Study on Standards of Ceramic Knives in Contact with Foodstuffs Part 2: Performance Requirements

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Abstract. In this paper, the performance requirements, test methods and safety instructions of ISO 8442-9 standard have been studied, and the principles for determining the ISO 8442-9 standard technical requirements have been analyzed, according to the test results of different specifications of ceramic knives from 22 production enterprises in 6 countries, and incorporating the opinions and suggestions from 6 countries including production enterprises, technology experts, consumers, international trade, etc.

1. Introduction
Ceramic knives that came in contact with food were born in Japan in the 1980s [1-2], extending to daily ceramics from industrial zirconia ceramics. Zirconia ceramic knives have the advantages of high sharpness, high wear resistance, corrosion resistance, and cutting food without peculiar smell, etc. [1-8]. After more than 30 years of development, ceramic knives have been widely used in countries all over the world. China, Britain, France, Germany, Japan, South Korea, the United States and other countries have formed their own branded products.

On March 10th, 2014, the International Standardization Organization for Cutlery and table and decorative metal hollow-ware technical committee (ISO/TC186) voted to draft jointly by China for standardization technical committee and "ISO/TC186 Technical Committee on ISO 8442-9 Materials and articles in contact with foodstuffs - Cutlery and table holloware - Part 9: Requirements for ceramic knives" standard, namely ISO 8442-9 Technical requirements for ceramic knife for food contact materials and products, and a standard drafting working group has been established that consists of technical experts from the cutting tool industry in China, the United Kingdom, France and Germany that come into contact with food. After more than three years of hard working, the technical requirements of ceramic knife are basically determined.

The technical requirements for ceramic knives are the technical requirements for preparing and preparing food knives consisting of ceramic blades with knife edge and handles that come into contact with food, and specify the materials and performance requirements and test methods for ceramic knives used in food preparation.

ISO 8442-1:1998 Materials and Articles In Contact With Foodstuffs - Cutlery and Table Holloware - Part 1: Requirements for Cutlery for the Preparation of Food [9], which specifies the technical requirements for food contact with metal cutting tools. Based on ISO 8442-1, ISO 8442-9 shall be compiled in combining with the characteristics of ceramics, new testing techniques and the use of food contact tools. Based on the characteristics of ceramic knives, all technical parameter requirements and
test methods are required for ceramic knives, and no specific requirements are put forward for raw materials and production processes of ceramic knives. This paper has been studied on 12 aspects from the hardness, brittleness, sharpness, edge retention, blade clip impact resistance, blade coating bond strength, washability resistance, thermal shock resistance, blade strength, handle performance and the connection between the blade and the handle, safety instructions and others, the use performance of food ceramic knife and test methods were determined, and the principle of ISO 8442-9 technical requirements was evaluated and analyzed.

2. Hardness and brittleness
One of the characteristics of the ceramic is its high hardness. Among the ceramic knife samples tested, the minimum hardness is 1082 HV1, the highest hardness is 1274 HV1, and 98% of the samples have hardness values higher than 1100 HV1. For metal tools, ISO 8442-1 standard [9] specifies the hardness value not less than 52HRC, according to GB/T 1172-1999 ferrous metal hardness and strength conversion value [10], 52HRC is equivalent to 550HV, the Vickers hardness of ceramic knife is approximately twice the Vickers hardness of metal tools.

Although ceramics have high hardness, they have low toughness and are brittle materials, which have become common sense in daily life. According to the ISO 8442-1 standard, a total of 20 drop tests were performed by 5 times in four directions [9]. None of the ceramic knife samples were qualified. Therefore, ISO 8442-9 did not specify the drop test of the ceramic knife. Of course, preventing the falling of a ceramic knife is also a matter of daily life. However, the brittleness of ceramic knives severely affects the safe use of ceramic knives. For this reason, ISO 8442-9 specifies six aspects to control the brittleness of ceramic knives. First, in the safety instructions, the user is explicitly informed; second, macroscopic cracks are detected through the appearance and penetration test to control brittleness; third, the brittleness is controlled through the crack detection of the Vickers hardness indentation [11]; fourth, the brittleness is controlled by the impact test. Fifth, the brittleness is controlled by the thermal shock resistance test. Sixth, the micro-cracks, the size and uniformity of the pores, inclusions, etc. are controlled by the metallographic examination to control the brittleness.

In the Vickers hardness test, if the load is 1 kg, the indentation of all samples is not cracked; if the load is 5 kg, the indentation of 78% of the samples is not cracked; if the load is 10 kg, only 20% of the sample’s indentation has no cracks. According to the relationship between the load and crack of Vickers hardness test, the brittleness of ceramic knives is measured [27]. It is required that the indentation should not crack at the load of 3 kg. An example of a ceramic knife Vickers indentation crack is shown in Figure 1. At the same time, hardness values are required to be measured in different areas to ensure the uniformity of hardness and brittleness of the ceramic blade.

