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Finite Element Analysis of The Influence of Edge Roundness on the Stresses and Cutting Forces for Ceramic Cutting Tools

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ABSTRACT - This work summarizes the effect of edge round preparation for three types of ceramic cutting tool materials (Al_2O_3/ZrO_2, Al_2O_3/ TiC, Si_3N_4/Y_2O_3) upon cutting forces and stress distribution on the cutting tool in orthogonal cutting as determined with Finite Element Method simulations. The results obtained from this study provide a fundamental understanding of the process mechanics for cutting with realistic cutting tool edges and may assist in the optimization of tool edge design. These results compare with other previously published papers and showed a good agreement. It is also proved, that for every cutting condition and tool material, there is an optimum geometry. The material of ceramic cutting tools proved, that it has been good in performance comparing with other previously published papers.

Keywords: Ceramic, Edge radius, Finite element.

1. INTRODUCTION

Machining efficiency is improved by reducing machining time with high-speed machining. When cutting ferrous and hard to machine materials such as steels, cast iron and alloys, the chemical stability of the tool material limits the cutting speed. Therefore, it is necessary for tool materials to possess good in high temperature and mechanical properties and sufficient inertness. While many ceramic materials such as AL_2O_3 or Al_2O_3/ZrO_2, Al_2O_3/TiC, Si_3N_4/Y_2O_3 possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The machining of hard and chemically reactive materials at higher speeds is improved by ceramic tool materials. Ceramic tool are resistance to abrasive wear and cratering(1).

Moving up the hardness scale, ceramic provide increasing competition for cemented carbides both in performance and in cost effectiveness, though not yet in reliability. hard metals themselves consist of ceramic-nonmetallic refractory compounds, usually carbonitrides-with a metallic binder of much lower melting point. Ceramic that competes directly with hard metals, mainly in the cutting tool category (2).

Many researchers have been focusing to study the effect of cutting-edge geometry because it has long been an issue in understanding metal cutting (3). Edge hones are commonly used as an edge preparation in many operations, like interrupted cutting, machining of hard materials etc., where increased edge strength is desired (4). According to recent studies, it is evident that the effect of edge hones geometry on surface quality and surface residual stresses (5, 6, and 7), cutting force and stresses (8-15).

In recent years, finite element analysis has become the main tool for simulating metal cutting processes. Therefore, this research is focused or developed a finite element model to study the effect of cutting-edge hone on the ceramic cutting tool performance.

2. MODEL GEOMETRY

In this work the Finite Element Model with boundary conditions and mesh is built by using program ANSYS are presented in Fig. (1) which is a general orthogonal cutting model. The length of the work piece (L_0) is assumed to be (30) mm. While the height of workpiece (h_0) is assumed to be (10) mm. the depth of cut is (0.5) mm.

The cutting tool was modeled with positive rake angle (α) to be constant and equal to (7°) and the clearance angle (γ) is assumed to be (5^0).Four models of cutting tools for three types of ceramic materials have been suggested having edge radius of (0.1, 0.2, 0.3, and 0.4mm). Modeling geometry and dimension is done using the Cartesian coordinate, with element type VISCO108 for workpiece and chip. This element is used for 2-D modeling of solid structures, and defined by eight nodes having up to three degrees of freedom at each node: translations in the nodal x, y, and z directions. While the element type of tool is PLANE 42 which is used for 2-D modeling of solid structures. This element can be used as a plane element (plane stress or plane strain), and is defined by four nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The type of contact models is surface to surface contact and the behavior of material properties is described as nonlinear and isotropic. The coefficients of friction between chip and tool and between chip and workpiece was assumed to be constant (μ=0.5).

The workpiece is fixed in all direction, and the tool is allowed to move towards the workpiece. The tool is considered to be rigid and moving at a constant cutting speed (V_c) in negative x direction. For the present model, the cutting speed is assumed to be constant (150) m/min. Constraints were placed on the tool allowing movement only in the x direction. The cutting conditions are reported in table (1).

