Crack Failure Analysis of 7Cr17MoV Steel Kitchen knife

Jiaxin Chen*
Yangjiang Supervision Testing Institute of Quality and Metrology, Yangjiang City, Guangdong Province, China

*Corresponding author e-mail: 406682535@qq.com

Abstract. A cracked 7Cr17MoV steel kitchen knife was analyzed by macroscopic inspection, hardness testing, chemical constituent test, metallographic inspection, scanning electron microscopy and energy spectrum analysis. The results showed that the cracking mode of the kitchen knives were stress corrosion; there were more large angular block carbides and uneven distribution of carbides in the kitchen knife material, causing stress concentration and initiation of microcracks, resulting in instability of the passivation film on the stainless steel surface. When the kitchen knives produced and processed in a chlorine-rich environment, chloride irons were preferentially corroded at the weakened passivation film to form corrosion pits. The bottom of the corrosion pit was microcracked due to stress concentration, and the chloride irons continued to corrode along the channels formed by the micro-cracks, which further expanded the microcracks. During the grinding process, the micro-cracks expanded outward under the action of external forces, resulting in cracking.

1. Introduction
7Cr17MoV steel is a high-carbon martensitic stainless steel, which is a new type of steel produced by adding a little molybdenum and vanadium to 7Cr17 steel to improve the hardness and wear resistance. This kind of steel is widely used in kitchen knives in foreign countries, and similar steel types in the world are ASTM440A in America and SUS440A in Japan. 7Cr17MoV steel is mainly used for making high-grade knives and scissors and medical instruments with high hardness and high wear resistance. However, 7Cr17MoV steel is seldom used in domestic knife and scissors manufacturers, and there are few relevant technical data. A manufacturer found that a batch of 7Cr17MoV steel kitchen knives cracked during grinding process after heat treatment, which seriously affected quality. The cracking knife was analyzed by macroscopic morphology, chemical constituent, hardness testing, metallographic inspection and SEM analysis methods to find the reason of crack.

2. Test methods and results
2.1. Macrographic inspection
The positions of crack on these knives were different. Figure 1 showed one of the cracked kitchen knives. The crack length was 38 mm from back of blade to middle of blade. The crack was opened by an external force for observing fracture surface. As shown in figure 2 (a), the front end of the fracture was 18 mm in length. The picture showed that the fracture surface was relatively flat and there were many brown corrosion products near the back of the blade, which were distributed at the outer end and both sides of the fracture. The radial pattern next to the corrosion products developed towards the cutting edge. It could be seen that the crack originates from the corrosion pits near the surface of the
back of the blade, and the fracture at the crack source was flat and dark gray. Figure 2 (b) showed macroscopic fracture morphology of propagation region of crack. From left to right, it was the direction from the back of the blade to the cutting edge, and the radial pattern converged near the corrosion pits.

![Figure 1. Picture of cracked kitchen knife.](image1)

Figure 2. Macroscopic morphology of fracture: (a) region of the front end; (b) propagation region.

2.2. Chemical composition test
The cracked part of the kitchen knife was analysed with a metal analysis spectrometer, and the results were shown in table 1. The phosphorus content of the kitchen knife was too high, the vanadium content was lower than the standard value, and the molybdenum content was much lower than the standard value. The material composition of the kitchen knife did not meet the standard composition requirement of 7Cr17MoV steel.

| Chemical constituent | Mass fraction (%) |
|----------------------|-------------------|
| C                    | 0.75              |
| Cr                   | 16.8              |
| Si                   | 0.7               |
| Mn                   | 0.3               |
| S                    | 0.008             |
| P                    | 0.055             |
| V                    | 0.07              |
| Mo                   | 0.07              |

Table 1. Chemical constituent (mass fraction).

2.3. Hardness test
In the light of standard GB/T 230.1-2009 [1], the hardness was measured near the crack of the kitchen knife and the normal region by the Rockwell hardness tester, and the hardness values were HRC 54.2~HRC 55.8. The hardness value of the superior product specified in standard QB/T 1924-1993 [2] is no less than HRC 52, so the hardness of the cracked kitchen knife meet the standard requirement.

