Effect of Multi-Coats of Cutting Tools on Surface Roughness in Machining AISI 1045 Steel

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Abstract

In this study, orthogonal machining tests in dry turning method are performed on (AISI 1045 St.), in order to examine the influences for the type and number of coatings on surface roughness. The cutting tools used are (TiN, TiN/TiC, and TiN/Al_2O_3/TiC); multiple layers coated cemented carbide inserts. The tests are performed at five different cutting speeds (80, 112, 155, 220 and 300) m/min, while the feed rates are kept to be (0.08, 0.11, 0.14, 0.16 and 0.2) mm/rev respectively, at constant depth of cut and tool geometry. The results showed that (TiN/TiC) coated cutting tools gave best results for surface finish compared with TiN/Al_2O_3/TiC, TiN and uncoated tool, for all the selected machining conditions. The experimental results showed that, when the cutting speed is increased from (80-300)m/min and feed rate is reduced by (250%), the values of surface roughness is decreased by: (20%) for uncoated tool insert ,(27%) for single coated layer insert (TiN), (55%) for double coated layer insert (TiN/TiC) and (49%) for triple coated layer insert (TiN/Al_2O_3/TiC).

Key words: surface finish, roughness, machining parameters, coated tools.

تأثير عدد طبقات الكساء لعدد القطع على الخشونة السطحية عند تشغيل صلب نوع (AISI 1045 St.)

الخلاصة

يتضمن هذا البحث دراسة لمجموعة تجارب مختبرية تحت ظروف القطع المتعامد عند التشغيل الجاف لصلب (AISI 1045 St.) ، وذلك لغرض معرفة تأثيرنوع وعدد طبقات الكساء لعدة القطع على الخشونة السطحية للمعدن المشغل. تم استخدام ثلاثة أنواع من مواد الكساء للعدة منها: المكسية بكل من المواد التالية: (TiN و TiN/TiC و TiN/Al_2O_3/TiC). في حين كانت العدة الرابعة غير مكسية. تم اختيار خمس قيم من سرع القطع وهي:
(155, 220, 300 80,112,) م/دقيقة ، كذلك تم اختيار خمس قيم اخرى للتغذية وهي (0.11, 0.140,0.08, 0.16, 0.2 ملم/دوره، في حين تم تثبيت قيمة عمق القطع وهندسية عدة القطع. أظهرت النتائج بأن عدة القطع المكسية بطبقتين (TiN/TiC) أعطات أقل القيم من حيث الخشونة السطحية وتحت جميع ظروف القطع المختارة وذلك بمقارنتها مع النوعين الاخرين وهما العدة ذات الطبقة الواحدة وذات الثلاث طبقات كساء فضلا عن عدة القطع الغير مكسية. حيث وجد عمليا بانه عند زيادة سرعة القطع من (80-300) م/دقيقة وعند تقليل قيم التغذية بمقدار(250%) فان قيم الخشونة السطحية تنخفض بمقدار يصل الى: (20%) لعدة القطع الغير مكسية، (27%) لعدة القطع المكسية بطبقة واحدة (TiN)، (55%) لعدة القطع المكسية بطبقتين من(TiN/TiC)، و(49%) لعدة القطع المكسية بـثلاث طبقات (TiN/Al_2O_3/TiC).

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1-Introduction:

