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STUDY OF THE CERAMIC CUTTING TOOL PERFORMANCE USING DOUBLE RAKE FACE

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ABSTRACT - The objective of this work is to study the effect of the types of ceramic cutting tools on the cutting performance by using double rake tooling. The simulation in this research concerned with the initial cutting process using contact with the workpiece state.

The results show that the concept of double rake tooling design proved to be the cutting performance of cutting process. It is also proved, that for every cutting condition, there is an optimum geometry and material of cutting tool. This work show that ceramic material of metal cutting tools has better performance from cemented carbide tools comparing with other previously published papers.
Keywords: ceramic, cutting tool, finite element.

1. INTRODUCTION

The study of metal cutting focuses on the features of the behavior of tool and work materials that influence the efficiency and quality of cutting operation. Development of cutting tool materials has held a key position. The technology of metal cutting has been improved by contributions from all the branches of industry with an interest in machining. Productivity has been increased through replacement of carbon tool steel by different types of cutting tool which allowed cutting speeds to be increased by many times. The special properties required for cutting machine steel at high speed have led to the development of the most advanced tool materials (1).

This development continues today with the use of ceramic cutting tools these are hard, completely nonmetallic substances that resist heat and abrasive wear. Increasingly used as clamped index able tool inserts, ceramics differ significantly from tool steels, which are completely. metallic. Ceramics also differ from cermets such as cemented carbides and carbonitrides, which comprise minute particles held together by metallic binders (1).

Many researchers have been focusing on computer modeling and simulate of machining process to solve many complicated problems arising in the development of new technologies (2,3,4,5, and 6). So, in order to clarify the complex ideas of the cutting process the study of this research is focused or developed a finite element model using ANSYS code programming language. The inputs were tool geometry, cutting conditions(cutting velocity, depth of cut, feed rate, land width, and rake angle) and material properties (density and mechanical properties and density). The simulator gets the input and determines stresses, stress distributions on the tool and maximum strength obtain from three types of ceramic tools (Alumina/Zirconium, Alumina/ Titanium carbide, and Silicon Nitride).

2. BUILDING THE MODEL

Finite element method has a great value in increasing the understanding of the cutting process since it reduces the number of experiments; therefore, this tool is recommended for tool design, process selection of material, and machinability assessment. In this work the finite element model as built as shown in Fig. (1) which is a general orthogonal cutting model in three diminutions. The length of the work piece (L_0) is assumed to be (20) mm. while the height of work piece (h_0) is assumed to be (10) mm. The stresses study applied to a case consist of initially cutting process double rake cutting geometry with constant secondary rake angle but different negative angles and land widths were adopted. The cutting tool was modeled with positive rake angle (γ) to be constant and equal to (5°) and the clearance angle (α) is assumed to be (7°). Three models of cutting tools have been suggested having negative rake angle with different value of land width for each angle (-10° with 0.2, 0.3, 0.5, and 1mm), (-15° with 0.2, 0.3, 0.5, and 1mm), and (-25° with 0.2, 0.3, 0.5, and 1mm).

The material used for the work piece is AISI 1006 steel, whose mechanical properties are shown is Table (1)(7). Three types of ceramic cutting tools used for this work (Alumina/Zirconium, Alumina/Titanium, Silicon Nitride) whose mechanical properties are shown in Table (2)(1).

More over the boundary conditions are shown in Fig. (2), Brick element SOLID95 used to represent the workpiece and tool, while CONTAC49 used to represent contact and sliding between workpiece and tool. That geometry consists of 2228 nodes and 1545 element. The workpiece is fixed in all direction and the tool is fixed in three directions. The tool considered to be rigid and moving at a constant cutting speed (V_c), the cutting speed is assumed to be (150) m/min. the cutting condition are reported in Table (3)[8].

Further more the study was conducted using one feed rate and cutting speed. The cutting forces were measured using 9263 Kistler dynamometer[8]. The FEM has been applied to analyze the cases of the test, given in Table (4)[8].

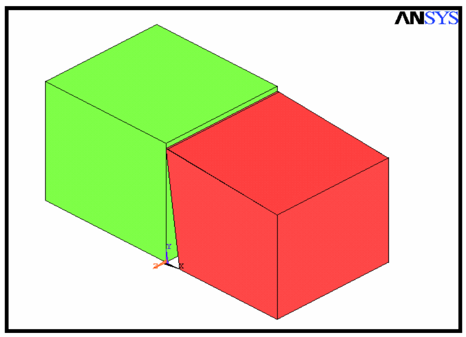

Fig. (1): Representation of initial geometry for the model used in simulated.

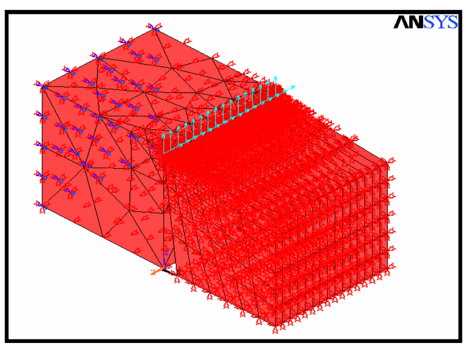

Fig. (2): Representation model boundary condition and mesh.

Table (1): Mechanical and thermal properties of AISI 1006 STEEL [7].

Density (ρ)	7850 kg/m^3
Young modulus (E)	220 Gpa
Poisson's ratio (ν)	0.30
Shear modulus (G)	82 Gpa
Yield stress (σ_y)	350 Mpa
Room temperature (T_0)	25 ^0C
Bullx modulus (K)	165 Gpa
Specific heat capacity (cp)	4500 J/kg ^0C

Table (2): Mechanical properties for three types of ceramic cutting tools[1].

