# Failure Analysis Report of Knife Blade Failure

Fracture Mechanics and Failure Analysis
ENME803

Longee Guo
15920362

Assignment 2

Investigated by:
Longee Guo
Sam Hayden
Rahjeev Singh
Pritesh Patel

October 24, 2020

# 1 Abstract

The contents of this report outlines the process to find the primary mode of failure experienced by a normal kitchen knife in daily use. This knife fractured when used to open a can. The sample used for SEM was 10mm x 8mm. After SEM analysis and review, it was determined that this failure was due to fracture starting from the top of the blade which then propogated toward the bottom of the blade which resulted in brittle fracture of the part examined. It was also noticed there were internal cracks - this may be due to manufacturing defects during forging which caused the premature fracture of the blade.

In general, microscopic scratches, pitting and misalignment of the blade along with manufacturing defects that cause most of the premature failures in knives today.

# Contents

## 2 Purpose

Figure 1 represents a fractured part of a kitchen knife blade, which has failed prematurely when trying to open a can. Failure analysis was conducted to investigate the cause of this premature failure.

Figure 1: Fractured knife blade

## 3 Background Information

The knife fractured under use. This is abnormal as a well kept and maintained knife should last many decades. Premature failure of a knife can be attributed to many reasons such as microscopic scratches caused by improper placement of knife, sustaining hot and soapy water from a washing machine and not sharpening the blade. A majority of families don't maintain their knives which means premature failure will occur especially not sharpening the knife - using a dull knife means more pressure will need to be applied to chop through food and this can cause blade misalignment. It is not common for households to have a knife sharpener. In commercial kitchens, knives are less likely to encounter premature failure - this is due to chefs having expensive and well made knives, maintaining and properly cleaning their knives everyday as a knife is their main tool so they have to take good care of it.

Different types of stainless steel knives are commonly found in the kitchen nowadays, with stainless steel offering many advantages, however, in general, stainless steel properties include:

Aesthetics: A variety of surface finishes, from matte to bright and including brushed and engraved. It can be embossed or tinted, making stainless a unique and aesthetic material.[3]

Mechanical properties: Stainless steel has good mechanical properties at ambient temperatures compared to other metals. It not only combines ductility, elasticity but also hardness which enables it to be used in difficult metal forming processes. It offers resistance to heavy wear as well.

Resistance to fire: Stainless steel has the best fire resistance of all metallic materials when used in structural applications, having a critical temperature above 800°C.[3]

Corrosion resistance: With a minimum chromium content of 10.5%, stainless steel is continuously protected by a passive layer of chromium oxide that forms naturally on the surface through the combination of chromium and moisture in the air. If the surface is scratched, it regenerates itself. This particularity give stainless steels their corrosion resistance.[3]

Cleanability: Stainless steel items are easy to clean, usual cleaning products such as detergents and soap are sufficient and do not damage the surface. [3]

Recycling: Stainless steel is considered a green material which means it can be recycled. In the construction industry, the recyclable rate is close to 100%[3]. It is environmentally neutral and inert when in contact with water

## 3.1 Manufacturing Process

First Method[1]
1) Laser Cutting - shaping: A laser beam is beamed onto the material to cut out the knife blade shape, in this case is stainless steel. This process is all controlled by a computer which allows it to cut out intricate and finely structured designs. This process takes longer than the conventional press working process with moulds but it is widely used in production of blades of intricate designs[1]

2) Thermal Process - hardening: The laser cut blade is heated at 1000°C in a furnace, cooled off at water temperature then heated again at 180°C. This changes the structure of the steel and makes the blade not only hard and tough but also elastic.

3) Periphery polishing / Surface grinding - whet: The periphery of the blade is polished with a polishing belt. A computer controls the whetstone, grinding the surface of the blade tip thin. This surface grinding process is important to obtain differing patterns on the blade

4) Blade leveling / Grazing - whet: Blade levelling consists of polishing the blade tip with a certain material making it take the shape of a smooth hard clam. After this, it is then finely polished in the grazing process in which the blade obtains a perfect surface

5) Mirror polishing / Abrasive blasting - whet: This process allows the blade to obtain a finish that is finer than the grazing process. The blade is inserted between two rolls and is polished until it reflects images like a mirror. The blade is then submitted to the abrasive blasting process - this consists of spraying glass beads on it. Due to this process, the difference of surface roughness of soft and hard parts of the steel is evidenced through the formation of stratiform patterns on the blade.