Surface roughness in addition to tolerances imposes one of the most critical constraints for cutting parameter selection in manufacturing process planning. A considerable amount of studies has been investigated to the general effects of the cutting speed, feed rate, depth of cut, nose radius etc, on surface roughness. In machining, surface finish is one of the most commonly specified customer requirements of surface quality on machined parts [1]. The first study on surface roughness was performed in Germany in 1931[2], because of this study, the surface qualities were arranged as the standard (DIN 140). Surfaces are expressed as “machined or not machined surfaces”. Surface roughness is mainly a result of process parameters and cutting conditions. The surfaces are classified according to tactile feeling and the naked eye; Surface qualities are designated in four different forms: coarse, rough, medium and fine. Kopac and Bahor (1999)[3], studied the changes in surface roughness depending on the process conditions in tempered (AISI 1060 and 4140 steels), found cutting speed to be the most dominant factor if the operating parameters were chosen randomly. They also reported that, for both steel types, the cutting tools with greater radius cause smaller surface roughness values. Similar studies were published by Yuan et al. (1996)[4] and Eriksin and Ozses (2002)[5]. Gokkaya et al. (2004)[6] investigated the effect of cutting tool coating material on the surface roughness of (AISI 1040 steel). In their study, the lowest average surface roughness was obtained using cutting tool with coated (TiN). A (176%) improvement in surface roughness was provided by reducing feed rate by (80%) and a (13%) improvement in surface roughness was provided by increasing the cutting speed by (200%). The cutting tool is the most critical part of the machining system today approximately (85%) of carbide tools are coated, almost exclusively by the chemical vapor deposition (CVD) process [1]. Yusuf Sahin et al**.** (2004)[7] studied the effect of PVD coated ceramic tools on surface roughness in turning of (AISI 1040 carbon steel) under different cutting conditions of cutting speed, feed rates and depth of cut. The established equations clearly show that the feed rate has greater effect on surface roughness followed by the cutting speed. However, it is increased with increasing the feed rate but decreases with increasing the cutting speed and the depth of cut.

2-Surface Roughness Parameters

Surface roughness could be specified in many different parameters. Due to the need for different roughness parameters were developed. Some of the popular parameters of surface finish parameters in a wide variety of machining operations, a large number of newly developed surface specifications are described as follows:

$$R_a = \frac{1}{L}\int_0^L |Y(x)| dx$$

where

R_a = the arithmetic average deviation from the mean line.

L = the sampling length.

y = the ordinate of the profile curve.

It is the arithmetic mean of the departure of the roughness profile from the mean line. An example of the surface profile is shown in Fig.(1), Roughness average (R_a), this parameter is also known as the arithmetic mean roughness value, AA (arithmetic average) or CLA (center-line average). (R_a) is universally recognized and the most used international parameter of roughness, (ISO 4287, 1997 standard). [8].

3-Cutting tools, machine tool and surface roughness measuring instrument

The following four types of cemented carbide inserts are used.

- Insert No.1 – uncoated cemented carbide (P20).
- Insert No.2 – (TiN) coated.
- Insert No.3– (TiN/TiC) coated.
- Insert No.4 – ($TiN/Al_2O_3/TiC$) coated.

All the inserts have identical geometry designated by the American National Standard Institute (ANSI) as [CNMM 120404]. Table (1) shows the mechanical properties of coating layers.[9]. The inserts were mounted rigidly on a right hand style tool holder, the tool holder is designated by (ANSI) as [PCLNR 2020 K 12]. [10,11]. During the experimental investigations, (AISI 1045St.)test samples are hollow cylinder of dimensions(Ø72 × 350) mm, are prepared and used to achieve orthogonal cutting conditions. Chemical composition obtained by spectral analysis and other mechanical properties of the test samples are given in table (2). Table (3) shows the Chemical composition of the (AISI 1045 St.). The machining conditions are selected as recommended in the standard (ISO 3685).

- 5 different cutting speeds, (80, 120, 155, 220 and 300) m/min.
- 5 different feed rates, (0.08, 0.11, 0.14, 0.16 and 0.2) mm/rev.
- Depth of cut (0.5 mm), the tool nose radius is (0.04 mm).
- Rake angle (-5°), clearance angle (5°).

Cutting tools are made of tungsten based cemented carbide (P20), surface roughness was measured by a (Talysurf4) and measurements were repeated (3) times. To measure the surface roughness formed by machining the workpieces, the cut-off length was taken as (0.8) mm and the sampling length as (5.6) mm. For the turning operations, a (TOS) type (SN50) universal lathe was used under orthogonal machining conditions.

Specifications of the lathe are mentioned in table (4).

