.

As stated above, if it is taken into account that the cutting conditions used are the same, and the length turned per cut is known, the tool life of the insert or the time necessary can be calculated to reach that stated condition as limit.

The ANSI / ASME B94.55M standard states precisely: For carbide and ceramic inserts, the wear limit value on the flank is determined by: V_B =300µm; where this V_B is the maximum depth of wear allowed, which defines the tool life using the insert. Applying the wear data and cutting conditions used, the results of table VII are obtained.

Table VII. Tool life using insert for finishing cylindrical turning: Material: AISI 1020 steel.

Regime: [n= 1500 r.p.m, a= 0,25 mm/rev; d = 0,4 mm]

Insert	Machined length	Tool life (min)
Uncoated	3000 mm	8,0 min (VB_B= 300 µm)
coating layer: TiN	5400 mm	14,5 min (VB_B= 300 µm)
coating layer: TiN/Al_2O_3	12,000 mm (max. length)	not defined (VB_B= 162 µm)
coating layer: TiC/Al_2O_3/Ti	12,000 mm (max. length)	not defined (VB_B= 65 µm)

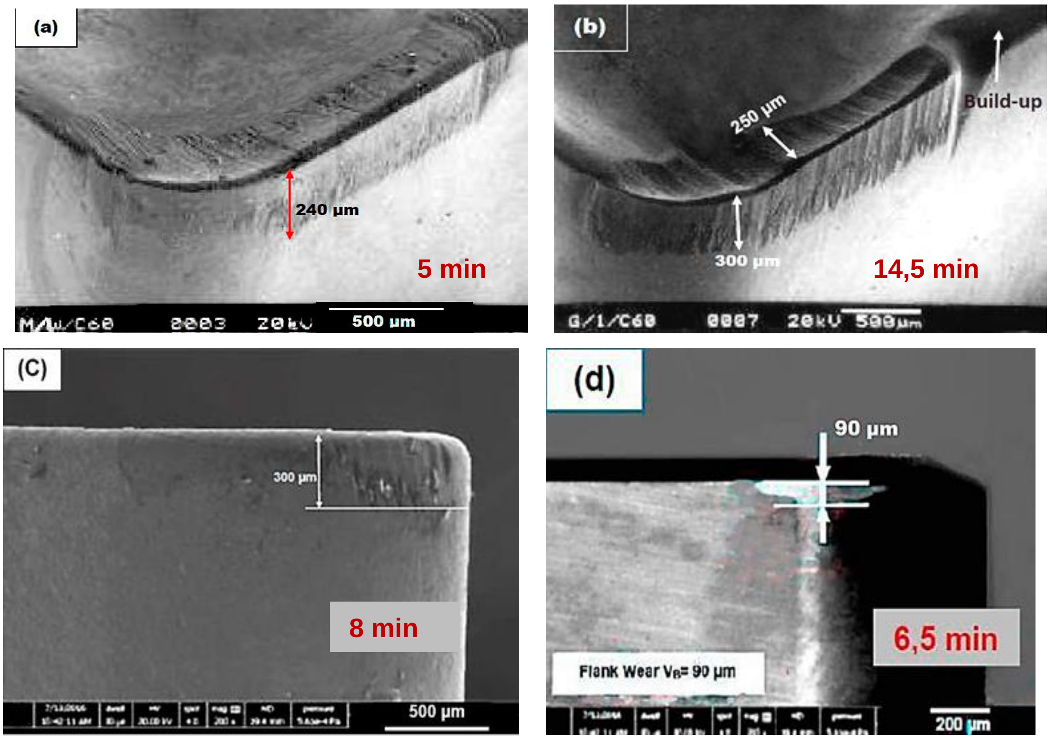

Figure 6. Photomicrographs SEM showing flank wear and time, in four selected inserts: a) coated: TiN, time: 5 min; b) coated: TiN, Tool life:14,5 min; c) uncoated: Tool life: 8 min d) coated: TiN/Al_2O_3. time: 6,5 min