2.4. Microscopic analysis of fracture
The cracked portion of the kitchen knife was opened by external force to make a fracture surface sample, which was physically cleaned and placed in a scanning electron microscope for observation.
Figure 3 (a) showed the fracture morphology of source region of the crack. The morphology was clay pattern and quasi-cleavage fracture characteristics. The fracture region was covered by uneven corrosion products. Figure 3 (b) was the fracture morphology of the crack propagation region, showing quasi-cleavage fracture characteristics, a large number of tearing ribs and dimples, as well as the intergranular crack, with a small number of muddy patterns next to the cracks; Figure 3 (c) showed the fracture morphology of the end of crack. It was dimple fracture characteristics, intergranular secondary crack and a large number of dimples were visible. As could be seen from the three figures in Figure 3, the source region and propagation region of the crack both existed the intergranular secondary cracks.

![Figure 3](image)

**Figure 3.** SEM morphology of crack: (a) crack source region; (b) crack propagation region; (c) final crack region.

The energy spectrum analysis was carried out at the position 1 of the mud pattern and the position 2 of the quasi-cleavage characteristic in the fracture source region, and the results are shown in Figure 4 and Table 2.
Figure 4. EDS analysis results: (a) muddy pattern region; (b) quasi-cleavage feature region.

According to the test results, there was chlorine in the muddy pattern and a small amount of potassium, indicating that the source region of the crack was corroded by the chlorine-containing medium, and both regions were oxidized. In addition, both of these places contained high carbons, which in the region of carbide-rich regions.

|       | C     | O     | Fe    | Cl    | Cr    | K     |
|-------|-------|-------|-------|-------|-------|-------|
| mass  | 30.20 | 22.50 | 37.54 | 0.65  | 9.06  | 0.21  |
| fraction | 41.45 | 7.04  | 45    |       | 10.90 |       |

The morphology, particle size and distribution of the carbides were further clearly observed by scanning electron microscopy. Figure 5 showed the morphology of large granular carbides on the fracture. Figure 5 (a) showed the bottom morphology of the maximum corrosion pit in the source region of the crack. It can be observed that there were large angular carbides in the center of the bottom of the corrosion pit; Figure 5 (b) showed the large angular block carbides in the crack propagation region. Most of the carbides were 20 μm or more in a strip shape. Scanning the entire fracture, it was observed that from the source of the fracture, there were many large-angle massive carbides distributed throughout the fracture, and there were microcracks around the carbides.

Figure 5. Micromorphology of carbides: (a) crack source region; (b) crack propagation region.
2.5. Metallographic examination

The metallographic sample was cut longitudinally at the crack location. The sample was fine ground and polished, and placed under a metallurgical microscopy for observation. As shown in figure 6 (a), there was a low content of non-metallic inclusions in the sample. According to the standard GB/T 10561-2005 [3], the non-metallic inclusions were evaluated as: 1.0 grade of fine series to Type B (alumina), 1.0 grade of fine series to Type D (spherical oxide).

Figure 6 (b) was the microscopic morphology of the middle part of the crack. The crack propagation form is characteristic morphology of stress corrosion cracking. The crack cracked along grain boundaries and produced secondary cracks.

Figure 6 (c) showed the presence of severe banded segregation in the sample, which in contrast to the morphology observed by SEM. According to the fifth standard diagram of standard GB/T 14979-1994 [4], the grade of carbides unevenness was level 3. The existence of ribbon carbides would reduce the strength of materials and increase brittleness.

Figure 6 (d) showed the results of metallographic examination of non-fracture sampling of the kitchen knife, and the results of microstructure examination were basically consistent with those at the fracture, which were hidden needle tempered martensite, fine needle tempered martensite, granular carbide, residual austenite, and a large amount of granular carbides could be seen.

![Figure 6](image)

Figure 6. Microstructure morphology of the kitchen knife: (a) non-metallic; (b) middle part of crack; (c) carbide segregation; (d) non-fractured microstructure of the blade.