4-Results and Discussion

This paper demonstrated that the cutting speed had a significant impact on surface roughness despite its complex nature of impact. In a certain range, the surface roughness improves as the cutting speed increases. However, the surface roughness will deteriorate due to many reasons as well as chatter when speeds reach a certain region, after this region, the surface roughness will be found to improve again. The average surface roughness values (R_a) obtained by orthogonal cutting conditions for five values of cutting speeds and five values of feed rates, using four different cutting tools in order to investigate the effects of coating layers on surface roughness of machined surfaces. According to the coating type and number of layers, the results show that the lowest average surface roughness was obtained when using double layer coated insert tool (TiN/TiC), followed by triple layer coated insert tool (TiN/Al_2O_3/TiC) and then by single layer coated insert tool (TiN). The highest average surface roughness is obtained in machining by uncoated cemented carbide tool tip. Table(5) shows the final results for the experimental tests needed for this paper, the table shows one hundred tests being achieved in order to select the optimum cutting conditions related to the type of coating and surface roughness. Fig (2,3,4,5and 6) shows the relation between cutting speed and surface roughness for various coated tools and uncoated one, the figures show that when the cutting speed is increased from (80 to 300)m/min , the feed rate is reduced from(0.2 - 0.08) mm/rev, the surface roughness is reduced by (14-24)% for uncoated tool, (23-31)% for (TiN) coated insert, (20-41)% for (TiN/TiC) coated insert, (21-32)% for (TiN/Al_2O_3/TiC) coated insert. The reason for the lower average surface roughness obtained from the tools coated with (TiN/TiC) could be that the insert coated with (TiN/TiC) have a higher coefficient of friction and thermal conductivity compared with the other (3) tools. The roughness values obtained are high, possibly due to the ductility of the (AISI 1045 Steel). The improvement in surface roughness depending on the augmentation of cutting speed is an expected feature and improving the surface roughness by increasing the cutting speed is a widespread method according to the literature [1, 11, 12, 13, and 14]. The improvement in surface roughness can be explained due to easier deformation process, because of the increasing temperature at high speeds, i.e. the easy deformation of workpiece type at the cutting side beyond the tip radius, and chip flow zone occurring at these high temperatures.For double layer coated insert tool (TiN/TiC), at low feeds (0.08)mm/rev, and low cutting speed (80)m/min, the considerable improvement is achieved from R_a=(3.2 - 1,9) µm, i.e. (41%) by increasing the cutting speed till it reaches to (300) m/min i.e. by about (275%), that reveals the effect of cutting speed on the surface roughness clearly. Table (5) shows that the surface roughness is affected by the cutting tool coating material, cutting speed and feed rate. The surface roughness values obtained by using (TiN/TiC) coated tool is lower than those obtained by using (TiN/Al_2O_3/TiC), (TiN) coated, and uncoated cutting tool. Again, this difference is more considerable at lower cutting speeds. The better surface features of (TiN/TiC) coated tools may be due to the smaller friction coefficient of this type than the others, and the developing temperature. At lower cutting speeds (80 m/min), depending on the developing low temperatures at the tool-chip interface region, the developing high temperatures at high speeds facilitate the occurrence of flow zone, Consequently, the differences between the surface roughness values obtained by using each of the (4) sets are decreasing.

Finally it can be concluded from the main results involved in table (5), that when the cutting speed is increased from (80-300m)/min and feed rate is reduced by (250%),

- For uncoated tool insert, the values of surface roughness is decreased from Ra= (5 to 4) µm, i.e. (20%).

- For TiN coated layer insert from Ra = (4.8-3.5) µm, i.e. (27%).
- For TiN/TiC coated layer insert from Ra = (4.2-1.9) µm, i.e. (55%).
- For TiN/Al_2O_3/TiC coated layer insert from Ra = (4.5-2.3)µm, i.e. (49%).

