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A Study on Influence of Process Parameters on Tool Wear of PVD Coated Cutting Tools in Orthogonal Machining of Al6351: A Finite Element Analysis

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Abstract:

Objectives: In this effort, Finite Element Methods (FEM) were applied to judge the impact of various cutting factors on the machining of Aluminum alloy Al6351 by using diverse inserts. **Methods/Statistical Analysis**: Stress variations on the tool inserts were examined by the FEA using ANSYS. Finite Element Study stood incorporated in learning of power in variety of coatings and uncoated cutting insert on manufacturing of Al 6351. Various coatings like TiN, TiC, Al_2O_3 and uncoated tungsten carbide inserts were used in this learn. The happening and allotment of various stress in the cutting insert were premeditated and related for uncoated and various coatings. **Findings**: The stress on the cutting tool rise with feed. Though an effective force in machining was nearly similar observed in overall experiments, cutting insert stress stood prejudiced with respect to feed force and machining force and without the passive force importance on metal cutting in aluminum alloy. **Application/Improvements**: Investigating the stress distribution in tool inserts and microscopic images depicting the tool wear and the type of wear.

Keywords: Finite Element Analysis, Orthogonal Machining, PVD Coated Cutting Tools

1. Introduction:

One of the majority issues witnessed in the area of cutting of aluminum and its alloys in modern years engages the footstep towards lessening or eradicating the application of coolants, because the employment of coolants distresses atmosphere, put in to the cost of cutting and the cost involved in removal of ravage[1, 2]. In precise, aluminum alloys are typically known as significant metals with aspect to manufacturing without coolants. Without the utilization of coolants, these metals harshly stick to the insert outside and shape a metal formed edge because of their small melting temperature and elevated ductility, following to decline of the exterior profile of the job and machining insert breakdown[3].

Therefore, a large amount of research is carried out with respect to cutting insert metals, tool dimensions, insert coatings and roughness. Aluminum alloy is also called to be one of the utmost hard-to-machine metals. Deposition of aluminum alloys on the superficial of the tools suffered through metal elimination of these blends grow hefty notching and alteration of the tool rake superficial due to the frequent withdrawal of the insert metals[4]. Owed to its extraordinary strength, machining forces developed during machining touch extraordinary value, alter the metal removal system and may cause vibration which affects the external roughness[5].

In later days, FEA grounded on Eulerian and modernized Lagrangian originations have been established to analyze the metal cutting. The Eulerian formulation was functional in numerous FEA models employed to model metal removal process. Though, application of the Legrangian formulation was further well-known due to its capacity to replicate chip development from the initial level to steady-level machining[6, 7]. Finite element methods like element separation principle, the replication of the cutting tool wear, remeshing zone and friction modeling smeared in advance for correctness with effective nessin

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FEA in machining. Concentrating in study on aluminum machining using FEA, will be noted as huge fraction of availabilities explain an imitation consequences in cut out materials development method throughout machining employing many analysis softwares[8, 9]. The consequences of the imitation relating to chip development process, heat and chip arrangement, the learning of machining tool wear, and residual stress distribution were studied. Countless researches are available in the area regarding the contribution of machining forces on insert stresses during manufacturing[10, 11, and 12]. Mathematical representation for insert stresses concerned during manufacturing products in dry condition and analyzed the power of a succession of conditions on machining forces by means of FEA software[13].

In this work, an authority of the machining conditions on the cutting forces through the machining of Aluminum alloy (Al6351) is studied. Dissimilarities observed in Von Misses stresses in the machining insert were examined by the FEA using ANSYS. Finite Element Analysis was employed to decide the power of a variety of coatings and uncoated cutting insert on manufacturing of Al 6351. Coated and uncoated tungsten carbide tools were used together experimentally and as FEM models to learn how the stress is shared and compared to each other, under a variety of cutting circumstances.

2. Experiment:

Aluminum alloy (Al 6351) with an initial 95 HRC was employed as job material in the experiments for machining. The metals present in of the job material is detailed in Table 1. In these experiments, tungsten carbide inserts (WC) with a standard description TNMG 16 04 08 H13A was employed. Machining experiments were performed on a turning lathe machine. In total 25 experiments for machining was performed out lacking of coolants where five unrelated machining speeds and feed, and lone penetration of machining were employed. For purpose in comparison of results obtained from uncoated inserts, the same machining operation with same process parameters were performed in coated inserts. The various coating employed are Titanium Nitride (TiN), Titanium Carbide (TiC) and Alumina (Al_2O_3). Main parameters which govern machining used in these tests are shown in Table 1. The cutting force (F_C) and feed force (F_F) were analyzed with help of Kistler piezoelectric dynamometer.

The micrographic images depicting the wear in the edges and faces of the inserts were obtained using SEM. The study was performed to analyze how the forces vary with respect to machining parameters on various conditions. The tool wear is quantified and studied using optical tool maker's microscope interpretation. Assessment of hardness of inserts without coating and with coating is done using Brinell hardness tester for various tests shown in Table 2. The value of surface finish gained out of machined jobs is measured using Perthometer.