To simulate the chip separation, the workpiece is tied with chip segment by constant force in negative y direction. The material used for the workpiece is AISI 1006 steel, whose mechanical properties are shown in table (2) [(16)].

Three types of ceramic cutting tools used for this work (Alumina/Zirconium, Alumina/Titanium, Silicon Nitride) whose mechanical properties are shown in table (3)[(2)]. Fig. (2). show the path for separating the chip from the workpiece and the simulation tool advance through the workpiece in steady state condition.

3. RESULTS AND DISCUSSION

3.1. Effect of The Cutting-Edge Radius on The Von Mises Stresses Distribution at The Tool Rake Face

Figs. (3, 4, and 5) shows the contour of Von Mises stresses distributions (σ) along the rake face for three types of ceramic cutting tools materials (AL_2O_3/ZrO_2 , AL_2O_3/Tic, Si3N4/Y_2O_3) cutting tool materials respectively using four models with different cutting edges radius (0.1,0.2, 0.3, and 0.4mm). Stress contours may be defined as an area of two boundaries; these boundaries have a maximum and minimum stress. Also it can be seen from Figs.(6-A, B, and C) the relation between Von Mises stress for the three types of cutting tool materials and distance along rake face of the cutting edge using different edge radii

The Von Mises stresses were found to be maximum near the cutting edge due to the effect of sticking friction that affects the behaviors of contacting area resulting in high values of Von Mises stresses at this region. The optimum state for the (AL_2O_3/ZrO_2) cutting tool materials form the four models is (0.4μm), where it minimized the Von Mises stress to reach the value of (2350 MPa). While the optimum state for the (AL_2O_3/Tic) cutting tool form the four models is (0.3μm) where it minimized the Von Mises stress to reach the value of (1610MPa) MPa, and the optimum state for the (Si3N4/Y_2O_3) cutting tool is (0.3μm), where it minimized the Von Mises stress to reach the value of (2420MPa).

It is clear also from the Fig. (7) shows that the maximum values for the Von Mises stresses (σ) nearly decrease with increasing cutting-edge radius. These may be due to the lower contact area between the sliding surface as well as, the total pressure on the tool. These results agree with the experimental and numerical results of the study [8-13]. The optimum state when using AL2O3/Tic cutting tool material this give minimum stress value on the tool tip.

3.2. Effect of The Cutting-Edge Radius on The Cutting Forces:

Fig. (8) show the predicted cutting force (F_c and F_t) with the difference cutting edge radius and different ceramic cutting tools materials. The results showed that both force components increase as the edge radius increase. Apparently, this is due to the increasing bluntness of the cutting edge, which requires larger forces for material shearing. In addition, the reduced shear angle and increased chip thickness lead to a larger shear plane in the deformation zone, which increases the cutting forces. On the other hand, the increased contact area around the tool tip and the ploughing force, due to the large edge radius, results in the increase of the specific cutting energy as well as cutting forces. The optimum type of tool material that gives maximum cutting forces is Si3N4/Y_2O_3 A comparison was made between predicted, experimental and simulated results from previous papers [12-15], showed good results.

4. CONCLUSIONS

With the FEM cutting simulation, it is possible to estimate the values of process variables that are not measurable or very difficult to measure by experiment, such as contact stresses on the rake face and flank face of the tool. This method provides a better understanding of the cutting physics and may enable the implementation of a systematic process optimization.