5-Conclusions

The effects of coated materials and machining parameters on the (AISI 1045 St.) workpiece are investigated under orthogonal cutting conditions. The results of experimental work can be summarized as follows:

- According to the coating types, the best surface roughness obtained by means of coated cutting tools with TiN/TiC double layer coats. The next best cutting tool was TiN/Al_2O_3/TiC, then TiN, then uncoated one respectively.
- For double layer coated insert tool (TiN/TiC), the considerable improvement is (41%) by increasing the cutting speed to. by about (275%).
- The surface roughness values obtained by using (TiN/TiC) coated tools are lower than those obtained by using (TiN/Al_2O_3/TiC), (TiN) coated, and uncoated cutting tools by about (10%).
- when increasing the cutting speed from (80-300m)/min and reducing feed rate by (250%), the values of surface roughness is decreased (20%) for uncoated tool insert, (27%) for TiN coated layer insert, (55%) for (TiN/TiC) coated layer insert, and (49%) for (TiN/Al_2O_3/TiC) coated layer insert.
- A good correlation of cutting speeds and feed rates can result in better surface finish.

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Table (1): Mechanical properties of coating layers tools used in experiments [9].

Coating layer	TiC	AL_2O_3	TiN
Young's Modulus(E)(Gpa)	450-496	340-400	250
Poisson's ratio (ν)	0.19-0.24	0.23	0.25
Density(ρ)(kg/m^3)	4650-49000	3780	4650

Table (2): Mechanical Properties of (AISI 1045 St.) at room temperature [10].

Ultimate tensile stress	(σ_u)	515 Mpa
Yield stress	(σ_y)	484 Mpa
Young's Modulus	(E)	200 Gpa
Poisson´s ratio	(ν)	0.29
Brinell Hardness	HB	170
Shear modulus	(G)	80 Gpa

Table (3): Chemical Composition of (AISI 1045 St.)[11].

C%	Si%	Mn%	P%	S%
0.45	0.2	0.58	0.02	0.025

Table (4): Specifications of Centre Lathe Machine used in Experimental Tests.

Spindle speed	Feed rate	Center length	Total power
22.4 – 2000 (r.p.m)	0.08 - 6.4 mm/rev.	1500 mm	6.6 KW for 50 Hz

Table (5): Surface Roughness values at different machining conditions for tools with multilayer-coated Inserts.

Feed rate (mm/rev)		0.08				0.11				0.14			
	Insert No*	1	2	3	4	1	2	3	4	1	2	3	4
		Surface roughness(Ra) (μm)											
Cutting speed m/min	80	4	3. 5	3.2	3.4	4.1	3.7	3.5	3.6	4.5	4.2	3.9	4
	112	3.7	3. 5	3.3	3.4	4	3.5	3.4	3.5	4.3	4	3.7	3.9
	155	3.5	3. 3	3.1	3.3	3.9	3.3	3.2	3.2	4.1	3.8	3.4	3.5
	220	3.2	3	2.6	2.8	3.5	3.1	2.8	2.9	3.8	3.5	3	3.1
	300	3.1	2.4	1.9	2.3	3.3	2.7	2.3	2.5	3.6	3	2.6	2.7

	Feed rate (mm/rev)	**0.16**				**0.20**			
	Insert No*	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
		Surface roughness(Ra) (µm)							
Cutting speed m/min	**80**	**4.8**	**4.5**	**4.2**	**4.3**	**5**	**4.8**	**4.2**	**4.5**
	112	**4.7**	**4.3**	**3.9**	**4.1**	**4.8**	**4.6**	**4.1**	**4.4**
	155	**4.4**	**3.8**	**3.6**	**3.8**	**4.4**	**4.2**	**3.8**	**4**
	220	**4.1**	**3.3**	**3.2**	**3.4**	**4.2**	**3.7**	**3.4**	**3.5**
	300	**3.9**	**3.1**	**2.8**	**3**	**3.8**	**3.3**	**3.1**	**3.1**

* Insert No.1 – Uncoated cemented carbide (P20).

Insert No.2 – (TiN) coated. /single layer.

Insert No.3– (TiN/TiC) coated. / double layer.

Insert No.4 – ($TiN/Al_2O_3/TiC$) coated. / triple layer.