Group	Alumina	Alumina/TiC	Silicon Nitride
Typical composition types	Al_2O_3 or Al_2O_3/ZrO_2	70/30 Al_2O_3/ TiC	Si_3N_4/Y_2O_3 plus
Density(g/cm^3)	4.0	4.25	3.27
Compressive strength (kN/mm^2)	4.0	4.5	4.0
Young Modulus (kN/mm^2)	380	370	300
Poisson ratio	0.24	0.22	0.20

Table (3): Cutting parameters selected for numerical test[8].

Cutting speed (V_c)	150 m / min
Feed rate (W)	0.17 mm/rev
Depth of cut (t_1)	0.5 mm

Table (4): work program [8].

Feed rate (mm/rev)	Speed (m/min)	Primary reake angle	Land width (mm)	Cutting force (N)	Feed force (N)
0.17	150	-10°	0.2	2275	1850
			0.3	3750	1775
			0.5	3000	1650
			1	3850	1950
		-15°	0.2	2200	1800
			0.3	3050	1550
			0.5	3150	1675
			1	4200	1900
		-25°	0.2	2650	3800
			0.3	2825	2200
			0.5	3100	1950
			1	3000	2100

3. RESULTS AND DISCUSSION

3.1 Effect of Tool Geometry of Von Mises Stress Distribution along Rake Face

Von Mises or effective stress is considered one of the theory that can reveal an acceptable explanation specially when complex stress system is due to mechanical effect (cutting force) on the cutting tool.

This theory has received a considerable verification in practice and is widely regarded the most reliable bases for design requirement for longer tool life and better distribution of the structure, therefore it has been chosen as one of the tools that could be used assessment of the cutting edge since disposed for complex stress action[9].

The reported investigation on performance of ceramic tool by using Von Mises theory of failure is very little, and therefore, in the present work, it is intended to use this approach in the cutting tool analysis in order to clarify the mode of failure that happens during cutting process.

It can be seen from Figs.(3,4,and 5) the relation between Von Mises stress for the (Alumina/Zirconium, Alumina/ Titanium Carbide, and Silicon Nitride) cutting tool and distance along rake face of the cutting edge using primary rake angle of (-10°). It can be noticed that the maximum Von Mises stress for land width (0.2mm) is (1530, 1520, 1380MPa) respectively at the tool tip and for land width (0.3mm) is (1490, 1480, 1350MPa)

respectively and for land width (0.5mm) is (465, 463, 418MPa) respectively and finally for land width (1mm) is(393, 391, 356MPa) respectively from these result, the optimum land width for this primary rake angle (-10°) was (1mm), because it gives minimum value of Von Mises compared with the other land width and gives good stress distribution along rake face and this agreed with the results obtained by[10].

Figs. (6, 7, and 8) show the variation of Von Mises stress for primary rake angle (-15°). Again the same behavior of previous case was obtained. When land width equal to (0.2mm), the maximum Von Mises stress at the tool tip was found have a value of (1110, 1110, 1000MPa) respectively. When land width increased to (0.3mm), the maximum Von Mises stress decrease to have a value of (802, 797, 715MPa) respectively. Also for land width (0.5mm) and (1mm) the same trend was obtained and the optimum value of land width was (1mm). From Figs. (9,10, and 11), the same behavior of Von Mises variation was obtained and the optimum value of land width was (1mm), because the minimum value of Von Mises stress occurs at this land width. This shows that failure does not occur in this case.

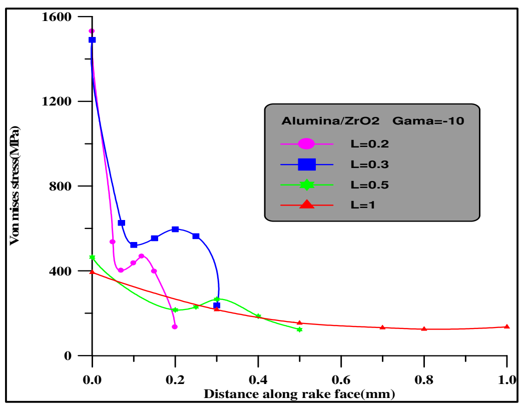

Fig. (3): distribution of Von Mises stress along rake face (γ= -10^0 and material tool AL_2O_3/ZrO_2).

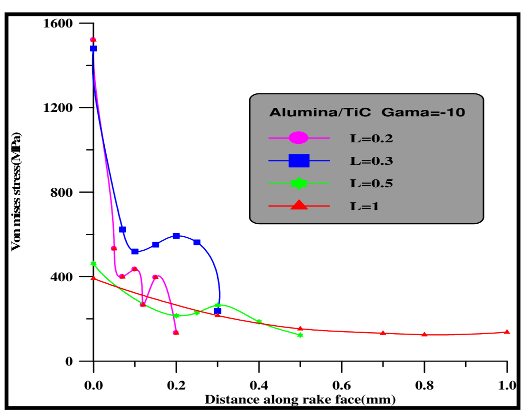

Fig. (4): distribution of Von Mises stress along rake face (primary rake angle = -10^0 and material tool AL_2O_3/Tic).

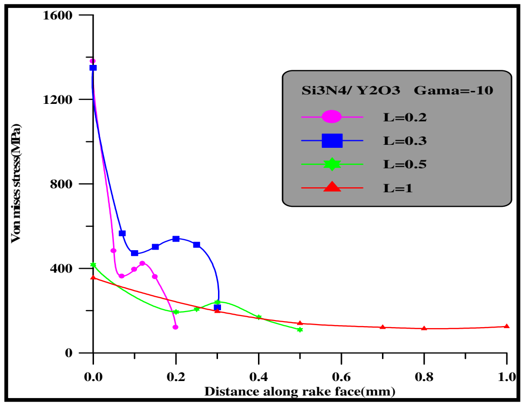

Fig. (5): distribution of Von Mises stress along rake face (γ= -10^0 and material tool Si3N4/Y_2O_3).