The effect of various tool edge radii on the stresses and cutting forces on the tool for three types of ceramic materials is analyzed by using FEM cutting simulation and presented in this work. The optimum tool material that gives minimum stresses on the rake face is AL_2O_3/Tic when edge radius equal to (0.3μm). While the optimum type of tool material that gives maximum cutting, forces is Si3N4/Y_2O_3. These results showed that for each material, there is optimum tool geometry and the material of ceramic cutting tools proved, that it has been good in performance comparing with other previously published papers [12-15]**.**

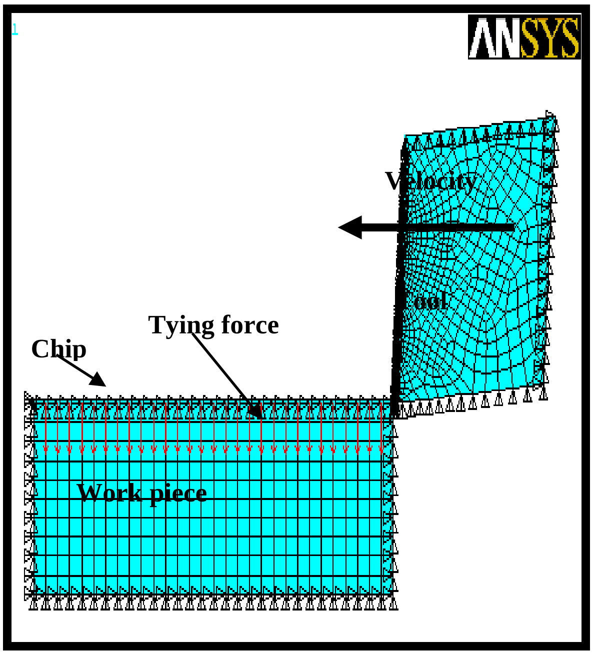

Fig. (1): Representation of initial geometry with boundary conditions and mesh for the model used in simulated tests

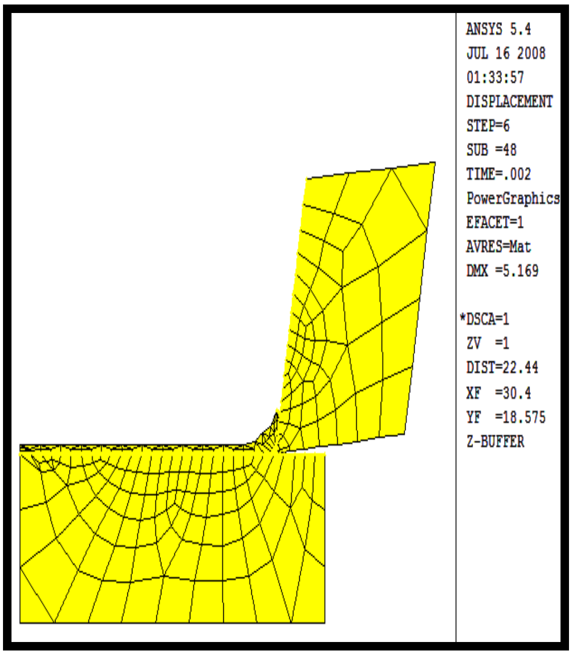

Fig. (2): the simulation tool advance through the work piece in steady state condition

Table (2): Mechanical and thermal properties of AISI 1006 STEEL [16].

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 C^0
Bullx modulus (K)	165 Gpa
Specific heat capacity (cp)	4500 J/kg C^0