6) Wet type blade edging - blade edging: By wet edging the blade, it avoids friction heat and increases the smoothness and cutting quality of blade tips

Second Method[2]

The second method is the conventional method in which all the elements are thrown together with carbon and iron, heated until they melt then thoroughly mixed. This mixture is then poured into moulds to form ingots. This cooled mixture is called an alloy.

Disadvantage of conventional method is that the steel cools slowly and unevenly. The elements that make up the alloy solidifies at differing temperatures which means lack of bonding at the microscopic level. The carbides that form are not consistent in shape or size and is not evenly distributed throughout the alloy. However, this method is still the most common method of steel production. Blade steels using this method include 1095, 440 series steels, 145CM and tool steels like D2.

Third Method[2]

The third method was pioneered by an American company called Crucible Industries. This method uses powdered metal to solve the cooling rate issues.

Similar to the conventional method, alloying elements are added to the steel and melted. But as the molten liquid is poured, high pressure gas is blasted onto it, creating tiny droplets that cool and solidify instantly. These cooled droplets become the grains of the metal powder. The elements in the alloy are mixed inside each grain evenly and smaller, more uniform carbides form within the grains. The powder is then put into a chamber where heat and pressure are applied, fusing together to form a solid piece of metal.

The smaller more evenly distributed carbides significantly improve the finish of the blade. As steel wears away via sharpening and utilisation, carbides become exposed and eventually pop out. Larger carbides formed through the conventional manufacturing process leave large, uneven gaps when they pop out. The uniform carbides from the powdered metal leave smaller gaps and the ones that remain, continue to provide structural support to the steel. This maintains durability and sharpness of the blade edge.

# 4 Analysis

In order to investigate the cause of failure, the snapped blade was washed first and prepared for the Scanning Electron Microscope (SEM). The SEM allows the user to observe the specimen fracture surface. The images captured by the SEM indicated the knife blade underwent sudden fracture with no fatigue propogation evident in the images.

## 4.1 Chemical Composition

The chemical composition of the Martensitic 400 Series Stainless Steel Alloy knife blade is:

| Material | C | Al | Si | Cr | Mn | Fe |
|---|---|---|---|---|---|---|
| 400 series | 2.87 | 0.14 | 0.41 | 13.85 | 0.51 | 82.23 |

Table 1: Chemical composition of Martensitic Stainless Steel Alloy

## 4.2 Sample Preparation

For an ideal fit in the SEM chamber, the fractured specimen was sectioned to a small piece which preserved the original fracture surfaces. The specimen was then cleaned to remove any dirt, grime and other contaminants which may have been present. It was then fit into the SEM tray as seen in figure 2.

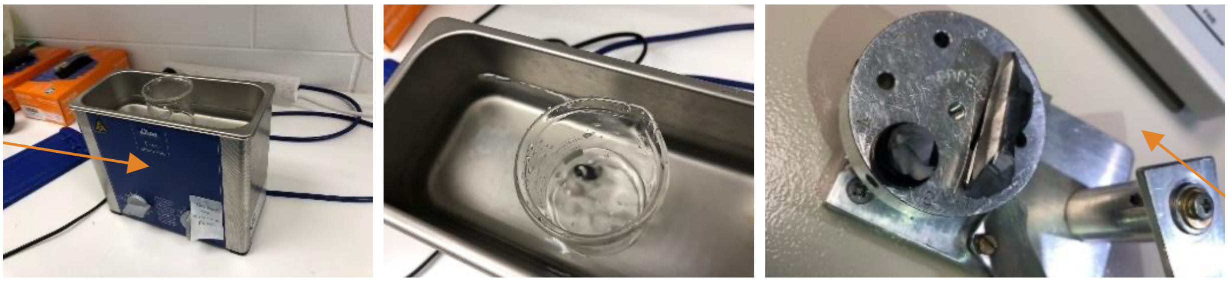


Figure 2: Cleaning and loading of specimen

## 4.3 SEM Images of the specimen

Multiple images of the fracture surface were taken at differing magnification factors aiding to the investigation of the type of fracture present along the surface grain boundaries. As seen in figure 3, the captured images show no signs of fatigue, dimples however, very faint lines show internal cracking due to manufacturing defect. This would be the cause for premature failure. With ductile fracture on the top of the blade propogating along with internal cracks from manufacturing defects, it aided the sudden brittle fracture indicated in these images below. Because this knife was a cheap, mass produced knife, it was manufactured using the conventional method as talked about in subsection 3.1 - forging where internal cracks can easily form due to different cooling rates at different points.