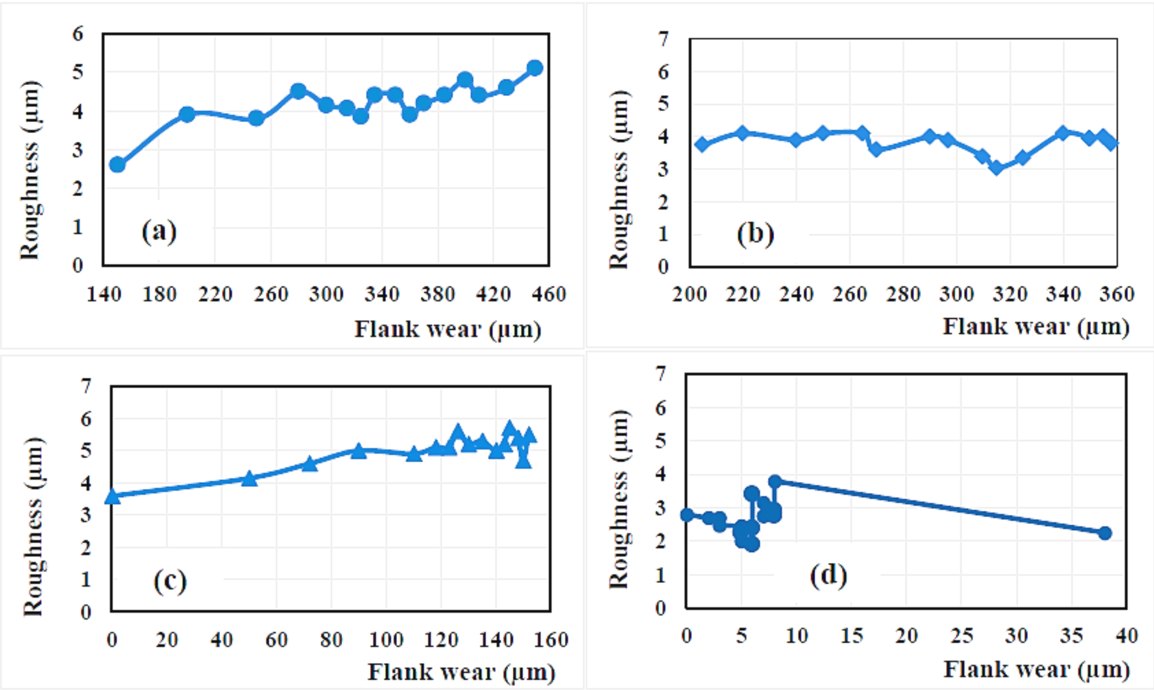

Figure 7. Graphs showing the relationship: Tool wear - Surface roughness, using different inserts: a) uncoated; b) coating: TiN; c) coating: TiN/Al_2O_3; d) coating: $TiC/Al_2O_3/TiN$

The Fig.6 shown SEM photomicrographs of four selected uncoated and coated inserts.

In Figures 6a) and 6b), two TiN inserts are shown; The first did not reach its life cycle, showing a flat surface worn in the attack zone and a medium wear on the flank of 240 µm. In the second case, the same insert is observed fulfilling its life cycle (14.5 min) by showing a limit of flank wear: $VB_B = 300$µm. También se observan cráteres de desgaste en la zona de ataque. The first insert only used 65% of its cutting capacity in a time of 5 min. In Fig. 6c) there is an uncoated insert fulfilling its life cycle (8 min) reaching a wear on the limit flank $VB_B = 300$µm. In Fig. 6d) TiN/Al_2O_3 coated insert show a flank wear of 90 µm, using 30% of its cutting capacity employing 6.5 min.

As shown in the graphs in Fig. 5, the inserts coated with TiN /Al_2O_3 and TiC /Al_2O_3/TiN, after machining the entire length of cut tested, obtained as flank wear values of 162 and 65µm respectively; that is, they used 32 min consuming 54% and 22% of their total performance respectively. As can be seen in table VII, in these cases it is denoted as indefinite life, showing that multiple coatings have a much higher performance than simple coatings with a notable difference. The mechanisms that explain this phenomenon are discussed later.