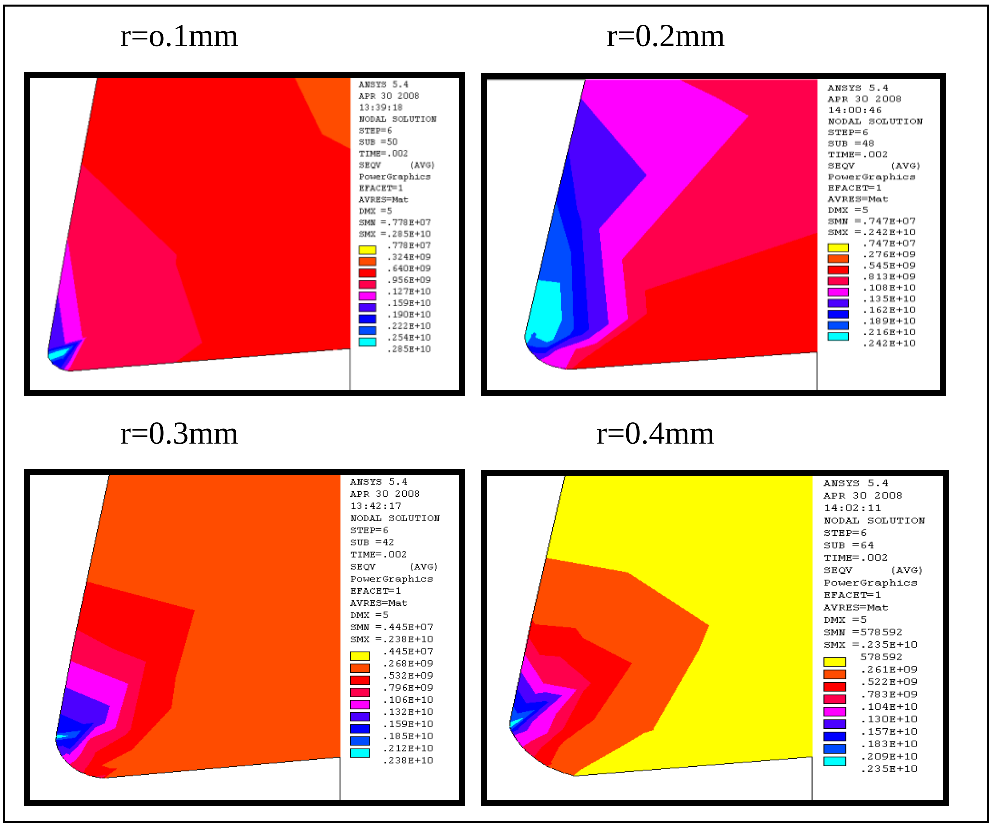

Fig. (3): the contour of Von Mises stresses distributions along rake face with different edge radius for AL_2O_3/ZrO_2 tool.