![Figure 1. The Vickers hardness Indentation crack of ceramic knife.](image)

The specific technical requirements of ISO 8442-9 on the hardness and brittleness of ceramic knives are: to divide the blade length and width into 3 equal parts and form 9 areas, the upper area of the blade tip part, the center area of the blade body part, and the center area of the blade root part. Vickers hardness value are measured at least 1 point per center part. According to ISO 14705, the
central hardness values at all three sites should be greater than 1100 HV3, and all indentations for testing Vickers hardness should be effective crack-free indentations specified in ISO 14705 standards [12].

3. Sharpness and edge retention

Sharpness and edge retention are very important performance indicators for ceramic knives, the testing method is based on the ISO 8442-5 standard [13]. In the ISO 8442-5 standard, the cutting edge is divided into an A-type edge and a B-type edge. A-type edge refers to the blade which can be sharpened by the user and the spacing of the teeth is greater than 1 mm. And B-type edge can no longer be resharpened with a sharp blade. Ceramic knife edge belongs to B-type edge.

The technical requirements of the sharpness and edge retention in ISO 8442-5 standard are: sharpness \( z(3) \) is \( \geq 50 \) mm, edge retention of the A-type edge \( z(60) \) is \( \geq 150 \) mm, and edge retention of the B-type edge \( z(200) \) is \( \geq 1500 \) mm. The British CATRA (Cutlery and Allied Trades Research Association) analyzed the test data of knife sharpness and edge retention for 30 years, and divided the sharpness and edge retention of the knives into six grades. The detailed classification rules are shown in table 1.

### Table 1. Food Contact Tool CATRA Grade /mm.

| Parameter       | Sharpness \( z(3) \) | A-type edge \( z(60) \) | B-type edge \( z(200) \) |
|-----------------|-----------------------|-------------------------|--------------------------|
| Technical requirement | \( \geq 50 \)     | \( \geq 150 \)          | \( \geq 1500 \)           |
| Very poor       | \( \leq 30 \)       | \( \leq 100 \)          | \( \leq 1000 \)           |
| Poor            | 31-49                | 101-150                 | 1000-1500                 |
| Average         | 50-80                | 151-280                 | 1501-2500                 |
| Good            | 81-100               | 281-370                 | 2501-3500                 |
| Very good       | 101-110              | 371-550                 | 3501-4000                 |
| Excellent       | \( \geq 111 \)      | \( \geq 551 \)          | \( \geq 4001 \)          |

The two parameters of sharpness and edge retention of the knife are the most important and key parameters of the knife technical indicators. The requirements of ISO 8442-1 are the basic requirements. Ceramic knives are sharper and more durable than metal knives. Ceramic knives are superior in terms of sharpness and edge retention. The specific indicators proposed by ISO 8442-9 are: sharpness \( z(3) \) \( \geq 60 \) mm, edge retention \( z(30) \) \( \geq 300 \) mm, and detection method carries out the ISO 8442-5. From the perspective of daily use of ceramic knives, the requirements for sharpness and edge retention in this standard are also basic requirements or minimum requirements for ceramic knives.

In the detection of edge retention, the 200-week cutting cycle is relatively long, but it can reflect the service life of the knife. From the point of view of production process evaluation, a 200-week cutting cycle should be considered, ie \( z(200) \) \( \geq 2501 \) mm. Considering the economical efficiency of the test, the cutting cycle is determined to be 30 weeks, ie \( z(30) \) \( \geq 300 \) mm. The index is equal to the required ceramic knife cut 30 weeks to reach the metal cutting tool A-type knife cut 60 weeks of "good" rating, the ceramic knife should have better edge retention.

From the inspection data, ceramic knives currently on the market are not all ceramic knives that have sharper and more durable characteristics. In 40 ceramic knives, the 57.5% of ceramic knives sharpness does not meet the technical requirements of steel knives [14].

4. Impact resistance of blade clip

The weakest position of the ceramic knife is its edge area, and the area is prone to collapse. The small ceramic fragments generated by the chipping are easily mixed in the food. If the food is swallowed, it will cause serious damage to the body.

There are two suggestions for detecting the impact resistance of the blade clip. The first is to use the D type device, which is specified in the hardness test method of the metal material of ISO 16859-1,
and the clamping mouth is intact [15]. The impact body of this method is a Ø3 mm, mass 5.5 g WC carbide with an impact energy of 11.0 N•m; the second is the use of ISO 4532 glaze ceramics and enamel products for the determination of impact resistance. The mouth and the clip are intact [16]. The impact body of this method is a Ø5 mm steel ball, the impact surface is a Ø2.5 mm circular plane on the steel ball, and the force range that can be applied when impact is 0-90 N. The working group decided to choose the first method. The structure of the two impact devices is basically the same, but the first method determines the energy impact, and the second method measures the impact with the force value. The second method is suitable for the detection of the bond strength between the ceramic coating and the non-ceramic substrate, whereas the test for the impact resistance of the ceramic knife holder is the brittleness test of the ceramic body (the blade strength test is the same as ISO 8442-1).