3. Finite Element Analysis:

Finite element analysis was used in this paper to study how the stresses are distributed with esteem to machining forces throughout metal removal. Tool frame, tool and the holding component were initially modeled in modeling package by taking into account all the geometric clearance angles and then exported to analysis package.

SOLID 95 model, 3D ten-nodule tetrahedron structure hard incorporated in four dislocation behavior was selected for the analysis. The density of meshing was also selected as fine for the cutting tool element. With respect to the solutions generated from the analysis software ANSYS, 48729 nodes and 11012 rudiments were functional for the insert frame and cutting tool.

Table 1. Composition of Al 6351

Element	Weight %
Al	97.8
Si	1
Mn	0.6
Mg	0.6

Table 2. Test Parameters

Job/Workpiece metal	Al 6351
Cutting tool insert	TNMG 16 04 08 H13A
Young's modulus	590GPa
Poisson's ratio	0.22
Tool Holder	
Young's modulus	210GPa
Poisson's ratio	0.3
Cutting Parameters	
Cutting speed,V (m/min)	225, 300, 350, 400, 500
Feed rate, f (mm/rev)	0.05, 0.075, 0.1, 0.125, 0.15
Depth of cut, d (mm)	1

Although holding equipment was abandoned on prototypical, holding force functional on the insert through the holding equipment are working in deliberation on study. Holding forces are applied to the insert with the frame. Machining forces are engaged to knots in the material – tool trace parts as set: the chief machining force was practical as triangular superficial load through the material – tool trace length. The feed force is set in negative Z way and the machining force in positive X way at the interaction parts. In instruction to lessen calculation period in the learning, some guesses were conceded out as follows:

- The weight in the insert frame and the insert are forsaken.
- The machining insert active on the study was fresh with indolent (strident).
- The vibrations and heats engaged on the machining are too bounced on learning.
- The still examination important technique was active.

As a border state for restraint, the degree of freedom of the nodules in the area to shape up the insert frame to the dynamometer, on the insert frame rising length, was selected zero in all directions.

4. Results and Discussion:

4.1 Cutting Forces

Uncoated carbide and coated carbide inserts having different geometries were employed to judge wear stuffs of Al-6351. The machining force and feed force outputs were analyzed and compared for dissimilar ranges of machining speed and the got yields are set in Table 3. Two stages of feed were deliberated, 0.1 and 0.15 mm/rev and plentiful machining speeds from 225 to 500 m/min. For the 0.1mm/rev feed and the insert without coating, the forces decline with the machining speed and their values are in the range 200 to 1000N. For the similar feed, the forces actions with all the tools with coatings are in the inferior intermission 200 to 600 N. The advantageous result in coat on machining forces is not regained in 0.15mm/rev. On the superior feed and self-sufficiently of the tried tool, the machining force curves depend on the machining tool.

Variations notice dare confidently clarified with connection in wear devices established throughout the experiments and witnessed in rack and flank faces on insert given in Figure 1 and Figure 2. On every experimented inserts, the machining forces shows at least

Table 3. Cutting Forces on Machining with (a) Uncoated Tool (b) TiC Coated (c) TiN Coated (d) Al_2O_3 Coated

(a) Uncoated Tool

S.No	Feed Rate = 0.1 mm/rev		Feed Rate = 0.15 mm/rev	
Speed	Feed Force (F_f)	Cutting Force (F_c)	Feed Force (F_f)	Cutting Force (F_c)
225	173	170	165	200
300	183	287	195	385
350	185	300	195	395
400	165	370	235	385
500	175	405	305	570

(b) TiC Coated

S.No	Feed Rate = 0.1 mm/rev		Feed Rate = 0.15 mm/rev	
Speed	Feed Force (F_f)	Cutting Force (F_c)	Feed Force (F_f)	Cutting Force (F_c)
225	184	180	167	210
300	195	292	198	398
350	198	312	208	399
400	186	380	240	390
500	190	417	310	575

(c) TiN Coated

S.No	Feed Rate = 0.1 mm/rev		Feed Rate = 0.15 mm/rev	
Speed	Feed Force (F_f)	Cutting Force (F_c)	Feed Force (F_f)	Cutting Force (F_c)
225	162	160	165	190
300	175	277	190	375
350	176	290	185	385
400	159	360	225	380
500	166	400	290	550

(d) Al_2O_3 Coated

S.No	Feed Rate = 0.1 mm/rev		Feed Rate = 0.15 mm/rev	
Speed	Feed Force (F_f)	Cutting Force (F_c)	Feed Force (F_f)	Cutting Force (F_c)
225	195	190	185	220
300	205	297	205	405
350	205	310	215	415
400	183	380	255	390
500	195	415	315	580

worth. For the insert without coating, this least worth is got for a machining speed 400m/min, which parallels to a boundary value. For the inserts with coating this boundary cutting speed value appears to be bigger.

