A Study on the Modification of Composite Ceramic Tool

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ABSTRACT: Ceramic tool because of its high hardness characteristics are widely used in various types of cutting. Its fracture failure often occurs, so the poor toughness of ceramic materials is the main factor limiting the development. In order to overcome these disadvantages of poor toughness of ceramic cutting tools, the carbon nano tube as relatively excellent mechanical properties added into the Al_2O_3 matrix ceramic tool, and studies its performance optimization. Analyzed the different carbon nanotube content of Al_2O_3 ceramic cutting tool performance, 2% samples of carbon containing nano tube has the best mechanical properties.
KEYWORD: Al_2O_3 ceramic tool, Carbon nanotube, Modified

1 BACKGROUND

The grinding process pursuits the high efficiency and low cost in the future. High speed machining is the representative of the direction. At present, to meet the modern advanced manufacturing technology, low cost and environmental protection tool concept, it is ceramic tool (Yuan Shuai et al, 2015). Due to the characteristics of ceramic with high hardness and high brittleness, it is very prone to failure. Carbon nanotubes due to its high elastic modulus, high strength and good mechanical properties are widely used in the field of reinforced composites (Wu Zhenjiang et al, 2014) (Lu Changyong, 2013). This paper will be applied to the study of carbon nanotubes modified alumina-matrix composite ceramic tool. It hopes can make the mechanical properties of alumina-matrix ceramic tools are improved. It can make better use of the various types of cutting.

2 EXPERIMENTAL MATERIALS AND EXPERIMENTAL PROCEDURES

Table 1 Experimental material

Material name	purity	granularity	effect of raw material
Al_2O_3	>99.9%	<3um and 30nm	reinforcement and matrix
TiC	>99.9%	<3um	reinforced phase
Mo	>99.9%	30-50nm	binder
Ni	>99.9%	20-100nm	binder
nanotube	>99.9%		additive

This experiment was prepared Al_2O_3 ceramic knife samples by hot pressing sintering. The main raw materials expect used nano Al_2O_3 powder and nano carbon tube, it is also used the additive, metal binder etc in the process of preparation Al_2O_3 ceramic tool. The raw materials are shown in Table 1.

After a lot of literature review (Jin Hua et al, 2013), preliminary determine the ratio of raw materials for preparation of Al_2O_3 ceramic tool as shown in Table 2.

Table 2 preparation of Al_2O_3 ceramic tool

raw material	Content/wt%
Al_2O_3 powder	5
TiC	25
Mo	7
Ni	3
nanotube	0-5

According to the melting point of raw materials and sintering conditions considering the phase transition temperature of Al_2O_3 matrix ceramic tool were determined (Duan Liuyang et al, 2015). The specific parameters are shown in Table 3.

Table 3 Sintering conditions Al2O3 ceramic knife

Sintering parameters	sintering temperature	holding time	sintering stress
parameter values	1600℃	30min	30Mpa

Preparation of Al_2O_3 composite ceramic tool material sample process as shown in Figure 1:

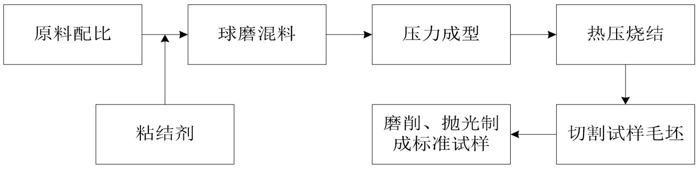


Figure 1 the sample process of materials Al_2O_3 composite ceramic tool

3 THE RESULTS OF CHARACTERIZATION METHODS

The mechanical properties of ceramic tool are the most important performance indexes. So this experiment tests the standard sample mechanical properties as following measurements.

3.1 *The anti-bending strength test*

According to the testing method of GB/T4741-1999 ceramic material anti-bending strength, it tested the anti-bending strength of SiC sintered ceramic samples. The anti-bending strength measurement of three samples, the result is average value. The principle is shown in Figure 2.