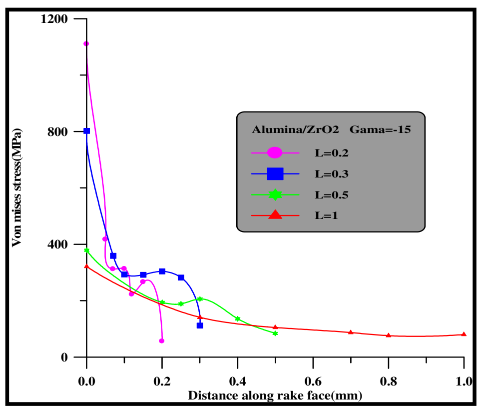

Fig. (6): distribution of Von Mises stress along rake face (primary rake angle = -15^0 and material tool AL_2O_3/ZrO_2).

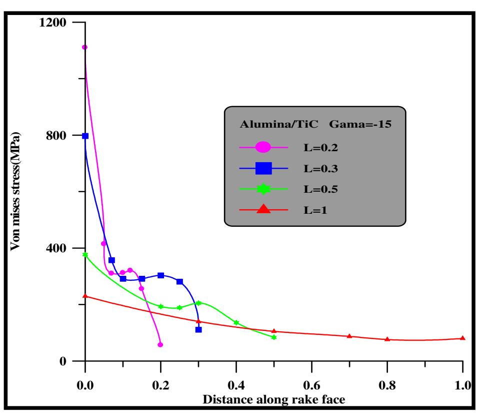

Fig. (7): distribution of Von Mises stress along rake face (γ= -15^0 and material tool AL_2O_3/Tic).

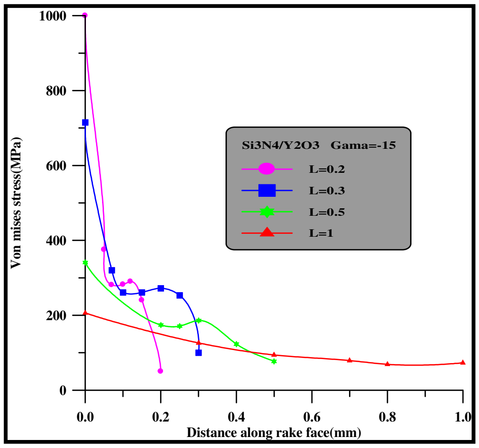

Fig. (8): distribution of Von Mises stress along rake face (primary rake angle = -15^0 and material tool Si3N4/Y_2O_3).

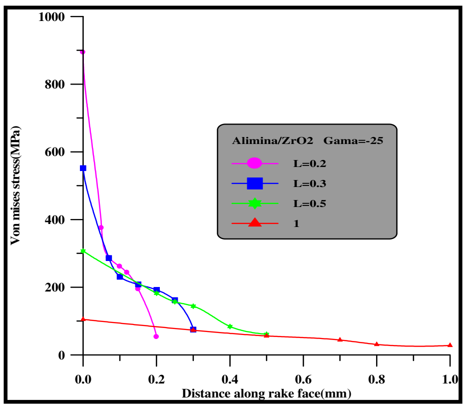

Fig.(9): distribution of Von Mises stress along rake face ($\gamma= -25^0$ and material tool AL_2O_3/ZrO_2).

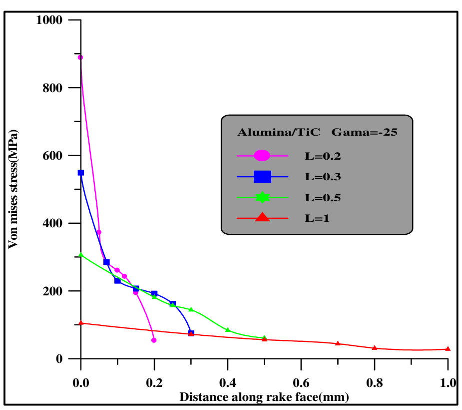

Fig.(10): distribution of Von Mises stress along rake face (primary rake angle = -25^0 and material tool AL_2O_3/Tic).

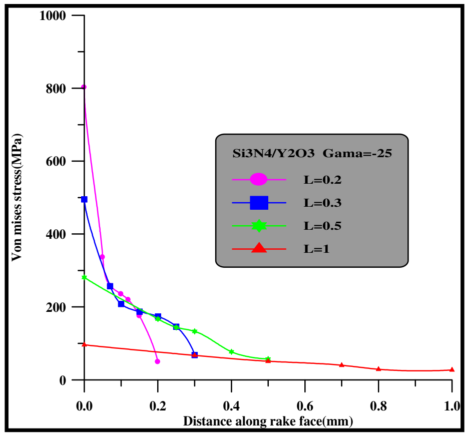

Fig. (11): distribution of Von Mises stress along rake face (primary rake angle = -25^0 and material tool Si3N4/Y_2O_3).

3.2 Contour of Von Mises Stress Along Rake Face

As mentioned before, the stress analysis using Von Mises is very little, therefore it is intended to carry out a complete series of computing stress distribution which represents the behavior of the cutting tool using above technique.

when primary rake angle has a value of (-10°), the contour of Von Mises stress for Al2O3/Zrc2 cutting tool material is illustrated in figs (12-A,B,C, and D) with variation land width (0.2, 0.3, 0.5, and 1mm) respectively. It can be seen that Von Mises stress distribuyion with land width (0.2mm) is maximum value at the tool tip (1530 MPa), and the minimum value recorded to be (134 MPa). When land width (0.3mm) maximum stress at the tool tip is (1490MPa), and the minimum value recorded to be (237MPa), when land width increased to (0.5mm) the maximum value of stress is (465MPa), and minimum value is (123MPa), increasing land width to (1mm) stress become less than that of land width (0.5mm). the maximum stress at the tool tip was (393 MPa) and minimum value was (136MPa). From the above results, the optimum land width for this primary angle was (1mm), because it gives minimum value of Von Mises stress compared with the other width and this case gives a good distribution of stresses along rake face.