4.2 Stress Distribution

The forces involved in metal cutting during different experiments by varying feed rate and speed are given in Table 3. In overall, cutting forces rise with a rise in the feed rate for all experiments. On every machining tests, key machining force (Fc) was determined as greater than extra machining forces. Determined machining force on 0.15mm/rev feed is greater than for 0.05mm/rev feed. Experiments were performed out for all 25 machining tests by different process parameters. Figure 3displays stresses scattering on 225m/min machining speed, 0.05mm/rev feed, 1mmdeepness of machining. Figure 4 displays stress scatterings for 225m/min machining speed, 0.15mm/rev feed, 1mm deepness of machining. Von Mises stress is said as *S*EQV. The serious region in footings in the insert attire for machining speed of 225 m/min, 0.15mm/rev, 1mm deepness of machining, is established as being corresponding to the deepness of machining on the vile machining side of the insert. The possessions on variations in the speed value on von mises stress are displayed in Figure 4. The possessions on variations with feed value on von mises stresses are shown in Figure 5. Normally, for all machining speed, result is exposed every stress rise in analogous to arise in the machining speed irrespective of the deepness of machining. Stress rise as the feed upsurges. The feed is a noteworthy outcome on stresss pecifically for a deepness of machining gauging 1mm. For machining speed of 225m/min, von misses stress enlarged around to 5031MPa at feed 0.15mm/rev when matched to 4745MPa at feed 0.05mm/rev. Riseson machining speed consequences in arise in stress. The outcome in feed on stresses can be obviously witnessed for the cutting speed of 500 m/min. The outcomes for the stresses (*S*EQV) display which

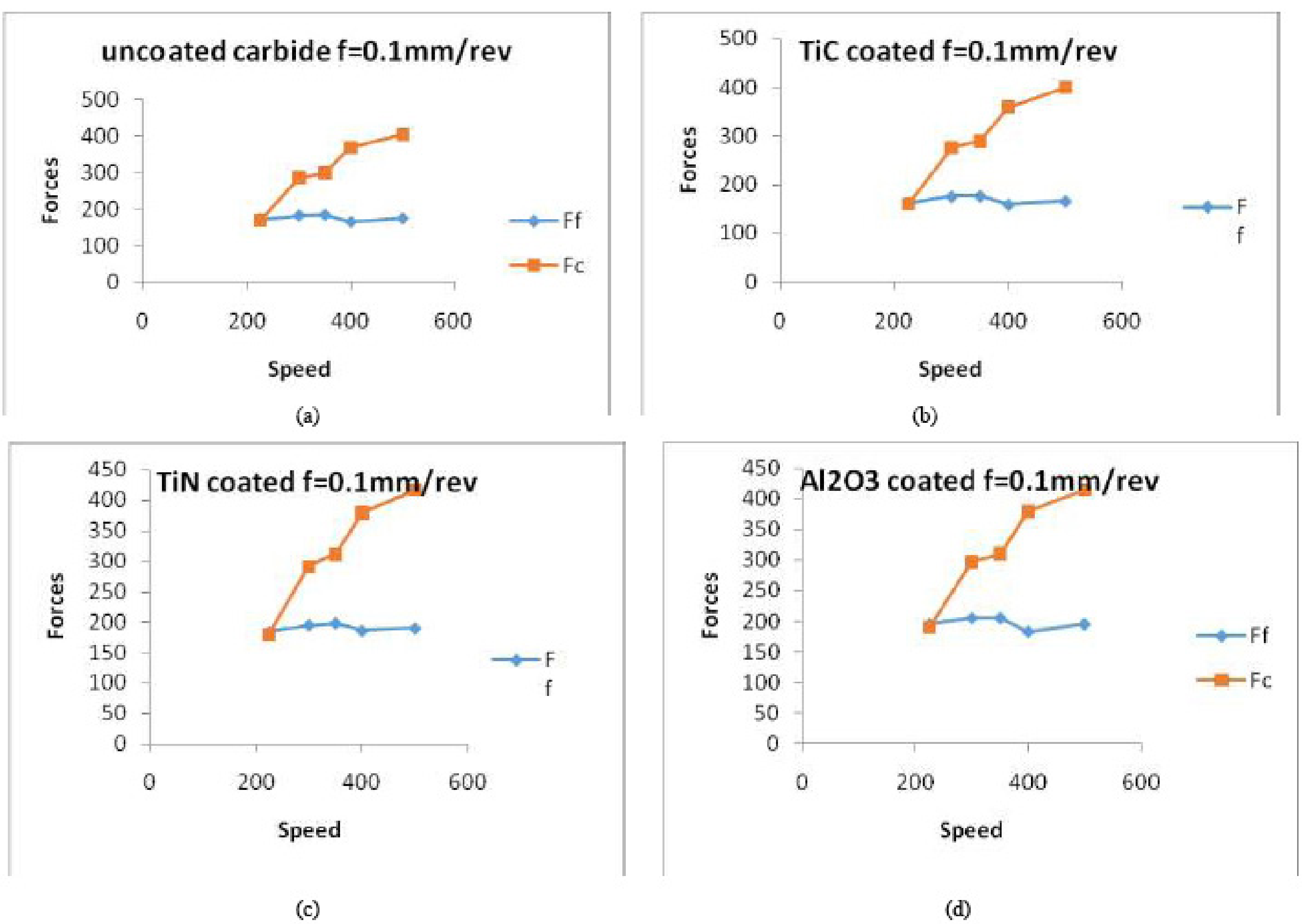


Figure 1. Cutting Speed Vs. Force for **(a)** Uncoated **(b)** TiC Coated **(c)** TiN Coated **(d)** Al2O3 for 0.1mm/rev.

