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A Technical Review on Ceramic Cutting Tool Inserts

Keyur V. Parmar[1],*, Hemantkumar R. Thakkar[2]
[1]Research Scholar, Gujarat Technological University, Ahmedabad, Gujarat, India
[1]Assistant Professor, Mechanical Engineering Department,
Atmiya Institute of Technology and Science, Rajkot, Gujarat, India
[2]Associate Professor, Mechanical Engineering Department,
G.H. Patel College of Engineering and Technology, V.V. Nagar, Gujarat, India

Abstract
This paper deals with detail information about ceramic cutting tool used in CNC/VMC machine. Ceramic cutting tools are more frequently used in high speed application, dry machining and hard part turning. Ceramic cutting tools are also available with combination of aluminum and silicon oxides to improve mechanical properties. In this paper, advantages, disadvantages and properties of ceramic cutting tools are explained. Different methods of tool wear measurements are also discussed in this paper. At the end of this paper comparison is given to select suitable ceramic cutting tool material for appropriate cutting application.

Keywords: *Ceramic cutting tools, Tool wear measurements, Al_2O_3, Si_3N_4*

****Author for Correspondence*** E-mail: keyurme032@gmail.com

INTRODUCTION

Ceramic cutting tool materials are generally available in single and multiphase which is sintered with different oxides, nitrides and carbides. In ceramic cutting tool metallic binders are not required as compared to cemented carbides. Ceramic cutting tool provides high hardness at high temperature near about 1200°C. Ceramic cutting tool materials are mostly used for turning at high cutting speed approximately more than 500 m/min [1].

Ceramic cutting tools are generally used for machining cast iron, high temperature alloys, martensitic stainless steel. It is also suitable for high speed machining and in the cutting of hard materials. Due to stronger inter atomic ionic bond ceramic materials are more chemically stable compared to conventional tooling (High speed steels and Carbides). It will not generate built up edge during machining because of its lower tendency to adhere with other metals. Thus ceramic inserts are used in machining of precision metal parts for good surface finish [2] (Figure 1).

Advantages and Disadvantages of Ceramic as Cutting Tool Material

Advantages [3]

- Ceramic can be used for machining all kinds of metals, except nickel alloys and titanium.
- It is best suitable option for continuous cutting operations.
- It will not create any kind of built up edges hence it will give good surface finish.
- With ceramic cutting tool dry machining is possible (Coolants are not required).
- Ceramic cutting tool materials are having such high hot hardness.

Disadvantages

- Ceramic cutting tools are not suitable for rough milling operation because of their low toughness [4].
- It also gives fracture wear as compared to gradual wear as in case of carbide.
- Thermal shock resistance and fracture toughness are general limitation of ceramic materials.

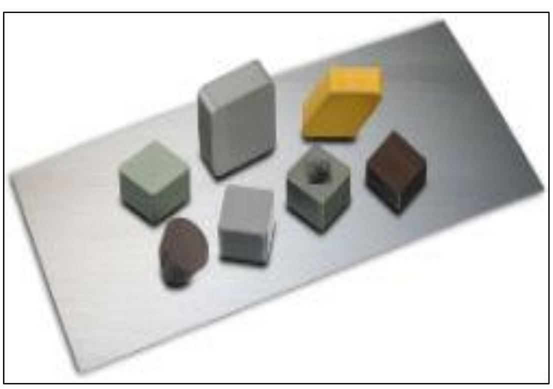

Fig. 1: *Ceramic Cutting Tool as Inserts [5].*

Properties of Ceramic Material [6]

Ceramic is very hard and brittle material. It can withstand more compressive forces than tension force. Due to its hardness it can have abrasive or wear resistant properties. It can also be used for acid resistant, corrosion and hear resistant material. It is chemically inert even at high temperatures also.

Types of Ceramic Cutting Tools

Ceramic cutting tools are having most applications in machining of all materials specially turning, milling of cast irons, super alloys. It is also suitable candidate for machining of hardened materials.

Ceramic cutting tools have two kinds of composite materials which are used commonly and given below:

1. Aluminum oxide (Al2O3) and
2. Silicon nitride (Si3N4).

Ceramic cutting tools can take more heat in the range of 2200°C as compared to carbides which is in the range of 870°C. Ceramic cutting tools are differentiated as pure, mixed and reinforced ceramics according to oxide which is used [7].

Pure ceramics does not contain any metallic binder, and has lower-melting-point as compared to others. Ceramic is hard, nonmetallic component which will resist heat and abrasive wear. Increasingly used as clamped indexable tool inserts, ceramics differ significantly from tool steels, which are completely metallic [8].

Alumina-zirconia, which is also known as white ceramics, contains up to 10% ZrO_2. This will improve toughness of material. When 40% TiC or Ti(C,N) are added in Alumina then it will become black ceramic and gives more resistance to abrasion (Figure 2) [7].

When Al2O3 reinforced with SiC whiskers it will become very tough and most resistant to thermal shock. Due to this combination of SiC whiskers in to the ceramic matrix, new material will have properties like very high strength, fracture toughness, thermal conductivity, thermal shock resistance and high temperature creep resistance [7].

At high temperature Al2O3-based ceramic have special mechanical and chemical properties, like high wear resistance, high hardness and relatively low chemical reactivity with steels and other materials. Application of alumina ceramics are limited due to its brittleness and poor damage tolerance properties [9]. Usage of alumina ceramics also restricted due to its bending strength and fracture toughness are lower than cemented carbide.