Figs. (13-A,B,C, and D) and Figs. (14-A,B,C, and D) show the variation of Von Mises stress for primary rake angle (-15°) and (-25°) respectively. Again the same behavior for previous case was obtained when used varies land width.

Figs. (15, 16, and 17) show the contour of Von Mises stress for AL_2O_3/Tic cutting tool material with rake angle (-10,-15, and -25) respectively, and Figs. (18,19, and 20) show the contour of Von Mises stress for Si3N4/Y_2O_3 cutting tool material with rake angle (-10,-15, and -25) respectively. Where can be seen the same results for previous case was obtained when used AL_2O_3/ZrO_2 cutting tool material. From above results can be seen that the maximum value of stress for three materials shows at the tool tip and decreases rain to advance step to step to have a minimum value at the end of land width this happens because the shortage of contact area between workpiece and tool, leading to the reduce the stresses along rake face.

Also It can be concluded for all that the Von Mises stress has a high value at the area close to the cutting edge, due to the existence of the sticking zone between tool and work piece and this agreed with the previous studies results[10,7].

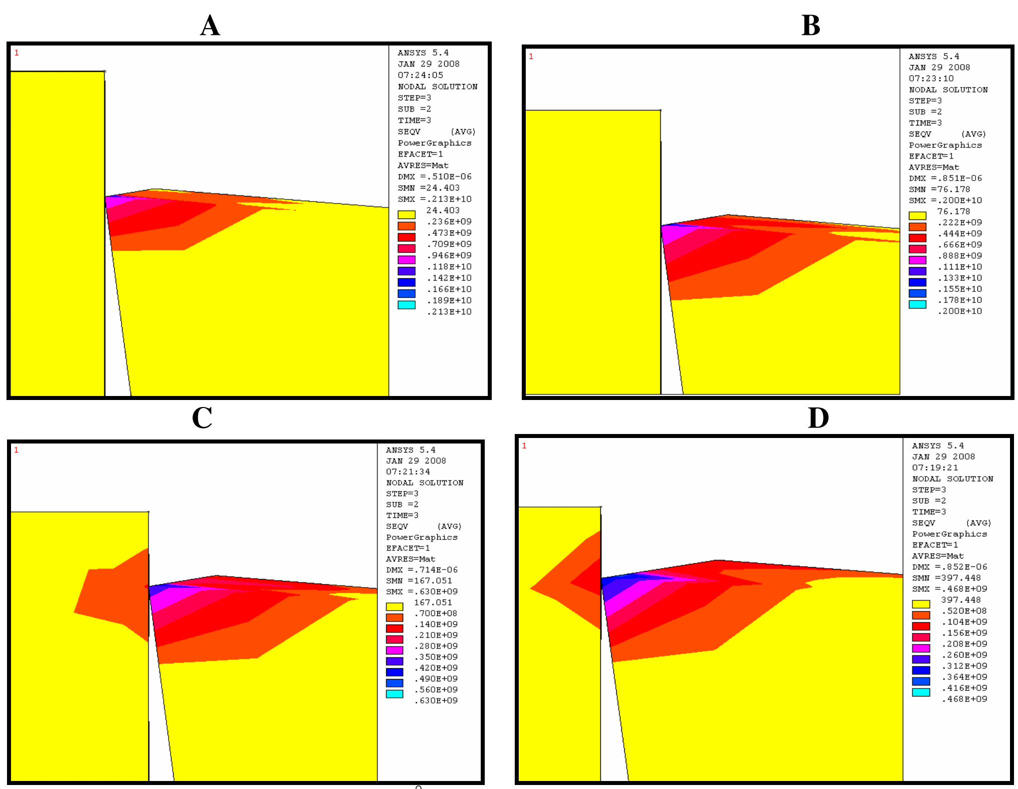

Fig. (12): effect of rake angle (-10°) and different land width on Von Mises stresses for AL_2O_3/ZrO_2 tool material.

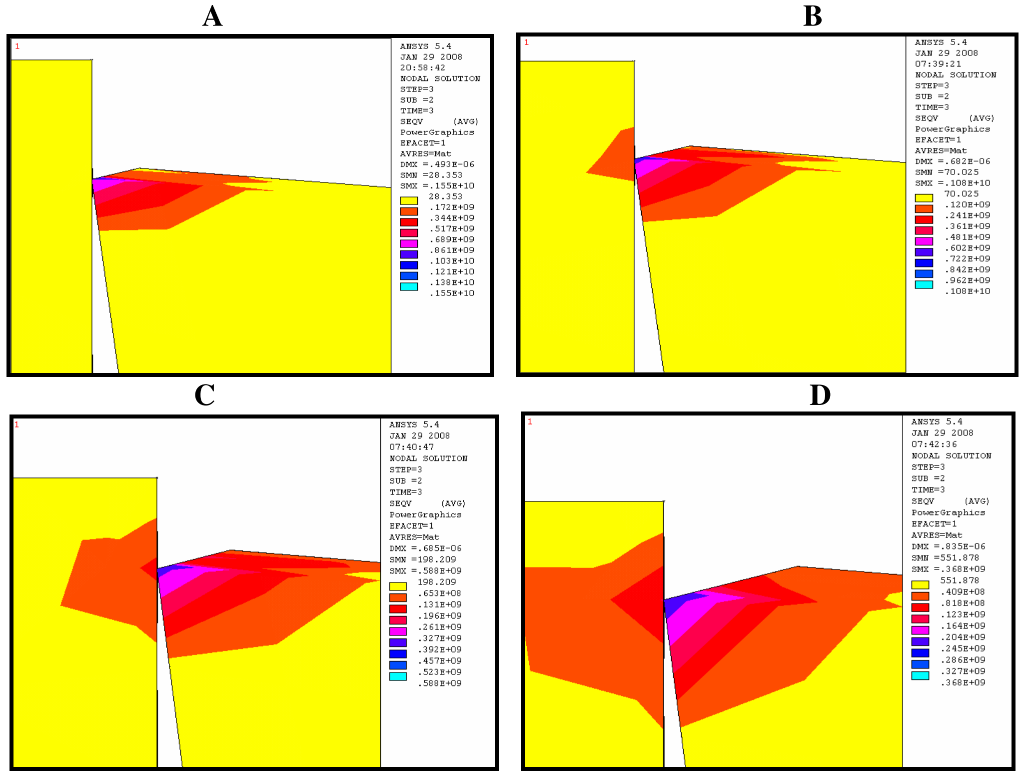

Fig. (13): effect of rake angle (-15) and different land width on Von Mises stresses for AL_2O_3/ZrO_2 tool material.