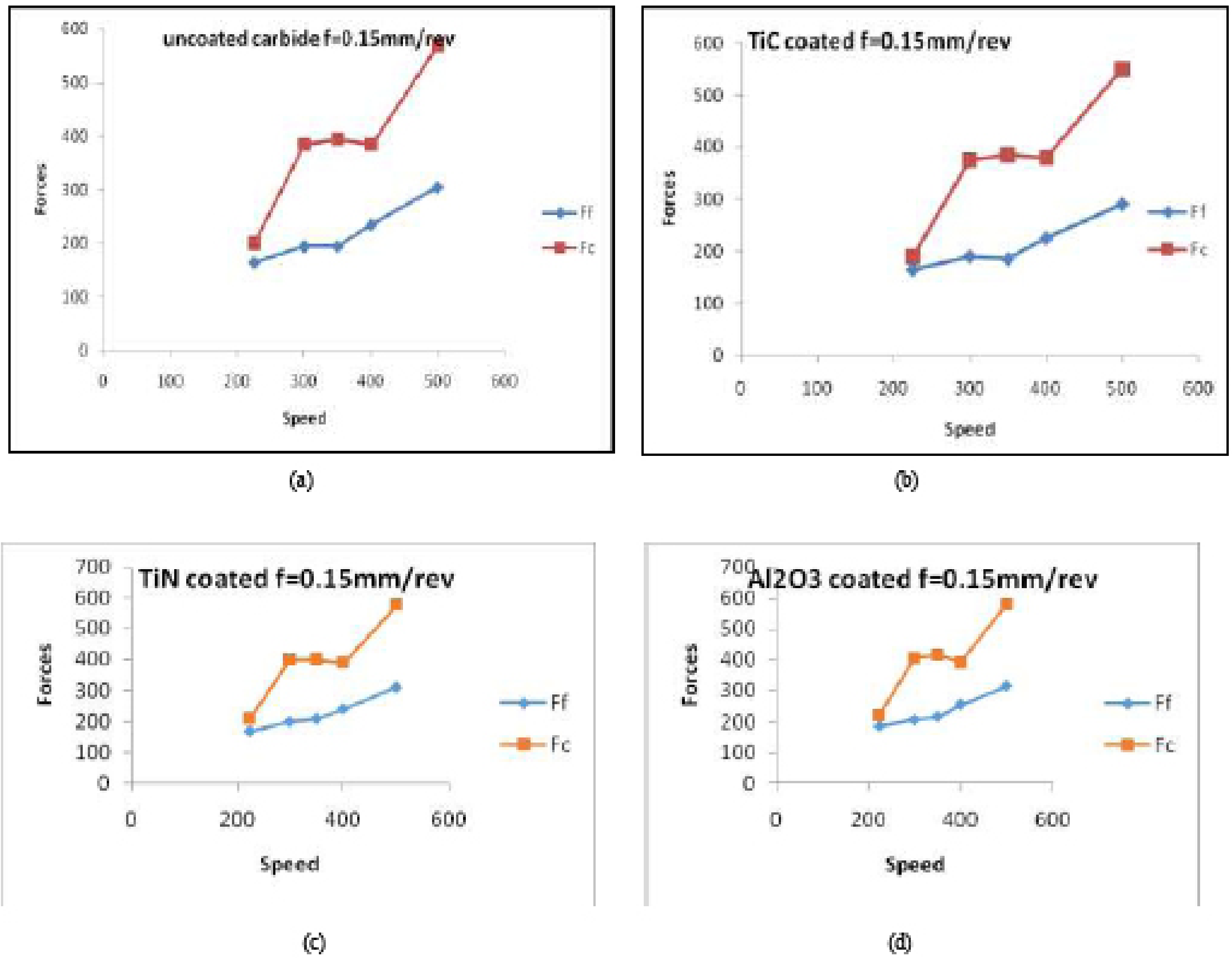


Figure 2. Cutting Speed Vs. Force for **(a)** Uncoated **(b)** TiC Coated **(c)** TiN Coated **(d)** Al_2O_3 for 0.15mm/rev.

the uppermost stress value (11627MPa) happens over for a machining speed at 500 m/min, feed at 0.15mm/rev, and 1mm deepness of machining (Figure 3).Tests of the machining inserts completed after the machining tests display that the uppermost machining insert wear may happen in analogous with stress outcomes for a machining speed at 500 m/min, feed at 0.15mm/rev, and 1mm deepness of machining.