Second type of ceramic cutting tool contains: 1. Fully dense Si3N4 and 2. SiAlON materials (which are solid solutions of alumina in Si3N4). Fully dense Si3N4 has very good thermal shock resistance properties due to its high fracture toughness and low coefficient of thermal expansion characteristic. Silicon based ceramics are tougher as compared to alumina ceramics and it can also maintain its hot hardness property at hither temperature then cemented carbides.

Ceramic cutting tool materials are used for turning grey cast iron at higher cutting speed (above 400 m/min). It is also used for milling of grey cast iron. For turning operation coolant can be used. SiAlONs are not good resistance to thermal shocks but it is chemically more stable than Si_3N_4.

Fig. 2: *White and Black Ceramic Cutting Tool [7].*

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Table 1: *Typical Properties of Cutting Tool Ceramics[8].*

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
Density (g/cm3)	4.0	4.25	3.27
Transverse rupture strength (N/mm2)	700	750	800
Compressive strength (kN/mm2)	4.0	4.5	4.0
Hardness (HV)	1750	1800	1600
Young's modulus (kN/mm2)	380	370	300
Modulus of rigidity (kN/mm2)	150	160	150
Poisson's ratio	0.24	0.22	0.20
Thermal expansion coefficient (10−6/K)	8.5	7.8	3.2
Thermal conductivity (W/m K)	23	17	22
Fracture toughness(K1cMN/m3⁄2)	2.3	3.3	5.0

Fig. 3: *Silicon nitride-based ceramics [7].*

Applications

Different grades of ceramic cutting tools are applied in very wide range of application and materials mostly in high speed turning operation. It can also be used in grooving and milling operations. The specific properties of each ceramic grade enable high productivity, when applied correctly. Grade-wise applications are given below: white ceramic grade materials are more suitable for machining operation on steels. Black ceramic is suitable for turning of chilled cast irons and hardened steels. Typical application of whisker reinforce ceramic cutting tools are high speed finishing of nickel or cobalt based super alloys [7]. Si_3N_4 is most suitable for machining of grey cast iron. SiAlONs are mainly used in rough turning of nickel-based super alloys [7].

Tool Wear Patterns and its Measurements Techniques

At high cutting speed generally all grades of ceramic cutting tool gives high wear resistance. In hard part turning process main cutting edge will experience significant mechanical and thermal loads and chemical reactions. Result of all this effects leads to wearing of the cutting tool. Thus, tool wear cannot be neglected in machining process as it plays an important role in dimensional accuracy and surface finish. The most common type of tool wears are flank wear and crater wear.

Prediction of tool wear is very important to avoid catastrophic tool failure, which affects component dimensional accuracy and performance of machining process. Abrasive wear is most common type of wear patterns observed in hard part turning process. When machining with high cutting speeds, chemical properties also plays vital role. The temperature in the cutting zone accelerates the chemical reactions between the cutting tool and workpiece material [10-13].

There are few methods of wear measurement of ceramic cutting tools which are mentioned below:

Direct Wear Measurement

It is most common method of finding tool wear by following instruments:

1. Toolmaker's microscope
2. Scanning electron microscope
3. White light interferometers and (optical method)
4. Con-focal microscopes (optical method)

Optical method is more advantageous because it can measure various types of wear like flank wear, crater wear and notch wear.

Indirect Wear Measurement

Another indirect method is calculating tool wear by using standard equation. Some of the tool life criterions are defined in the ISO 3685 standard which can also be considered, it is based on maximum flank wear (VBmax).

Table 2: *Comparison of Ceramic Cutting Tools.*

Sr. No.	Ceramic Material Type	Properties	Limitation	Machining Application
1	Oxide ceramics (Al2O3) + zirconia (ZrO2)	Crack Inhibition	Lower resistance to thermal shock	Steel finishing operations
2	Mixed Ceramics with TiC and Ti(C,N) coating	Toughness and thermal conductivity	lower bending strength and fracture toughness	Chilled cast irons and hardened steels
3	Whisker-reinforced ceramics (SiCW)	More toughness and coolant can be used	lower bending strength and fracture toughness	Ni-based alloys
4	Silicon nitride ceramics (Si3N4)	Higher toughness	Chemical stability	Most suitable for grey cast iron
5	Sialon (SiAlON)	More chemically stable	Lower resistance to thermal shock	Heat resistant super alloys (HRSA)

Some researcher also focuses on nose wear because as the tool leaves the cut it will generate imprint on the component face. Wear is also possible by chipping or fracture phenomenon in the nose area of tool. It will create more significant effect on surface finish and dimensional accuracy of the final components.

A tool wear can also be calculated according to Taylor's Tool life equation VTn = C, Where n and C are constant which depend on type of materials, V is cutting speed in m/min, and T is in Time (Tool life) in min.

A cutting tool fails to machining when one of the following rejection criteria are matched as per ISO Standard 3685 for tool life testing [11, 14-18].

- If average flank wear is ≥ 0.3 mm
- It maximum flank wear is ≥ 0.4 mm
- If nose wears reaches to ≥ 0.5 mm

CONCLUSION

Chemical stability of ceramic cutting tools is more as compared to conventional tools like HSS and carbides due to its inter-atomic ionic bonding is strong. Ceramic cutting tools are having special application and it can be used in materials where normally carbide inserts are failed to use. Properties of different ceramic materials discussed above are mentioned below in Table 2 along with their limitation and application.

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