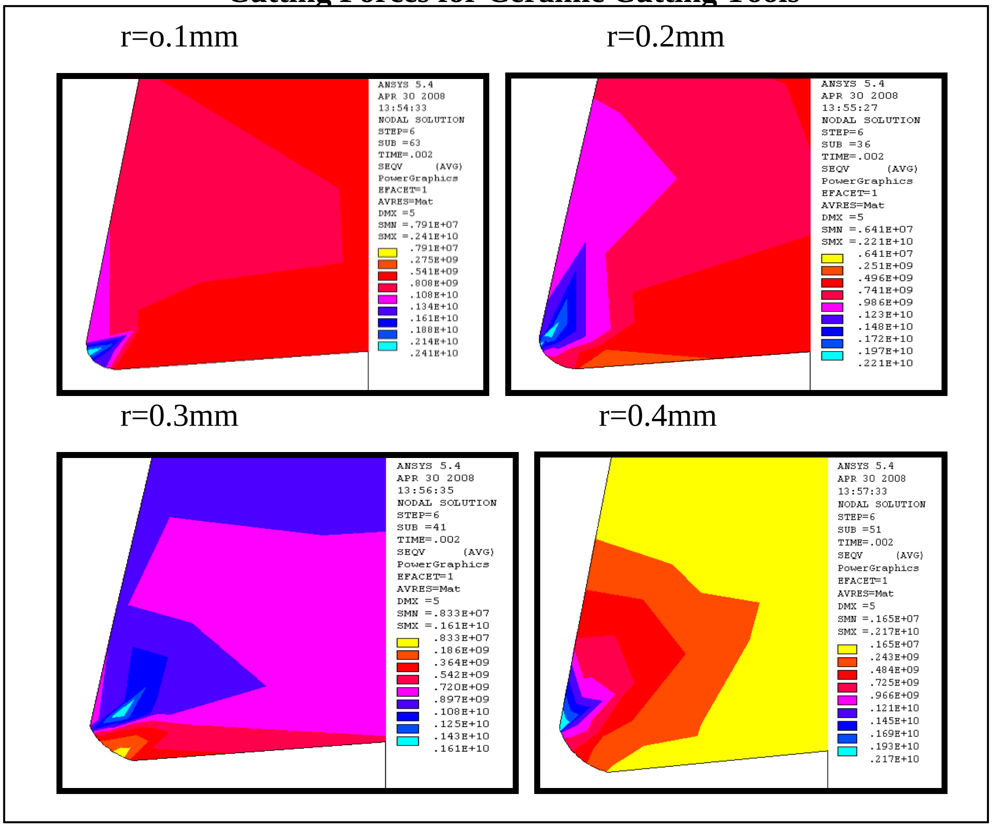

Fig. (4): the contour of Von Mises stresses distributions along rake face with different edge radius for AL_2O_3/Tic tool.

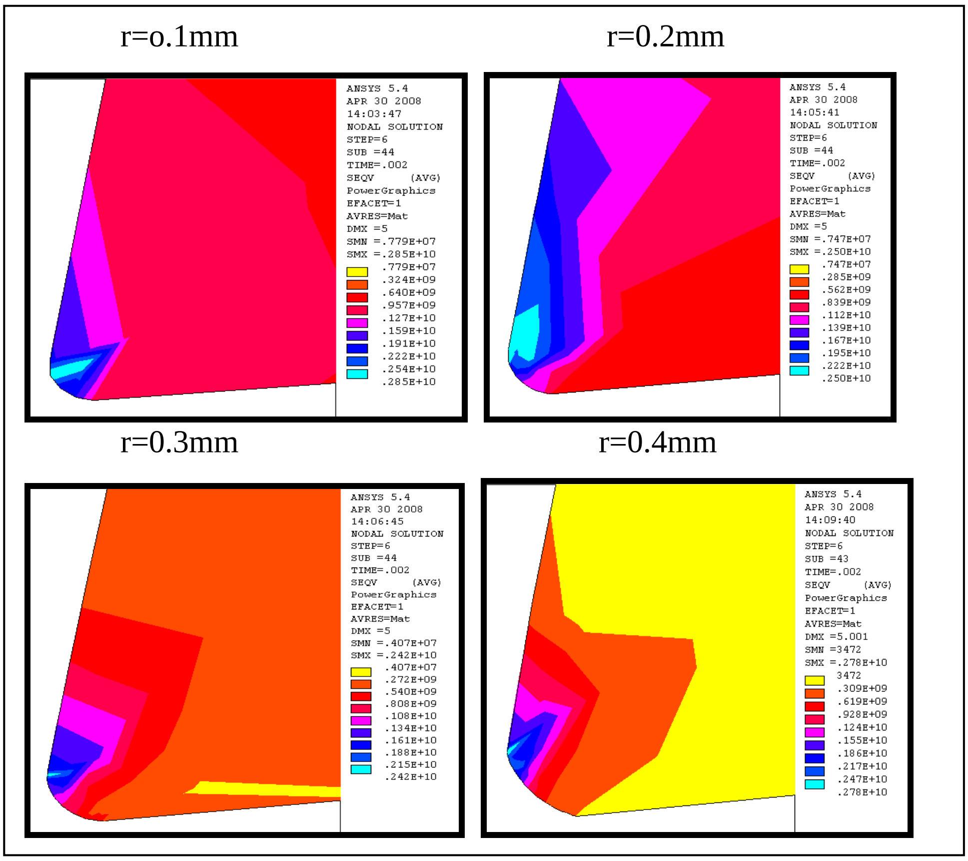

Fig. (5): the contour of Von Mises stresses distributions along rake face with different edge radius for Si3N4/Y_2O_3 tool.