4.3 Tool Wear Pattern Observations

The phase and the alteration in the machining force with speed and feed was analyzed before on direction of experiment numerous process parameters and dissimilar coated tools and to permit dry metal cutting of Al 6351. To endure and attain this process, it is currently thought-provoking to detect the tool wear decorations by exhausting SEM and optical tool makers microscope interpretations. Larger cutting force rise severely the insert wear degree and are insufficient on water less metal cutting Al 6351 in numerous inserts with coatings.

These tools were experimented by machining Al 6351 in persistent feed 0.20 mm/rev, tenacious deepness of machining 2mm and dissimilar machining speeds between 50m/min to 200m/min captivating onto thought of ISO 3685 and developer's commendations. On every test job metals was machined and average flank wear determined. These numerical and wear type are exposed in the following Figure 6 and Table 4, correspondingly.

Position flank attire V_B = 0.3mm was selected in standard rendering to International Standard Organization (ISO 3685). Inserts were disallowed with additional

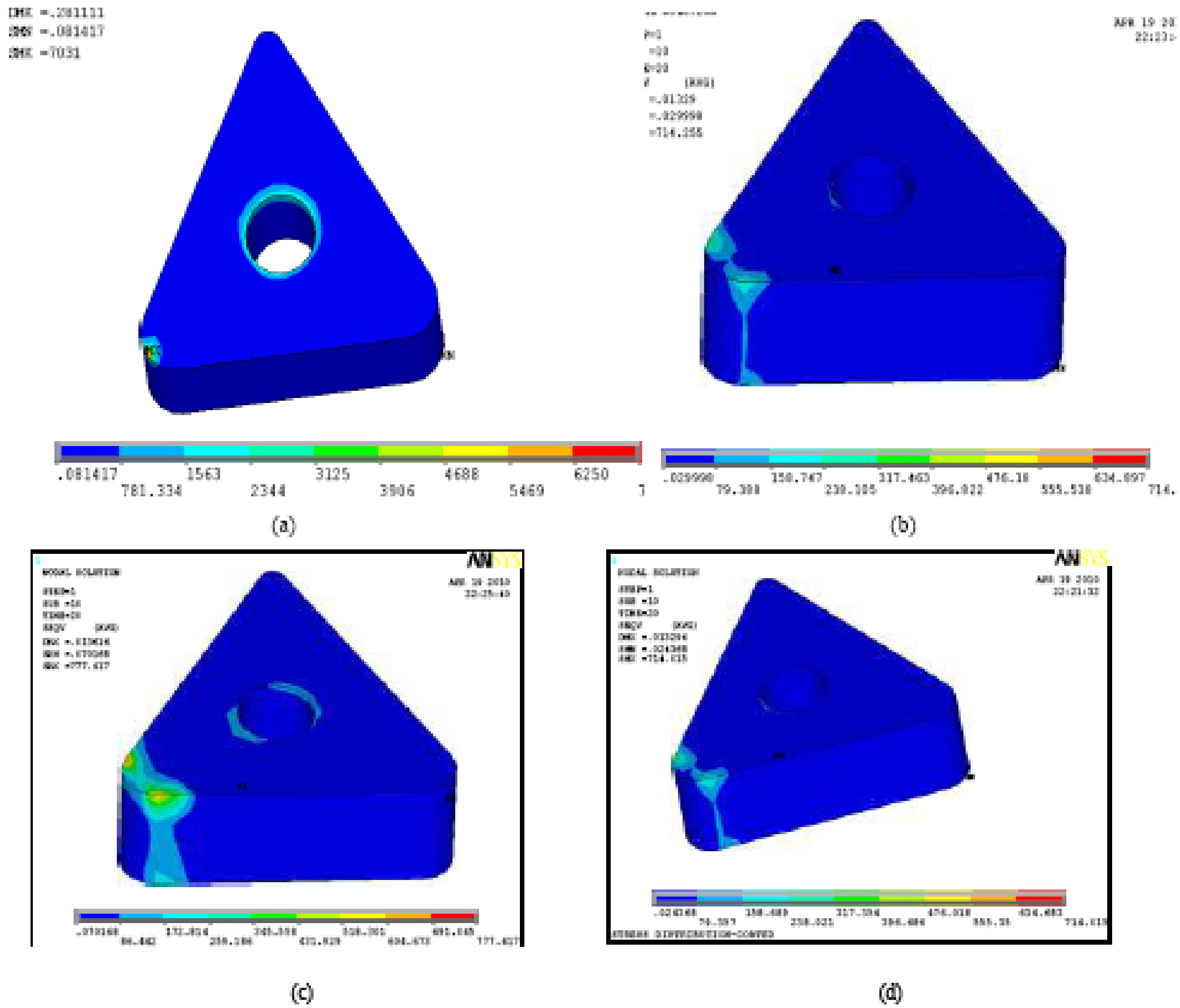


Figure 3. Stress distribution on **(a)** Uncoated **(b)** TiC Coated **(c)** TiN Coated **(d)** Al_2O_3 Coated(Test Conditions: Speed = 225rpm; Depth of cut = 1mm; Feed = 0.1mm/rev).