3. Analysis and discussion

The above test results showed that hardness, content of non-metallic inclusions and microstructure of the kitchen knife meet the standard requirements. The macroscopic morphology of the fracture showed
the fracture existed multi-source characteristics. SEM and energy spectrum analysis showed that the kitchen knife was corroded by external chlorine containing medium. Since the kitchen knife was produced near the sea, the air and water contained many chlorine ions, Martensitic stainless steel is prone to stress corrosion in seawater or chlorine-containing environment, and chloride ion has a destructive effect on stainless steel passivation film [5]. It could be seen from the scanning electron microscopy that there were many large-angle massive carbides in the material of the kitchen knife. These carbides were large in size and were not easily dissolved in the matrix during heat treatment process [6], which had an effect of squeezing and splitting the substrate. Then stress was generated, and microcracks were generated at the interface between the carbides and the substrate. Under the action of stress, the passivation film on the surface of the material was unstable, and the chloride ions took the lead in corroding and forming corrosion pits on the weakened passivation film. The microcracks generated around the carbides also provided a fast corroding channel for chlorine-containing medium.

It could be seen from the optical microscope that carbide segregation existed in the material. Banded carbides were caused by dendritic segregation during solidification of high carbon steel, which caused unevenness in material composition and structure. After the steel ingot or continuous casting billet is hot rolled, the regions of high carbon and high alloying elements are elongated in the rolling direction, and banded carbides are formed in the steel [7]. Under the heating conditions, the carbide enrichment region is prone to overheat, resulting in large tissue stress between the carbon and alloying element enrichment region and the barren region, which reduced the tenacity, plasticity and impact resistance of the kitchen knife. Alloying elements such as carbon and chromium are easily combined to form carbides. In the heat treatment process, if the chromium element does not diffuse enough to compensate for the loss of chromium around the carbides, the lean chromium region is prone to be formed around the carbides. When the chromium content in the lean chromium region is lower than the critical chromium content required for passivation, a stable passivation film cannot be formed and becomes a localized corrosion initiation region [8, 9, 10].

After the corrosion is initiated, the formed corrosion pit is the stress concentration region, which causes microcrack at the bottom of the corrosion pit. In the manufacturing process before the kitchen knife was grinded, the microcracks were formed and developed very slowly. In the subsequent grinding process, the microcracks at the bottom of the corrosion pits were subjected to the external force, prone to instability and expansion resulting in cracking. In addition, the results of energy spectrum analysis also showed that the oxygen content in the local region was high, while the iron content was relatively low, indicating that the oxygen element entered the material in large quantities and underwent an oxidation reaction, resulting in the weaken of grain boundary and easy to lead to Cracking failure under low stress.

The results of chemical composition showed that when phosphorus content exceeded the standard, the cold brittleness of the kitchen knife was easily increased, which reduced the plasticity, toughness and cold workability and promoted the cracking of the blade. On the other hand, molybdenum and vanadium elements could refine grains in steel and improve mechanical properties. In particular, the addition of molybdenum, which was stronger than chromium to form carbides, could improve the corrosion resistance of steel in non-oxidizing medium and enhanced the corrosion resistance of steel to pitting corrosion and crevice corrosion [11]. The content of molybdenum and vanadium was relatively low, especially the content of molybdenum was far lower than the standard value, which made the kitchen knife reduce the hardenability during heat treatment process [12], reduced the ability to restrain the brittleness of tempering, was disadvantageous to tempering, and increased the possibility of cracking of the kitchen knife.

4. Conclusions and recommendations
The failure mode of this kitchen knife was stress corrosion. There were many large-angle block carbides and uneven carbide distribution in the material of kitchen knife, causing stress concentration and initiation of micro-cracks, resulting in instability of the passivation film on the stainless steel surface. When the kitchen knives were produced and processed in a chlorine-rich environment, chloride ions preferentially corroded at the weakened passivation film to form corrosion pits, and
microcracks were also generated at the bottom of the corrosion pits due to stress concentration. The chloride ions also tended to rapidly corrode from the channels formed by microcracks around the large-angle block carbides, further expanding the microcracks. During the grinding process of the kitchen knife, the microcracks were unstable and expanded under the action of external force, leading to cracking.

There were many large-angle block carbides, uneven microstructure, and stress concentration in steel had great influence on stress corrosion. In order to avoid stress corrosion cracking caused by the stress of high carbon steel, the uneven structure inside the steel should be reduced, and it was recommended to avoid harmful media during the processing or storage of the kitchen knives.

It was recommended to strictly control the chemical composition of 7Cr17MoV stainless steel, and conducted sampling inspection before the material entering the factory to control the content of important elements such as phosphorus, molybdenum and chromium in the material.

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