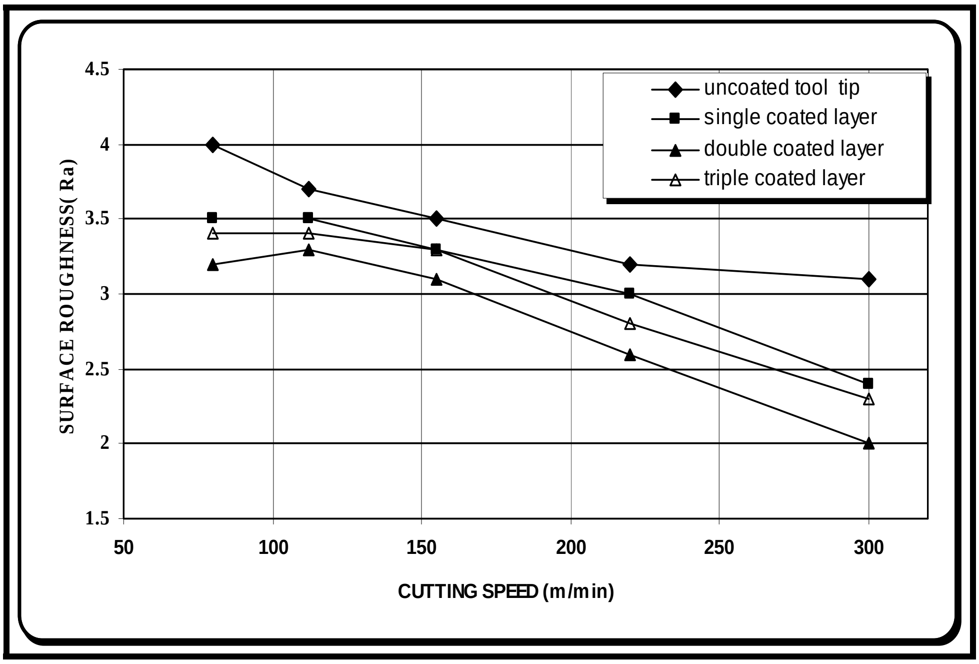

Fig. (2): Relation between cutting speed and surface roughness for various coated tools at (S=0.08) mm/rev.

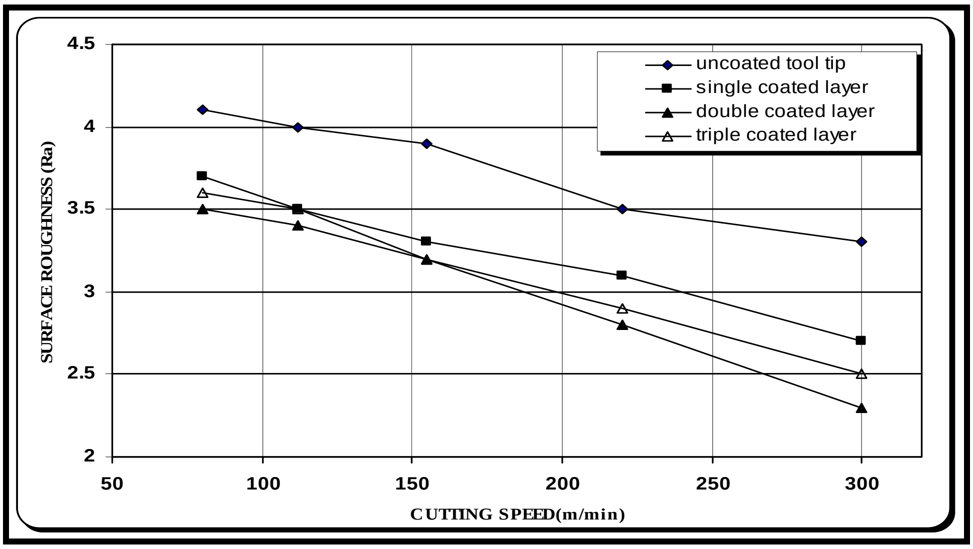

Fig. (3) Relation between cutting speed and surface roughness for various coated tools at (S= 0.11) mm/rev.