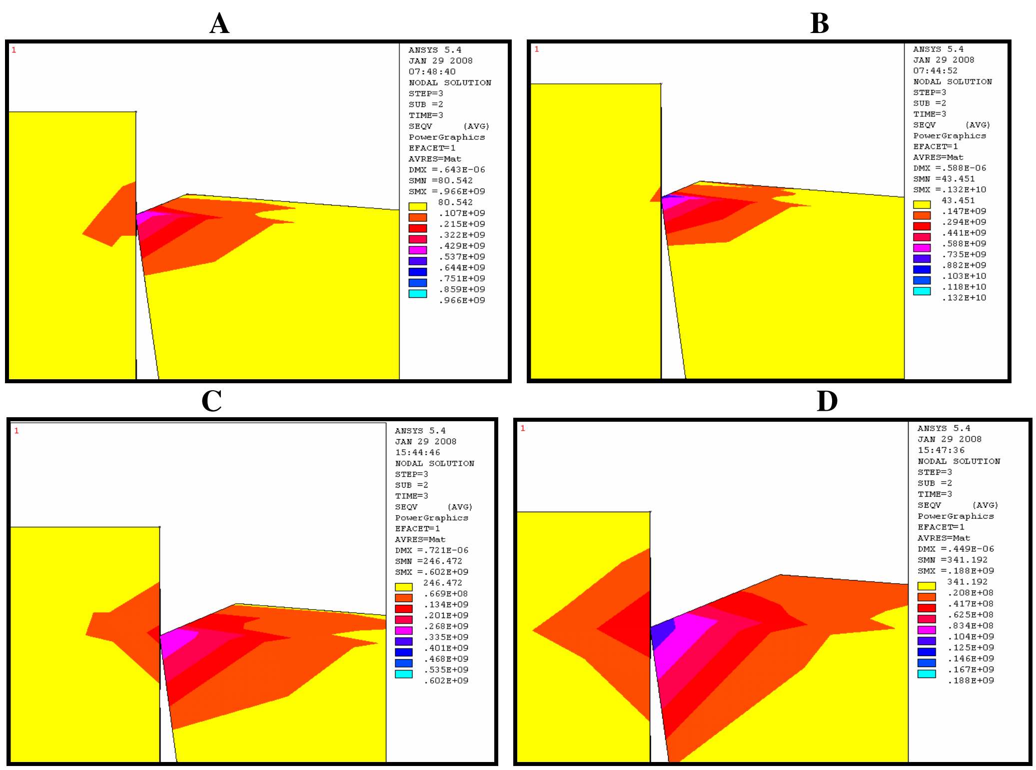

Fig. (14): effect of rake angle (-25) and different land width on Von Mises stresses for AL_2O_3/ZrO_2 tool material.

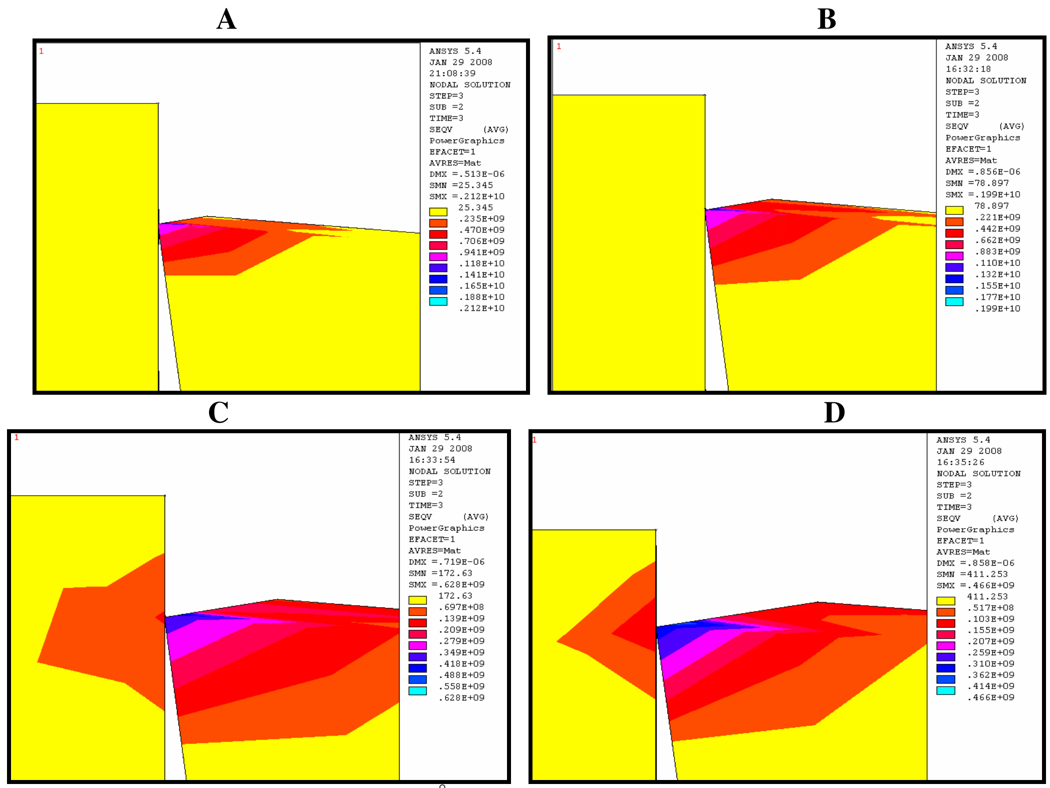

Fig. (15): effect of rake angle (-10°) and different land width on Von Mises stresses for AL_2O_3/Tic tool material.