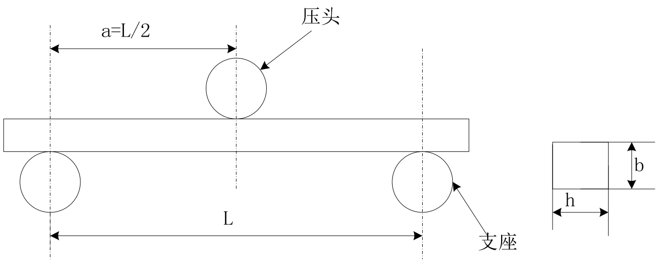


Figure 2 the anti-bending strength test principle diagram

The anti-bending strength calculation formula is as follow:

$$\sigma_b = \frac{3PL}{2bh^2} \tag{1}$$

In this formula: σ-three-point bending strength (Mpa)

P-the maximum load of fracture (N)

L-span (mm)

b-specimen width (mm)

h-specimen height (mm)

3.2 *Vickers hardness*

According to national standard GB16534-I996 indentation hardness tests Vivtorinox, it measured the indentation diagonal and the crack length by using optical microscope. Samples is 6 indentation measuring results averaged. Formula Vivtorinox hardness by indentation method is as follow:

$$H_V = \frac{1.8544P}{(2a)^2} \tag{2}$$

In this formula: Hv-Vickers hardness (Mpa);

P-indentation load (chosen 196N);

2a-the length of the diagonal of indentation (mm).

3.3 *Fracture toughness test*

Fracture toughness evaluation of ceramic materials used indentation method. Calculation of fracture toughness specimens from 6 indentation results averaged.

Figure 3 is a schematic diagram of indentation and crack.

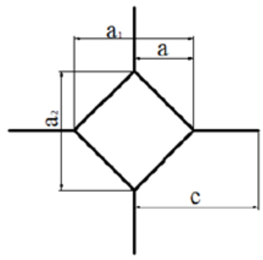


Figure 3 Schematic diagrams of indentation and crack.

It measured the indentation diagonal and the crack length by using optical microscope. The fracture toughness calculation formula of the indentation method is as follow:

$$K_{IC} = 0.37644 \times (\frac{c}{a})^{\frac{3}{2}} \times \sqrt{a} \times \frac{P}{(2a)^2} \times 10^{-6} \tag{3}$$

In this formula: KIC-fracture toughness ($MPa \cdot m^{\frac{1}{2}}$);

P-pressure load (N);

a-the average value of the half length diagonal (m);

c-half length of crack (m).

3.4 *Fracture morphology*

In this experiment, the morphology of the material fracture observed by scanning electron microscopy (SEM).

4 RESULTS AND ANALYSIS

The main purpose of this experiment is analyzed the content of Al_2O_3 ceramic tool materials carbon nanotubes and the variation material performance and influence. According to the difference content of carbon nanotubes in the raw materials, it tabbed the different sample. The relationship between sample label and the content of carbon nanotubes are shown in Table 4.

Table 4 the corresponding relationship between the number and content of carbon nanotubes samples

Sample number	T_0	T_1	T_2	T_3	T_4	T_5
Content of carbon nanotubes/wt%	0	1	2	3	4	5

4.1 *Carbon nanotube content affected on anti-bending strength of Al_2O_3 ceramic cutting tool*

The Al_2O_3 ceramic tools anti-bending strength of different carbon nanotubes content is shown in Figure 4.

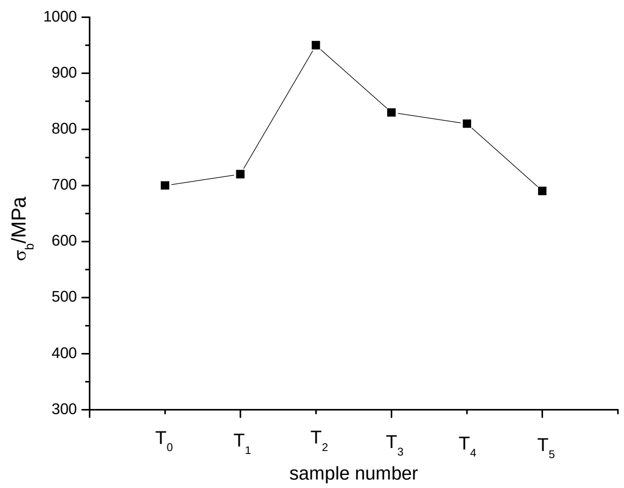


Figure 4 Carbon nanotube content affected on anti-bending strength of Al2O3 ceramic cutting tool