E)Wear / Roughness: Relashionship

All the curves that relate: Wear vs Roughness, (Fig.7) present different trends. For uncoated inserts (Fig.7a), the trend is increasing throughout the wear range (140-360µm) the roughness fluctuates in the range (2.5-5µm). For inserts with a single coating (Fig.7b) we can assume a trend is almost constant; because in the wear interval (200- 360µm), the roughness variation does not exceed 1µm, fluctuating between (3-4µm). For inserts with two coatings (Fig. 7c), a roughness increase of 2 µm is observed throughout the wear interval (0-160µm) within a range (3.5-5.5µm); and when it continues to increase, the roughness is oscillating. For inserts with three layers (Fig.7d), a total variation of 2µm is observed throughout the wear interval (0-40 µm). It is curious to note; at the beginning of machining, when a wear reached to 10 µm the roughness fluctuates by 2 µm, and then the roughness decreases by 1 µm until the wear is 40 µm. An increase in wear in the interval (0-8µm) produces a roughness that oscillates sharply between (1.8-4µm) then it is observed that the increase in wear almost does not affect the roughness, decreasing until 2µm.

It is observed that the most efficient performance in surface finish is obtained with the triple layer insert, as well as for wear; but it is not inferred that roughness and wear have a relationship of proportionality, neither direct nor inverse. It cannot be said that the increase in the wear of an insert, necessarily means producing a lower or low surface finish in the entire machining section. This is most clearly seen in multilayer inserts. The reason is that we are trying to relate a property that corresponds to the machined material that depends on many factors, with a property intrinsic to the tool material.

Studies on wear on cutting tools do not shed light on constant trends or regularities in these relationships. In one of the works by Hogmark, et all. **[27],** the following is expressed: “A general theory that encompasses all the relevant tribological properties and parameters involved in the design and application of coated cutting materials, we do not yet have it within reach”.

F) Mechanisms of inserts wear.

Abrasion and adhesion are the most active wear mechanisms for coated carbide inserts **[28].**

Each of these coatings is effective in its own particular field. TiN coating at low speeds is preferred because it is the most effective in preventing build-up.

The bonds that form in a compound determine many of its properties. In the case TiN, its bonds are a combination of ionic, covalent and metallic type **[29]** resulting a strong bond type, which justifies its high hot hardness and high melting point, making the TiN coated insert life be significantly larger than uncoated cemented carbide.

The TiN coating provides high wear resistance, low coefficient of friction, and chemical stability during machining. In turning operations, where wear is the primary failure mode, the TiN coating provides better resistance to abrasive and chemical wear; the most influential in the formation of craters **[30]**.

The bilayer and triple layer inserts, show higher performance due to the Al_20_3 compound that is chemically inert and maintains its hardness and resistance to wear at very high temperatures **[31]**. This compound delays the diffusion of oxygen towards the flank surface, which gives it greater resistance to oxidation. The high hardness at high temperatures and the low thermal conductivity of Al203 make the insert coated with this compound have a higher performance compared to the others, making the dry turning more stable **[32]**.

IV. CONCLUSIONS

The effect of uncoated and coated tungsten carbide (WC) inserts on machinability in AISI 1020 steel turning was studied, taking as machinability criteria: Tool wear and roughness. It was reached the following conclusions:

1. Over the entire length tested, the minimum roughness is obtained using Triple-layer inserts with a variation of Ra = 2µm, the maximum was obtained using an uncoated insert with a variation Ra = 5µm. The other inserts showed variations with Ra = 3µm.
2. The best performance with regard to wear is presented by the triple-layer inserts with a flank wear of 65µm and the minimum corresponds to the uncoated inserts, reaching 500µm of flank wear.
3. Taking as machinability criterion the maximum wear allowed on the flank: $V_B = 300$µm. The inserts that fulfilled their life for the length tested (12,000 mm) were: the uncoated insert (T= 8 mim) and the insert coated with TiN (T= 14.5min); The bilayer and triple layer inserts only consumed 54% and 22% of its total performance, and can be reused.
4. In general, increased wear causes a decrease in roughness; but, from the results obtained it can be inferred, that this is not always the case. Therefore, it cannot be said that there is a direct or inverse relationship between these two factors.

5. The most prevalent mechanism in insert wear is adhesion and abrasion. The inserts not coated and coated with TiN showed wear and accumulation of material, due to the effect of the welding between the piece and the cutting edge (BUE). In double and triple layer inserts it did not show this phenomenon due to the Al_20_3 compound that is chemically inert at high cutting temperatures

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