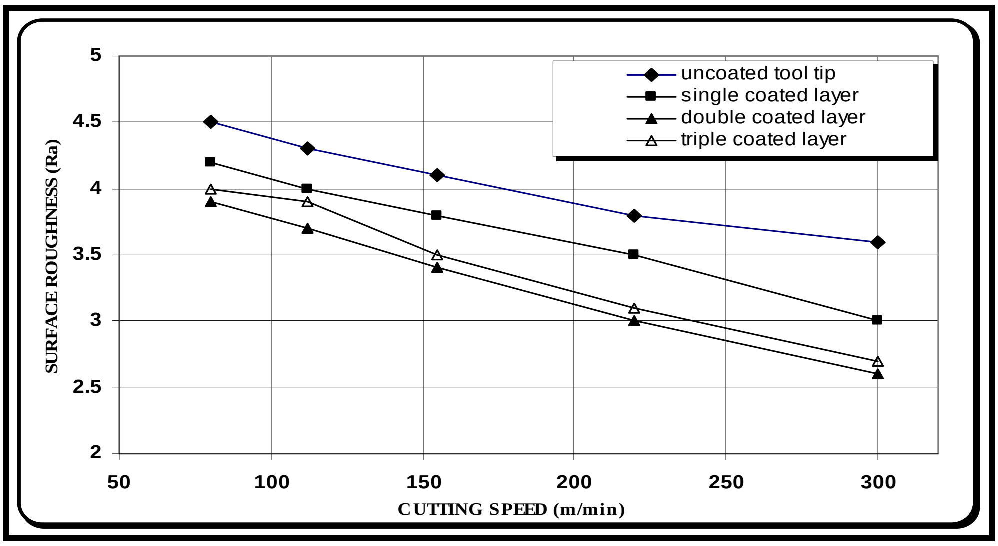

Fig.(4): Relation between cutting speed and surface roughness for various coated tools at (S= 0.14) mm/rev.

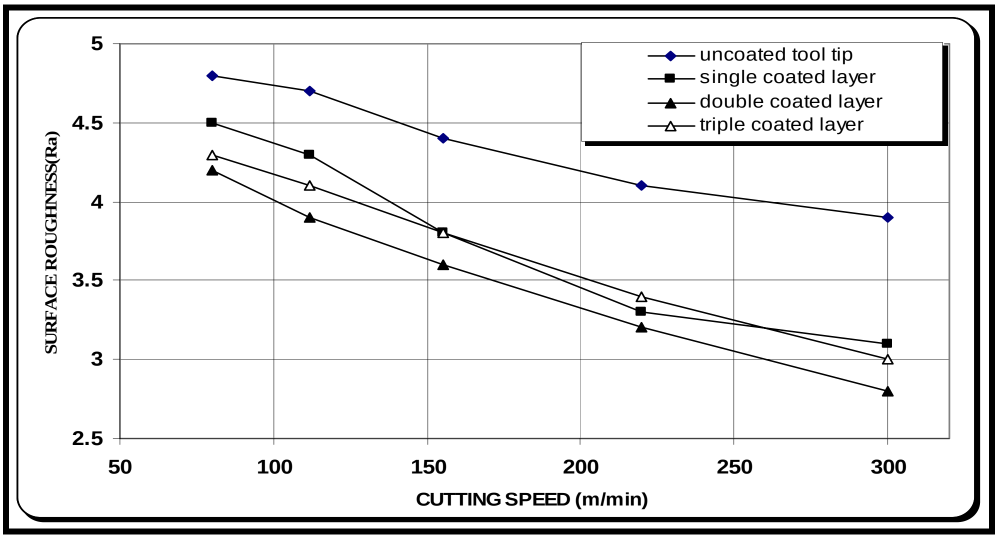

Fig. (5): Relation between cutting speed and surface roughness for various coated tools at (S=0.16) mm/rev.