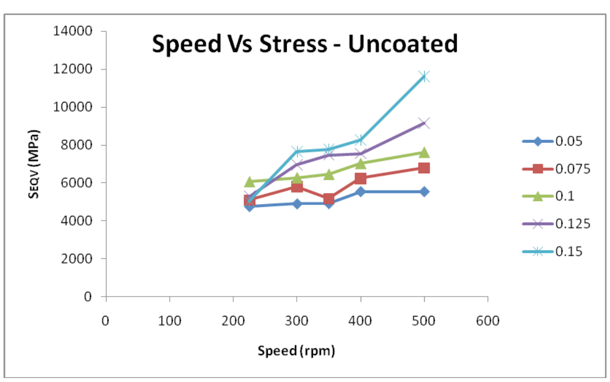


Figure 4. Relationship between the Stress and Cutting Speed for Uncoated Carbide Cutting Tool.

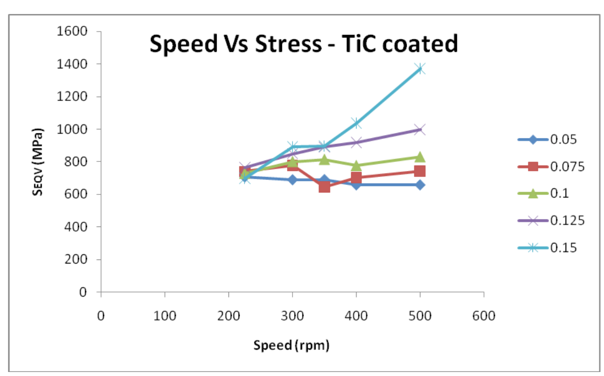


Figure 5. Relationship between the Stress and Cutting Speed for TiC Coated Carbide Cutting Tool.