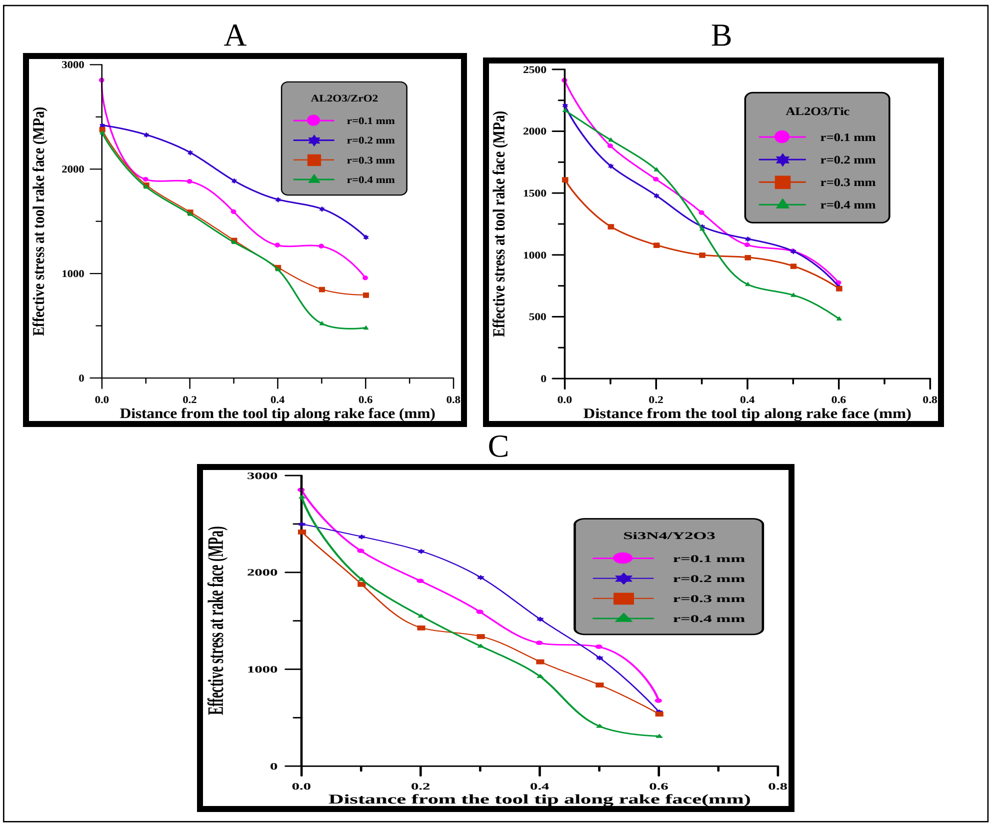

Fig. (6A, B, and C): distribution of Von Mises stress along rake face for three types of ceramic cutting tool materials.