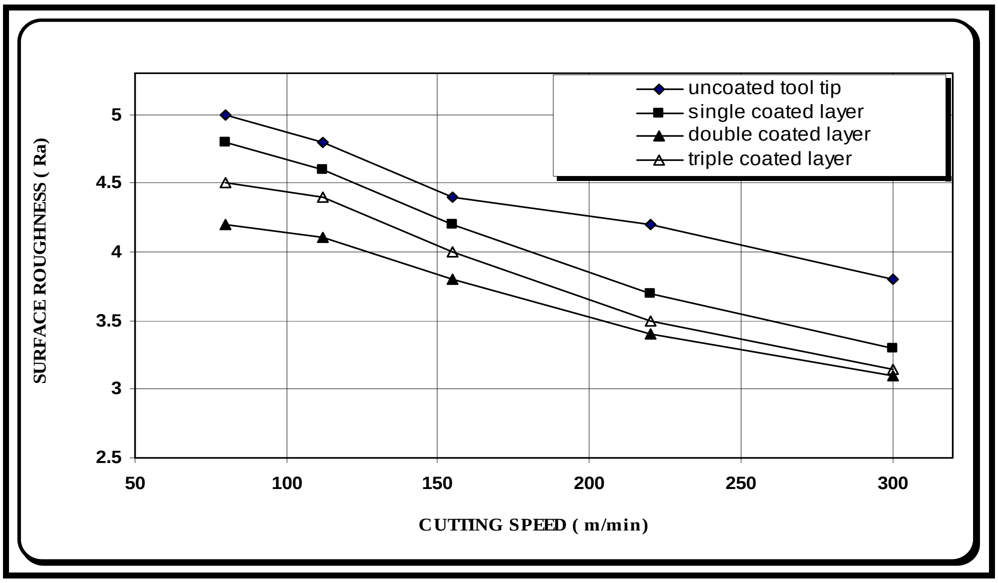

Fig. (6): Relation between cutting speed and surface roughness for various coated tools at (S= 0.2) mm/rev.

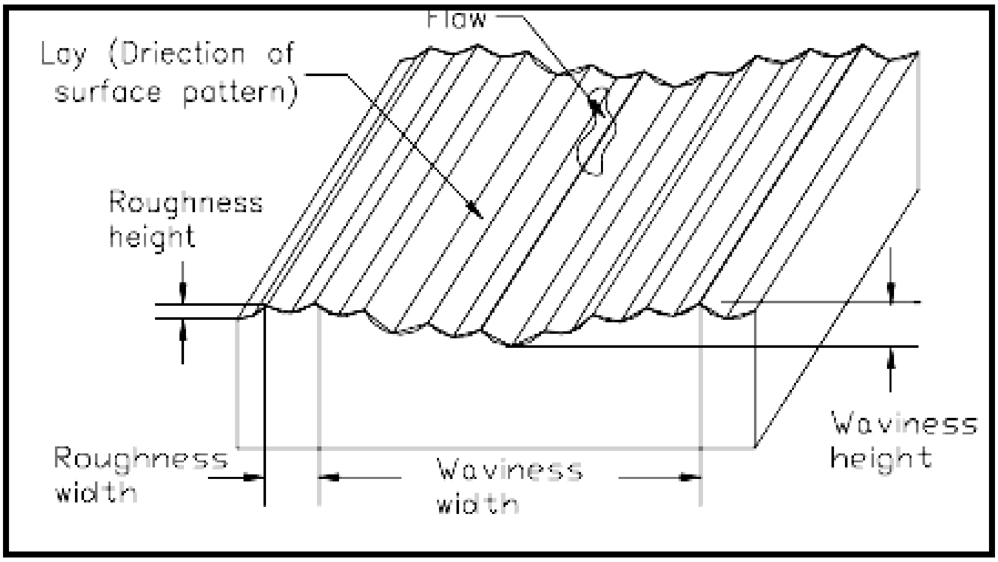

Fig. (1). Roughness and waviness profiles