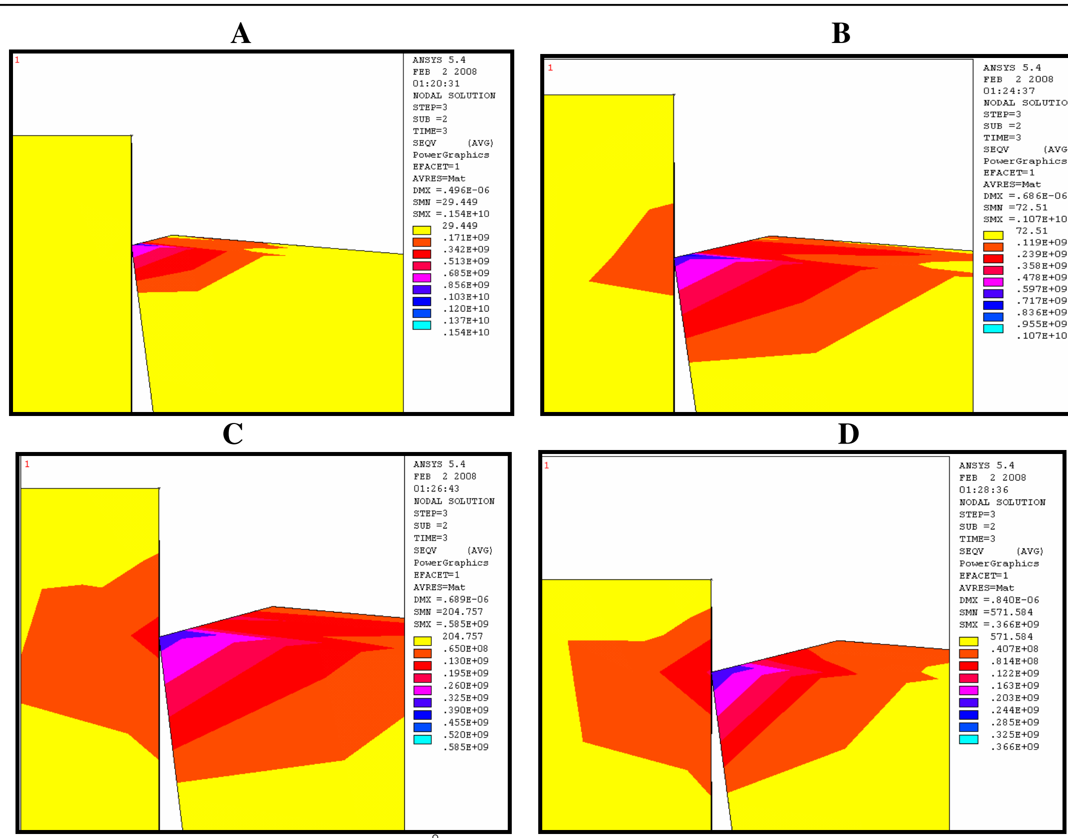

Fig. (16): effect of rake angle (-15°) and different land width on Von Mises stresses for AL_2O_3/Tic tool material.

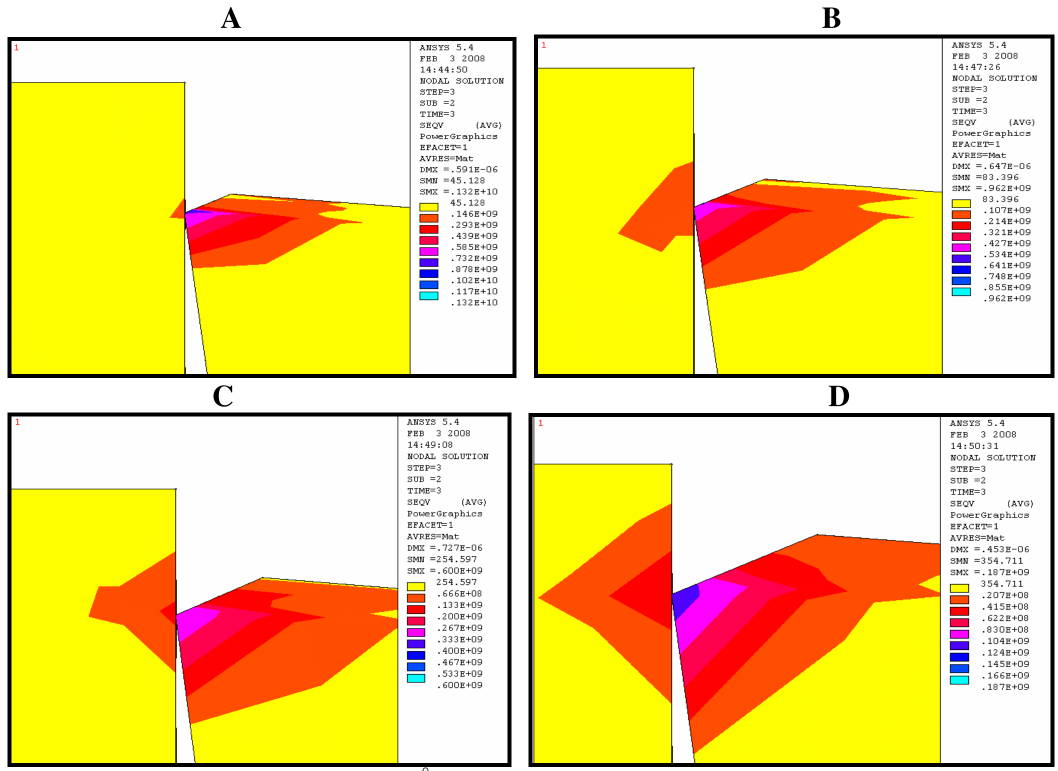

Fig. (17): effect of rake angle (-25°) and different land width on Von Mises stresses for AL_2O_3/Tic tool material.