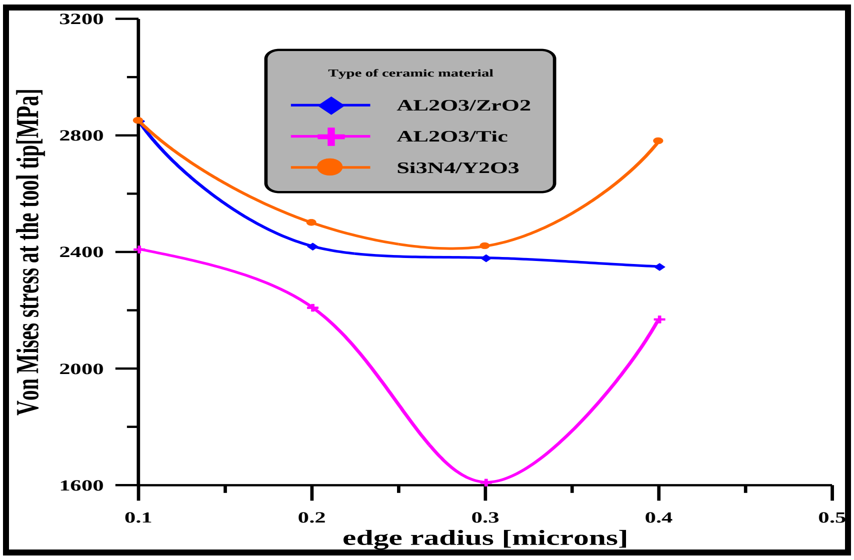

Fig. (7): the relation between maximum stress on the cutting tool and edge radius for different materials of ceramic cutting tools.

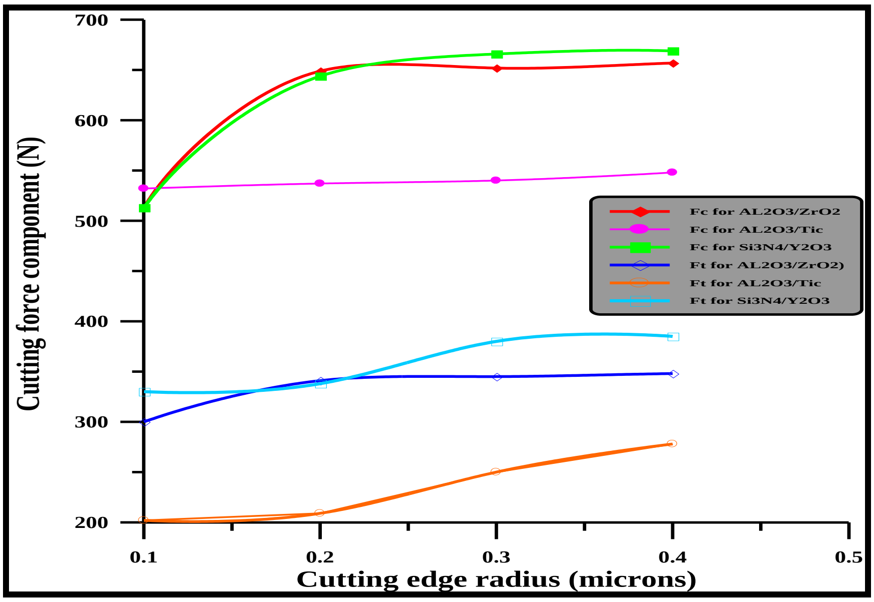

Fig. (8): the relation between cutting forces and edge radius for different materials of ceramic cutting tools.

NOMENCLATURE

Symbol	Definition
a	Undeformed chip thickness or depth of cut (mm).
E	Young modulus (Gpa).
r	Tool edge radius or round edge (mm).
T_o	Room temperature (°C).
V_c	Cutting speed (m/min).
ν	Poisson's ratio.
μ	Static coefficient of friction.
ρ	Density of work material (kg/m^3).
α	Rake angle (deg).
γ	Clearance angle (deg).
σ_y	Yield stress (MPa).
σ	Von Mises stress (MPa).
F_c	Tangential cutting force(N)
F_t	Thrust cutting force (N)