For the Al_2O_3 composite ceramics, the carbon nano tube after adding different content. The anti-bending strength of Al_2O_3 composite ceramic material has increased and then decreased with the contents of nanotube increasing. But the anti-bending strength of T2 sample (the content of nanotube is 2%) up to 935MPa. We can have the conclusion: When the carbon nanotubes /Al_2O_3 composite ceramic material density is very high, the internal defect is less, such as pores, micro cracks etc. Then the carbon nanotubes /Al_2O_3 composite ceramic material has stronger anti-bending strength. We can also find that many of the nanoparticles did not increase the anti-bending strength of carbon nano tube /Al_2O_3 composite ceramic material. It will reduce the anti-bending strength of the material. In summary, the added content of carbon nanotubes should be between 1-3%. It can make the composite ceramic tool material which has a high anti-bending strength.

4.2 *Content of carbon nanotubes effected on Al_2O_3 ceramic tool Vivtorinox hardness*

The difference carbon nanotubes content anti-bending strength of Al_2O_3 ceramic cutters is shown in Figure 5.

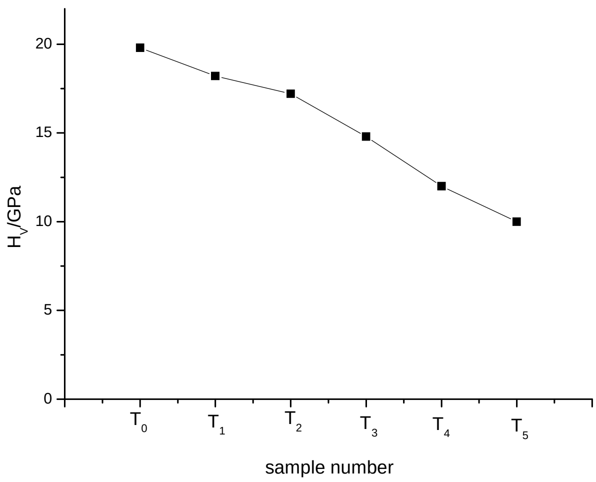


Figure 5 Content of carbon nanotubes affected on Al2O3 ceramic tool Vivtorinox hardness

Vivtorinox hardness measurement of Al_2O_3 composite ceramic material values also appeared to decline. Integrated some research shows that its particle size smaller more easily sintered in the process of sintering preparation. At the same time particles also tend to be the reunion. The rapid growth of agglomeration easily, it caused grain defects. So it added too much carbon nano tube, it will often make a large number of carbon nanotubes together. It is bad for the densification. The prepared materials tend to present many holes. The diamond indenter pressured to the hole will be increased tested by the Vivtorinox hardness. The measured hardness values will reduce.

4.3 *Carbon nanotube content affected on fracture toughness of Al_2O_3 ceramic tool*

The difference content of carbon nanotubes Al_2O_3 ceramic tool's fracture toughness are shown in Figure 6.

Fracture toughness measurement of carbon nanotubes /Al_2O_3 composite ceramic material values also appeared increased and then decreased. When it added carbon nano tube content is 1-2%, it can be fracture of Al_2O_3 composite ceramic tool toughness roughly doubled. But when the carbon nano tube added the content gradually increased, the fracture toughness exhibited to reduce. This research is applied in hot pressing sintering method. It is played a very good guarantee on the density of the composite, and plays a guarantee on the performance. Due to the toughening effect of carbon nanotubes, the Al_2O_3 composite ceramic tool materials show the strong fracture toughness. The fracture toughness of the composites increased significantly. However, the fracture toughness of materials Al_2O_3 composite ceramic cutting tool with the increase of carbon nanotube amount has been increasing. When the content of carbon nanotubes exceeds 4%, the fracture toughness of composite materials did not get any improvement. There will be even larger matrix defects, such as, appearing hole etc. The comprehensive performance of new composite materials will be severely damaged. The fracture toughness will be lower.