The specific requirements of ISO 8442-9 on the impact resistance of the ceramic blade clip are as follows: During the impact test of the ceramic blade clip, the ceramic blade should not be broken or cracked. Clip impact position: When the blade length is less than 100 mm, it will impact 3 points, and when the blade length is ≥100 mm, it will impact 5 points. The first point is at a distance of 5 mm from the tip of the blade, the second point is at the closest position to the handle; the other points are evenly distributed between the first point and the second point; all the impact points are 3 mm to 5 mm from the cutting edge. The impact device and the schematic diagram of the impact point are provided in the normative appendix.

According to the actual test results, about 68.3% of 41 ceramic knives cannot pass the impact resistance test [14].

5. Coating bonding strength
A decorative or functional coating can be formed on the entire surface of the ceramic knife blade by various processes such as plating, spraying, coloring, and deposition as shown in Figure 2a) and 2b). On the local surface of the ceramic blade, symbols or patterns, logos and logos, etc. (also referred to herein as coatings) are formed by printing and decals, as shown in Figure 2c). If the strength of the bond between the coating and the ceramic blade is insufficient, the coating or pattern will fall off and mix in the food during use. If the food is swallowed, it will cause serious damage to the body.

![Coatings and patterns on ceramic knives](image)

**Figure 2** The coating of ceramic knife.

The coating and pattern bonding strengths were tested using the A1 method of BS 7069:1988[17], which is based on British standard cookware coating inspection method [17]. According to the basic principle of the method, the thickness of the friction plate is 5 mm, the prescribed load and the size of the prescribed polishing plate are modified to determine the size of the friction plate according to the
size of the ceramic blade, and the load is further selected to ensure that there is $7 \times 10^{-3}$ MPa pressure between the polishing plate and the blade. The friction plate moving distance was modified to be consistent with the sharpness and edge retention test distance. Abrasive particle size in friction plates according to ISO 6344-2 standard [18].

The specific requirements for the bond strength of the coating in ISO 8442-9 are: the ceramic blade should not shed or expose the ceramic knife matrix during the wear resistance test. The alumina particle size in the friction plate: P180, friction plate density: (180-210) kg/m$^3$; the force value applied on the friction plate ensures that the friction plate rubs the coating under a pressure of $7 \times 10^{-3}$ MPa. The relative moving speed of the friction plate and the ceramic knife is 6.5 m/min, the moving distance is 40 mm, and the movement is back and forth. Replace the friction piece 50 times, a total of 250 times. The dust, stain, water, oil and other sundries on the surface of the sample should be removed to obtain a dry and clean surface before the test. After the test is completed, brush the dust and observe the test. A schematic diagram of the test device is provided in the normative appendix.

6. Wash resistance
In ISO 8442-1, the cutlery is classified into normal grade (with corrosion resistant blades or prongs capable of withstanding dishwasher cleaning procedures) and special grade (with corrosion resistant blades of withstanding dishwasher cleaning procedures and sterilization processes). The main difference is that special grade can withstand 100°C sterilization. It is now no longer necessary to disinfect at 100°C and ceramic knives are no longer graded.

The ceramic knife’s resistance to washing is based on EN 14875-1 standard [19] Mechanical dishwashing resistance of utensils - Part 1: Reference test method for domestic articles (ceramic, glass, enamel, metal, and plastic products), and put forward the demand of cycle and check the cycle.

The specific requirements of ISO 8442-9 for washing resistance are: After the ceramic knife is washed in a dishwasher, it should be free from damage, deformation and any visual changes. The test method is in accordance with EN 12875-1 standard [18] with 125 times and it is recommended to check every 25 cycles.

From the results of the sample test, 4 ceramic knife handles cannot pass the washing resistance test among 10 ceramic knives [30].

7. Thermal shock resistance
Brittle materials are prone to brittle fracture under thermal stress. Engineering ceramics and ceramics for daily use have corresponding methods for measuring thermal shock resistance [20-21]. The thermal shock resistance test method of ceramic knives draws on the method B of EN 1183:1997 Materials and articles in contact with foodstuffs - Test methods for thermal shock and thermal shock endurance[22], combine the unique use of ceramic blade environment (such as cutting of food in the oven), puts forward the specific test temperature requirements.