REFERENCES

1. Cho, S. S., Komvopoulos, K., "Wear Mechanisms of Multi-Layer Coated Cemented Carbide Cutting Tools", Journal of Tribology, Vol.119,pp 8-17, 1997.
2. Erik Oberk, Franklin D.Jones, Holbrook L.Horton, and Henry H.Ryffel, "Machinery ́ s Handbook 28th Edition", Industrial Press Inc., New York, 2008.
3. Roy J.Schimmel, William J. Endres. and Robin Stevenson, "Application of an Internally Consistent Material Model to Determine the Effect of Tool Edge Geometry in Orthogonal Machining", Transactions of the ASME, Vol.124, 536-543, 2002.
4. Roy J.Schimmel, William J. Endres, and Jairam Manjunathaiah, "Edge Radius Variability and Force Measurement Considerations" Transactions of the ASME, Vol.122, pp 590-593, 2002.
5. Ozel T., Tsu-Kong Hsu, and Zeren E.," Effects of Cutting Edge Geometry, Workpiece Hardness, Feed Rate and Cutting Speed on Surface Roughness and Forces in Finish Turning of Hardened AISI H13 Steel" , www.rci.rutgers.edu,.2004.
6. Jeffery D.T., and Shreyes N.M., "Effect of Cutting Edge Geometry and Workpiece Hardness on Surface Residual Stresses in Finish Hard Turning of AISI 52100 Steel", Transactions of ASME, Journal of Manufacturing Science and Engineering, Vol.122, No.4 642-649,2000 .
7. Jeffery D.T., and Shreyes N.M., "Effect of Tool Edge Geometry on Workpiece Subsurface Deformation and Through Thickness Residual Stresses for Gard Turning of AISI 52100 Steel", Journal of Manufacturing Processes, Vol.2, No.4, 2000.
8. Kalhori V., "Modelling and Simulation of Mechanical Cutting", Ph.D., Thesis, University of Lulea Tekniska, 2001.
9. Astakhov V.P., and Outeiro J.C., "Modeling of the Contact Stress Distribution at the Tool-Chip Interface", Proceeding of The CIRP International Workshop of Modeling of Machining Operations, ENSAM, CLuny, France, May 2004.
10. Ozel T., and Zeren E.,"Finite Element Analysis of The Influence of Edge Roundness on The Stress and Temperature Fields Induced by High Speed Machining",Rytgers University, Piscataway, New Jersey USA, 2003.
11. Altan T., "Modeling of Metal Cutting Using FEM", ERC/NSM, The Ohio State University, January 2003.

12. Altan T., Y.C. Yen, and Anurag J.," A Finite E lement Analysis of Orthogonal Machining Using Different Tool Edge Geometries", ERC/NSM, The Ohio State University Columbus, 2002.
13. Altan T., Y.C. Yen, Hamdi H., and Rech J., " Influence of Cutting Edge Radius of Coated Tool on Chip Formation in Orthogonal Cutting of Alloy Steel", ERC/NSM, The Ohio State University, May 2004.
14. T.Keven Chou, and Hui Song, "Hard Turning with Different Nose-Radius Ceramic Tools", Society of Manufacturing Engineers, www..sme.org, 2001.
15. Honglee T., "An Experimental and Theoretical Investigation for The Machining of Hardened Alloy Steels", Ph.D., Thesis, University of New South Wales, April 2007.
16. Aabid M., "finite element simulation of chip formation and comprison with experiment", PhD., Thesis, University of Technology, 2002.

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استخدام طريقة العناصر المحددة لدراسة تأثير تقوس حافة القطع على اجهادات وقوى القطع لعدة القطع السيراميكية

سهى كريم شهاب

مدرس مساعد

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الخلاصة

في هذا البحث تم التركيز على دراسة تأثير نصف قطر تقوس حافة الحد القاطع لثلاث مواد من عدد القطع السيراميكية على توزيع قوى القطع , كذلك على شكل وتوزيع الاجهادات على وجه العدة بأستخدام تقنية العناصر المحددة. وقد تم الحصول على نتائج أعطت زيادة في إدراك عملية القطع كذلك أمكن تحديد الاختيار الأمثل لتصميم حافة العدة وأظهرت النتائج توافقا واضحا عند مقارنتها مع بحوث منشورة مسبقا في هذا المجال. كذلك تبين ان لكل ظرف قطع ولكل مادة من مواد عدد القطع يوجد تصميم امثل لعدة القطع المستخدمة ,كما تبين إن للمواد السيراميكية في تصميم عدد القطع لها الاداء الامثل في عملية القطع.