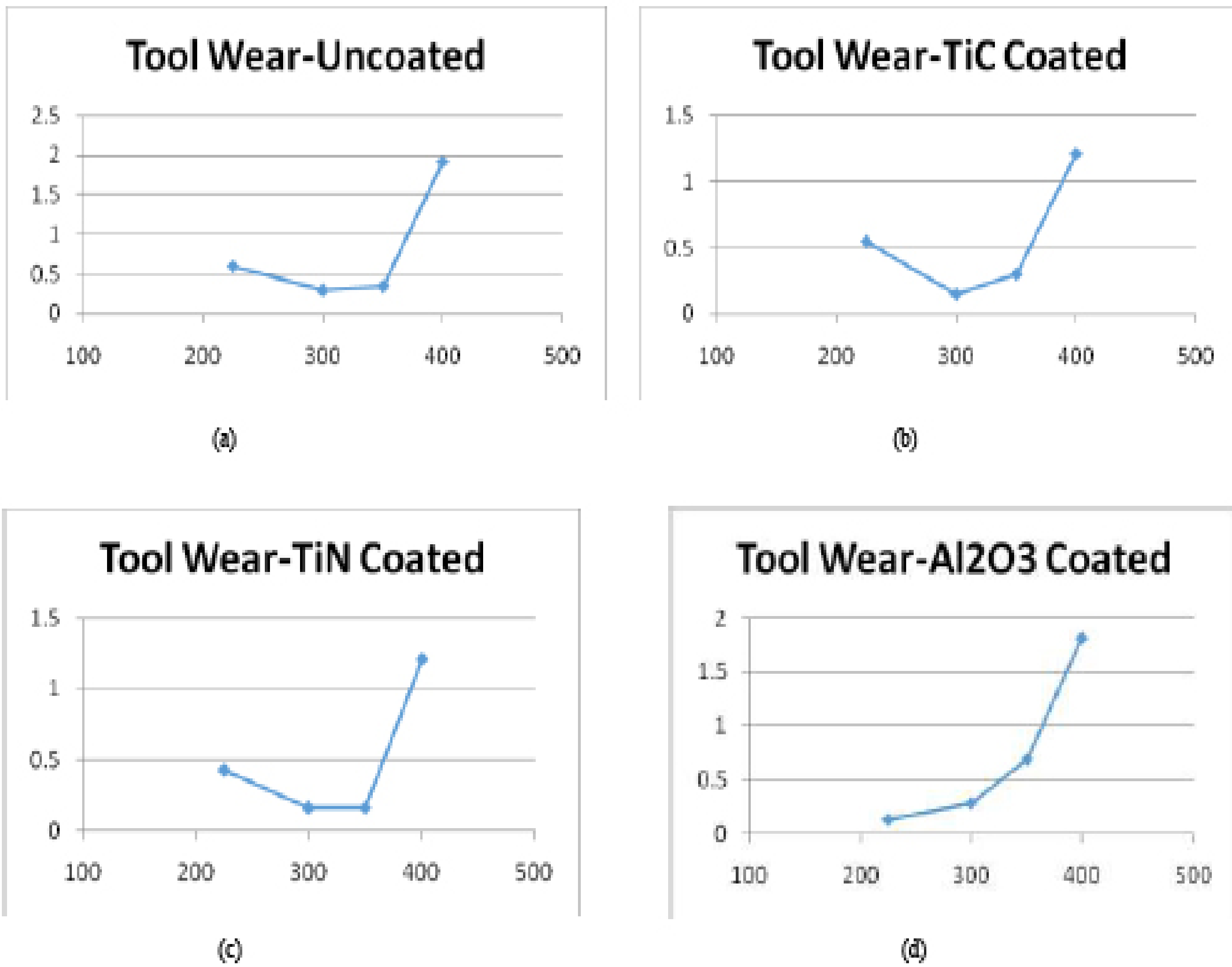


Figure 6. Cutting Speed Vs Tool Wear for **(a)** Uncoated **(b)** TiC Coated **(c)** TiN Coated **(d)** Al_2O_3.

Table 4. Wear Types and Flank Wear Values

Tool material	V=225 m/min		V=300 m/min		V =350 m/min		V =400 m/min	
	VB (mm)	Wear type	VB (mm)	Wear type	VB (mm)	Wear type	VB (mm)	Wear type
Uncaoted	0.6	Flank wear Notch Wear	0.3	Flank wear	0.35	Nose crack	1.92	
TiC	0.55	Flank wear	0.15	Flank wear	0.3	Flank wear	1.21	Plastic Def.
TiN	0.43	Crater wear Flank wear	0.16	Flank wear Notch wear	0.16	Flank wear Notch wear	1.21	Flank wear Notch wear
Al_2O_3	0.13	Flank wear Edge wear	0.28	Crater wear Flank wear	0.69	Crater wear Flank wear	1.82	Nose crack

metal cutting was made still grounded in mixture of the subsequent refusal standards in relative to ISO stock 3685 for insert durability experimentation:

- Typical flank attire is greater than 0.3 mm.
- Extreme flank attire is greater than0.4 mm.
- Tip attire is greater than0.5 mm.
- Notching in deepness of cutline is greater than 0.6 mm. As a consequence, tool without coating is repelled lone at small machining speeds. At large cutting speeds both TiN and TiC tools presented decent presentation related to the other tools. The commendation for the machining tools for the cutting of Al 6351 were TiC type at small cutting speeds Al_2O_3 at large cutting speeds. Carbide insert without coating was not appropriate for cutting Al 6351 at large speed.
- Extreme chipping or disastrous break of the cutting edge.

4.4 Tool Wear Observed with SEM

In the paper, flank side attire and extreme notch attire, which are significant difficulties dipping insert durability, were mostly detected in the metal cutting with machining inserts. They are strongly witnessed and noticeable as shown in the SEM images in Figure 7 and Figure 8.