The specific requirements of ISO 8442-9 for thermal shock are: ceramic blades without damage, deformation or any visual change of the ceramic insert after the thermal shock resistance test. The detection method implements method B of EN 1183:1997. The test temperature difference is 280°C. Recommended high temperature is 300°C and low temperature 20°C.

From the results of sample testing, one of the six ceramic knives cannot pass the thermal shock resistance test [14].

8. Other performance
The blade strength (bending strength), the handle performance, the connection between the blade and the handle of the ceramic knife shall meet the technical requirements [9] of ISO 842-1, and the ISO 8442-9 has no additional requirements.

Performance of the ceramic knife materials, such as fracture toughness [23], bending strength [24], tensile strength [25] and so on, based on the standard samples used in the test, according to the characteristics of ceramic knife product structure, standard sample processing particularity, these indexes are not used as a ceramic knife product performance index. The research and development of
ceramic knife products should be based on the performance of ceramic knife materials, and it can be considered to verify the requirements of ceramic knife products to meet this standard through type testing.

In the case of bending strength, connect the test load to the 3 mm x 4 mm rectangular section on the specimen until it fractures, calculate the bending strength \([2.4]\) of sample, the bending strength can be used as the basis of engineering material application in structural strength design. The applied load is based on the length of the blade according to the specification and detection method for the bending strength of ceramic of ISO 8442-9. The ceramic knife shall not fracture under the specified load. Evaluating method [9] for the fracture resistance of ceramic knife is based on the characteristics of ceramic knife in the use.

9. Safety instructions
Take into account the brittle ceramic knife, sharp features as well as the new ceramic knife products research and development, ISO 8442-9 does not stipulate specific safe use. Producers should determine the safety instructions according to the characteristics of their products. Other marks such as trademarks, origins, manufacturers, etc., should comply with national laws.

The specific requirements of ISO 8442-9 for the safe use of ceramic knives are: The relevant information on the safe use of ceramic knives should be provided on the surface of ceramic knives, or on the packaging, or as leaflets in the package inserts according to product characteristics, such as: preventing collision, preventing falling, prohibiting For hard foods (e.g. frozen foods, bones), away from guarded personnel, do not use with blades cracked or broken etc.

What needs to be pointed out is that once the blade is cracked or broken, there is a high possibility of unobserved cracks and it is unsafe to continue using it. This cautionary statement will not be explained based on the development of the product. For example, if a new ceramic knife is developed to meet the drop test in the ISO 8442-1 standard [9], then the safety instructions may not be marked to prevent the drop.

10. Health and safety
The Health and safety requirements for the migration of heavy metals, radioactivity, metal detector detestability, and the safety requirements for metal and plastics related to the handles of ceramic knives belong to the requirements of laws and regulations of the corresponding countries, and do not fall within the scope of this standard category, not as a technical requirement of ISO 8442-9. For example: The restrictions on migration of heavy metals specified in China's mandatory standards GB 4806.4-2016 National Food Safety –ceramic ware [26] are: lead \(\leq 0.8\) mg/dm\(^2\), cadmium \(\leq 0.5\) mg/L, whereas lead \(\leq 0.8\) mg/dm\(^2\), cadmium \(\leq 0.07\) mg/dm\(^2\) in Germany's DIN 51032-1986 standard [27], The European Union's EC 84/500/EEC Directive [28] and ISO 6489-2 Standard [29]. For example: China's Provisional Regulations on the Control of Certain knives [30] and the Controlled knives Recognition Standard [31] have specific provisions for the knives tip angle, blade thickness, and blade length. For example, the European Union's EC 1935/2004 Directive [32] specifies the test requirements for food-grade materials.

11. Conclusion
On June 14, 2017, Germany and the European Union adopted ISO/DIS 8442-9:2017(E) directly and issued and implemented E DIN EN ISO 8442-9:2017-05. ISO officially promulgated ISO 8442-9:2018 Materials and articles in contact with foodstuffs - Cutlery and table hollowware - Part 9: Requirements for ceramic knives on February 9, 2018.

Since the first successful development of the ceramic knife in contact with foodstuffs and the international standardization of the "Technical Requirements for the ceramic knife in contact with foodstuffs", the development of the ceramic knife has gone through more than 30 years. In the course of the research on the performance of ceramic knives, the working group has absorbed the opinions of production companies, technical experts, consumers, and international trade in six countries around the world, based on the detection results of ceramic knives of 55 specifications of 22 international
companies, researched and determined the technical requirements of the 12 aspects of the ceramic knife in contact with foodstuffs, and determined the principle of ISO 8442-9 technical requirements. The promulgation of international standards for the ceramic knife in contact with foodstuffs requires an important role in helping product quality improvement, ensuring user safety, promoting the development of production companies, and facilitating international economic and trade exchanges.

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