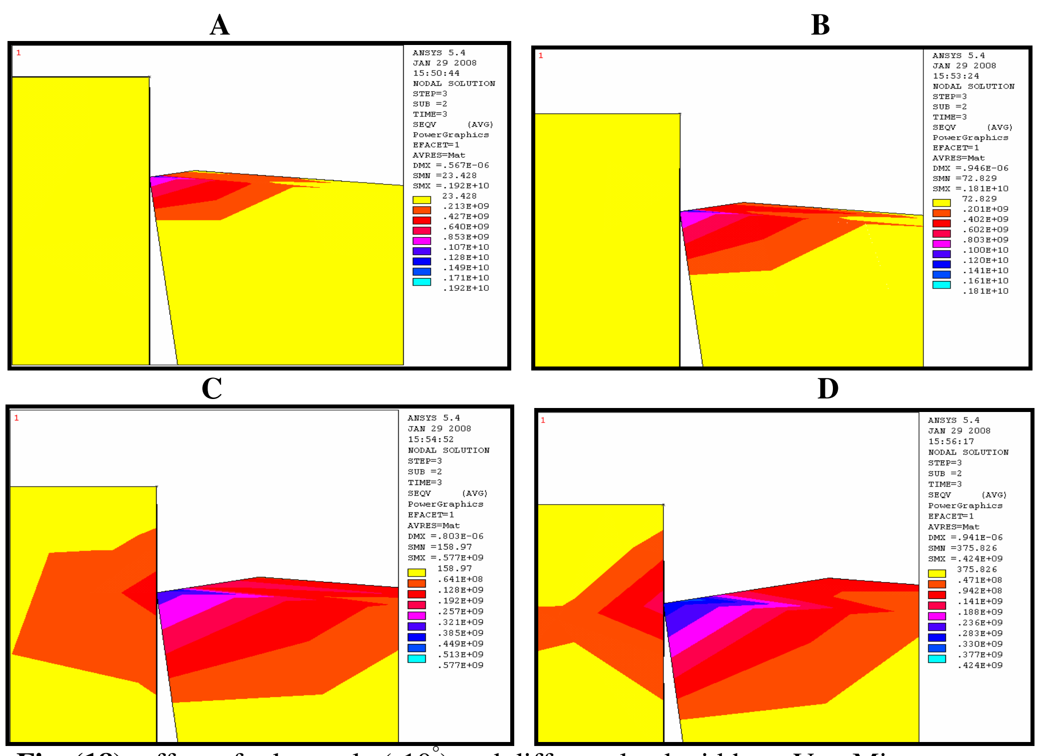

Fig. (18): effect of rake angle (-10°) and different land width on Von Mises stresses for Si3N4/Y_2O_3 tool material.

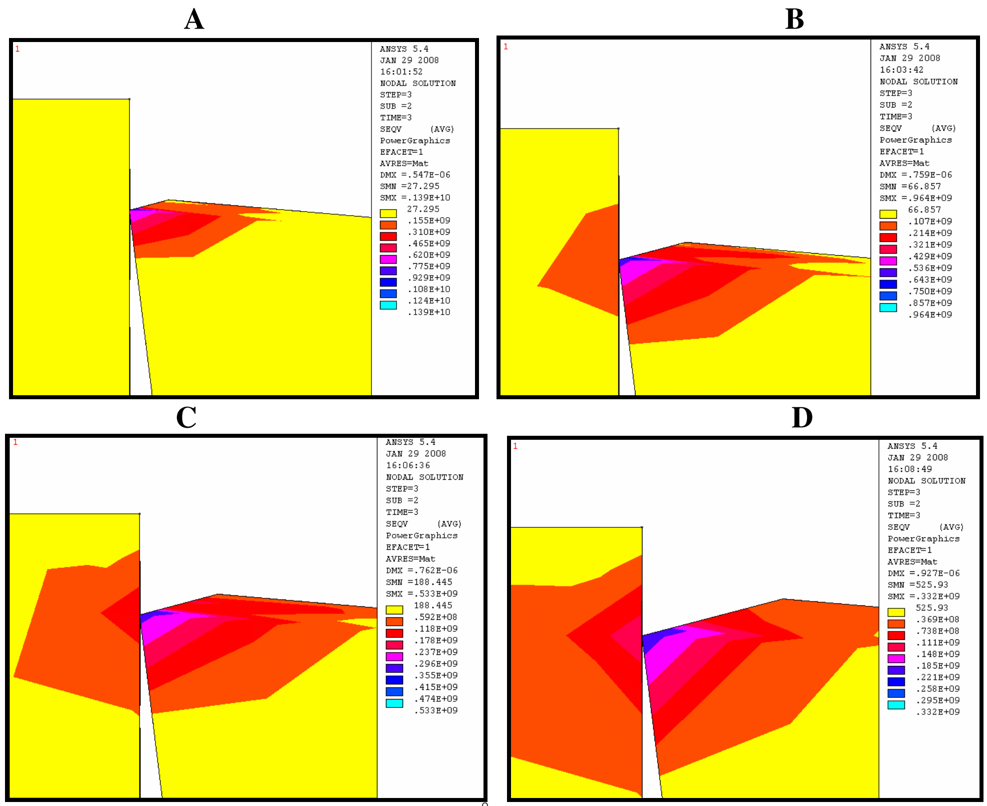

Fig. (19): effect of rake angle (-15°) and different land width on Von Mises stresses for Si3N4/Y_2O_3 tool material.