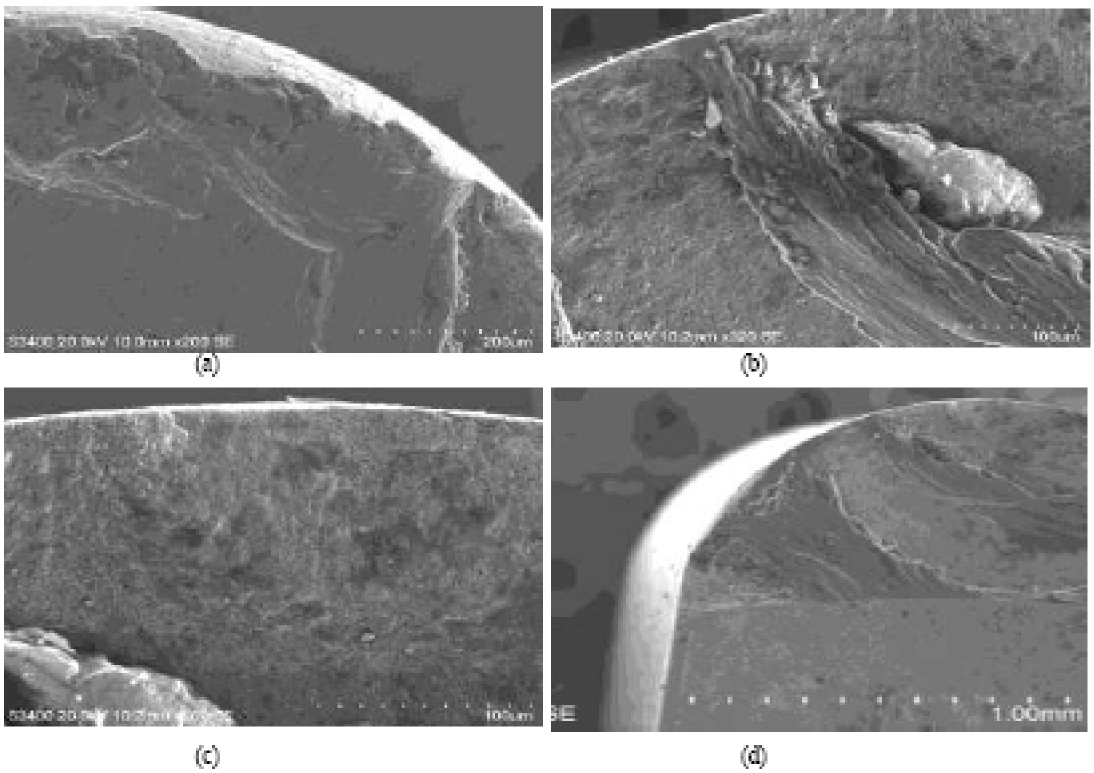
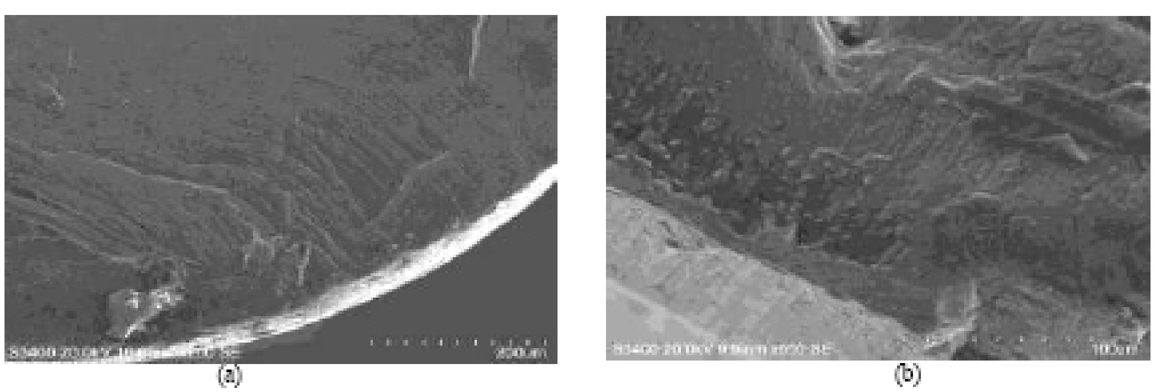
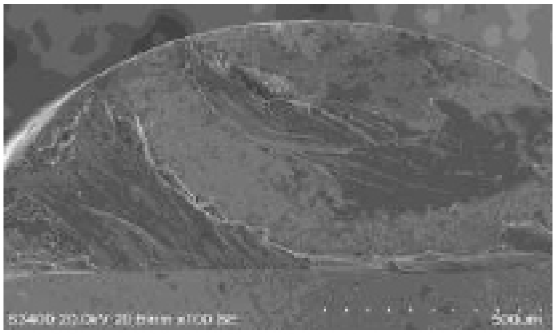
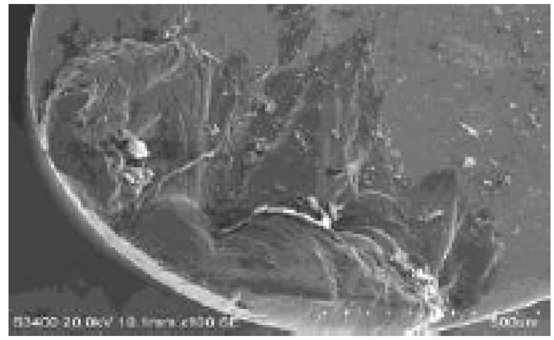


Figure 7. SEM Images of the Wear Profile of **(a)** Uncoated **(b)** TiC Coated **(c)** TiN Coated **(d)** Al2O3 Coated (Test Conditions V = 225rpm; a = 1mm; f = 0.1mm/rev)





(c)



(d)

Figure 8. SEM Images of the Wear Profile of (a) Uncoated (b) TiC Coated (c) TiN Coated (d) Al2O3 Coated (Test Conditions V = 225rpm; a = 1mm; f = 0.15mm/rev)

5. Conclusions

With the aid of the machining tests carried out on the Aluminum alloy work piece, using TNMG 16 04 08 H13A ceramic cutting insert, the consequences of the examinations got by the ANSYS program grounded on FEAis given below:

- Von misses stress in carbide tool rise along rises on feed.
- Thoughout come force in machining was about equal in every experiments, machining insert stresses remained prejudiced by the feed force and machining force and not by the passive force on machining of Aluminum alloy.
- On footings in price involved in metal cutting, the machining speed and feed essential to be designated amid 225 and 400 m/min, and 0.1 and 0.125 mm/rev, correspondingly.
- As an outcome in machining insert stress analysis, from von mises stress variations, the carbide tools in footings of the insert wear may wear out at the space equivalent to the deepness of machining in the base machining edge of the machining insert. Thereafter, this wear manner will be nearly such as the notch wear (groove), and the flank wear on the base cutting edge and grooves in relief face.

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