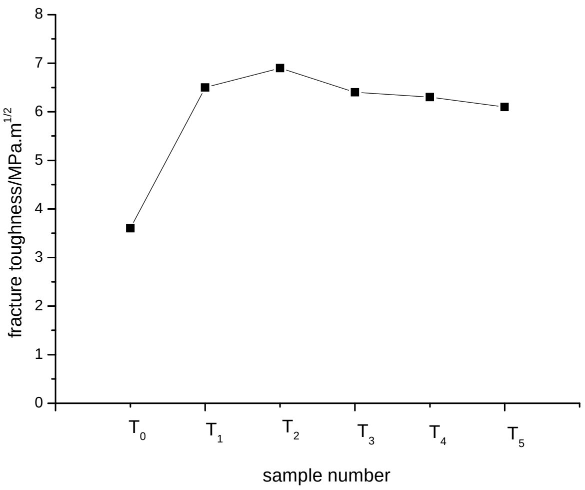
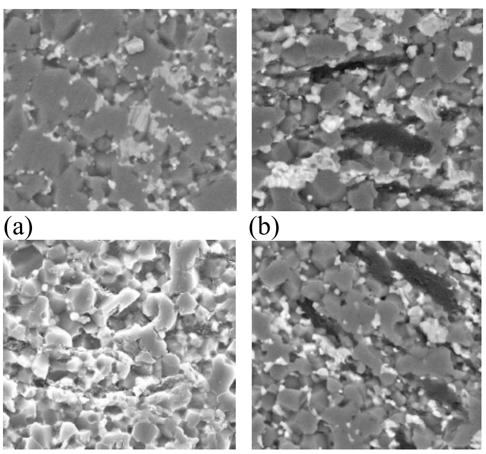


Figure 6 Carbon nanotube content affected on fracture toughness of Al2O3 ceramic tool

4.4 *Carbon nanotube content affected on fracture morphology of Al_2O_3 matrix ceramic tool*

From the front of the three indexes analysis, cutter mechanics Al_2O_3 ceramics prepared with excellent performance with the carbon nanotube content in the range of 1-3%. Then we special study the Al_2O_3 matrix ceramic tool fracture morphology (2000 times) which the content of carbon nanotubes was 0-3%. As shown in Figure 7.



(a) (b) (c) (d)

Figure 7 (a) containing 0% carbon nanotubes; (b) containing 1% carbon nanotubes; (c) containing 2% carbon nanotubes; (d) containing 3% carbon nanotubes

In Figure 7 (a), it is not difficult to find that between alumina particles which exhibit a very close combination without the addition of carbon nanotubes. Is there any basic pore, the density is very high. The dominant crack is mainly intergranular and transgranular fracture. In Figure 7(b), when the matrix add 1% carbon nanotubes, the combination between alumina particles which exhibit still very close. Only a small part of the pore, the density is higher. But there is a small amount of slender carbon nanotubes diameter to the original matrix interspersed. There are some short carbon nanotubes in peripheral section. In the figure 7(c), When the matrix added 2% carbon nanotubes, the combination between alumina particles which exhibit still very close, and only a few pores. Compared with adding 1% carbon nanotubes, the more slender carbon nanotube diameter into the original matrix, and there are a lot of short carbon nanotube terminals in the section. In figure 7(d), when the substrate added 3% carbon nanotubes, the combination between the alumina particles which exhibit still close, and there are more pores. It also increased significantly in the section of carbon nanotube terminals.

5 CONCLUSION

Due to the high hardness and high brittleness of ceramic properties, ceramic tool in high speed machining is often broken. So this paper will test the excellent mechanical properties of modified carbon nano tube Al_2O_3 ceramic cutting tools. Analysis of mechanical properties and fracture morphology of the Al_2O_3 through the ceramic tool based on different content of carbon nanotubes, when adding carbon nano tube content is 2%. The composite new material comprehensive performance is the best. Compared with Al_2O_3 materials without CNTs composite ceramic cutting tool, the anti-bending strength increased 33.95%. The fracture toughness increased 92.98%. A substantial increase in anti-bending strength and fracture toughness can effectively broaden the scope of application of ceramic tools, high speed cutting tool has better performance for more industry.

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