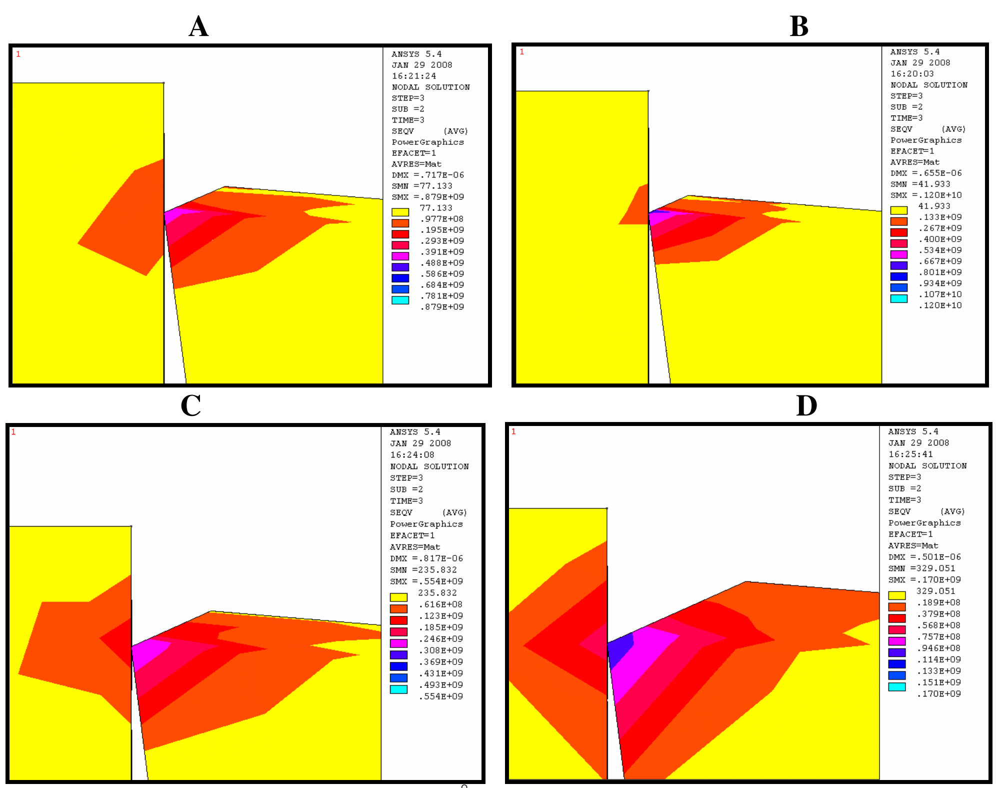

Fig. (20): effect of rake angle (-25°) and different land width on Von Mises stresses for Si3N4/Y_2O_3 tool material.

3.3 Effect of cutting tool materials on value and distribution Von Mises stress

It can be seen from Fig. (21) the relation between maximum stress on the cutting tool and land width for different materials of ceramic cutting tools (AL_2O_3/ZrO_2, AL_2O_3/Tic, and Si3N4/Y_2O_3). It can be noticed there are same behavior with different materials of ceramic cutting tools where the maximum stress decrease with increasing of land width for each cutting tool, due to distribution of stresses is on the larger area. At the same time, there are some simple different of stress value for the same value of land width with different materials of ceramic cutting tools. The optimum values of the maximum stress were when using Si3N4/Y_2O_3 cutting tool, because the minimum values of stress at the tool tip occurs when using this material. From these results it can obtain that the ceramic cutting tool has better performance from cemented carbide tool compare with previous study results(10).

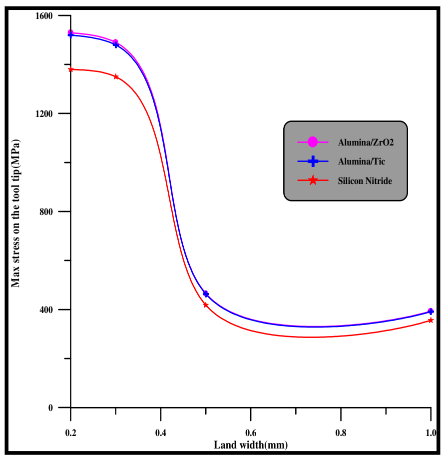

Fig. (21): the relation of maximum stress on the cutting tool and land width for different materials of ceramic cutting tools.

4. CONCLUSIONS

In this study, we have a FEM simulation model for orthogonal cutting of AISI 1006 steel using double rake angle geometry and three type materials of ceramic cutting tools. The results show that:-

1. For every cutting condition, there is an optimum geometry and material of cutting tool. The optimum primary rake angles from the three models (-10°, -15°, -25°) is (-25°) when land width (1mm), this angle gives minimum value of Von Mises stress.
2. The optimum material from the three types of ceramic cutting tools is Si3N4/Y_2O_3, this material also gives minimum value of Von Mises stress.

3. the ceramic tool has better performance from cemented carbide tool.
4. From the results obtained by the FEM demonstrate that the technique can be used in the selection of materials and design of cutting tools to analyze the conditions occurring in metal cutting.

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دراسة أداء ُعدد القطع السيراميكية باستخدام حافة قطع مزدوجة

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الخلاصة

إن الهدف من هذا البحث هو دراسة تأثير أنواع عدة القطع السيراميكية (باستخدام زاوية جـرف مزدوجـة (سالبة وموجبة) على أداء عملية القطع. وركزت عملية المحاكاة على بداية عملية القطع في حالة تمـاس العـدة مـع الشغلة. بينت النتائج أن استخدام عدة ذات تصميم زاوية جرف مزدوجة تحسن من أداء عملية القطع ،كذلك بينت بأنـه لكل ظرف قطع يوجد تصميم مثالي ومادة مثالية لعدة القطع. إذ أن استخدام عدة القطع المصنعة من مـواد سـيراميكية تحسن من أداء عملية القطع وقد أعطت نتائج أفضل عند مقارنتها مع عدة قطع مصنعة من كاربيد السمنتايد في بحوث سابقة.