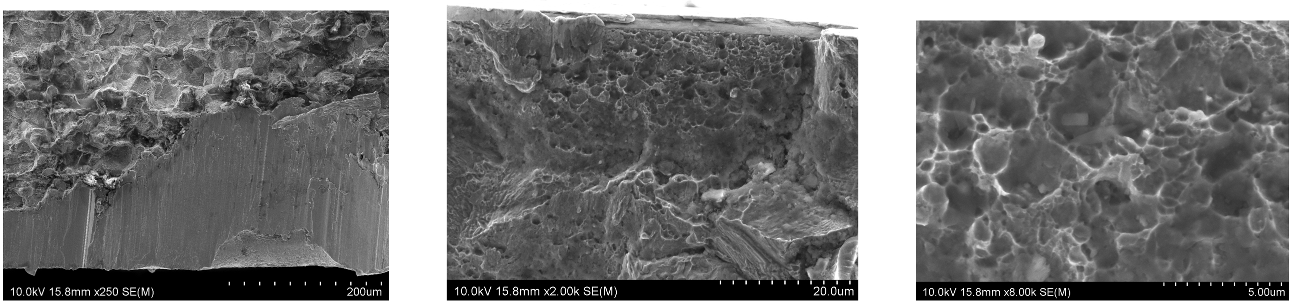



Figure 3: SEM Magnification

# 5 Results

Post inspection of the fractured blade surface SEM images, there were found to be no definitive signs of what may have caused the fracture, though, through SEM images it was deduced to be either manufacturing defect or sudden brittle fracture.

Looking at the SEM image of high magnification, (5$\mu$m), the carbide structure around the iron grain boundaries appears to have been pulled/sheared, suggesting the knife was under more pressure than it was designed to handle leading to fracture. The fracture is probably a intercrystalline fracture due to grain boundary embrittlement setting up micro stress fractures during the tempering / heat treatment in production as seen in figure 9.

The blade was quenched too fast and not properly tempered as part of the heat treatment as evident with porous surfaces.
Another possibility is that the blade was placed in the fire for a period of time. This ruins the temper and allows for diffusion of carbon and other alloys toward the grain boundaries, where they precipitate and points of failure, weakening the over structure.

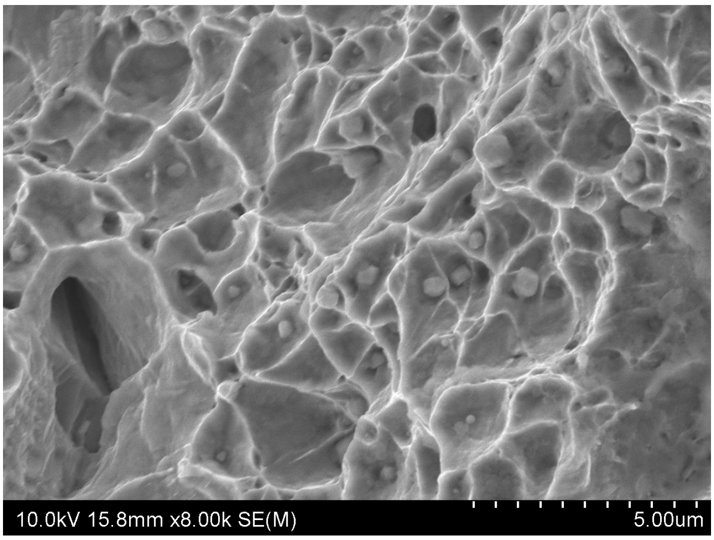



Figure 4: SEM of grain structure

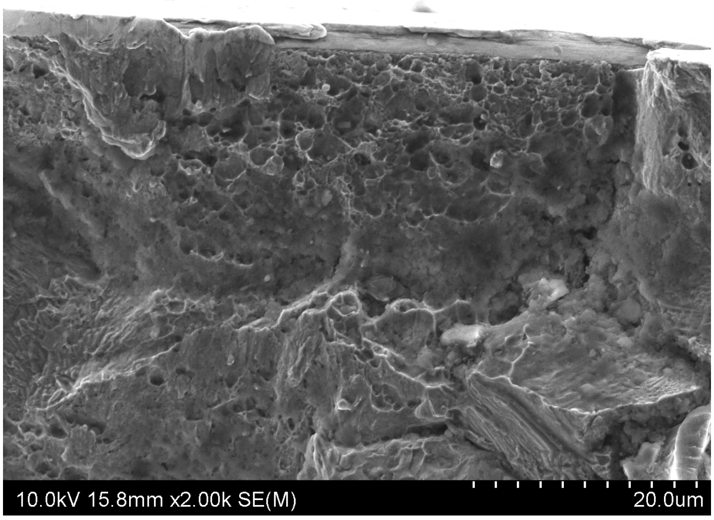
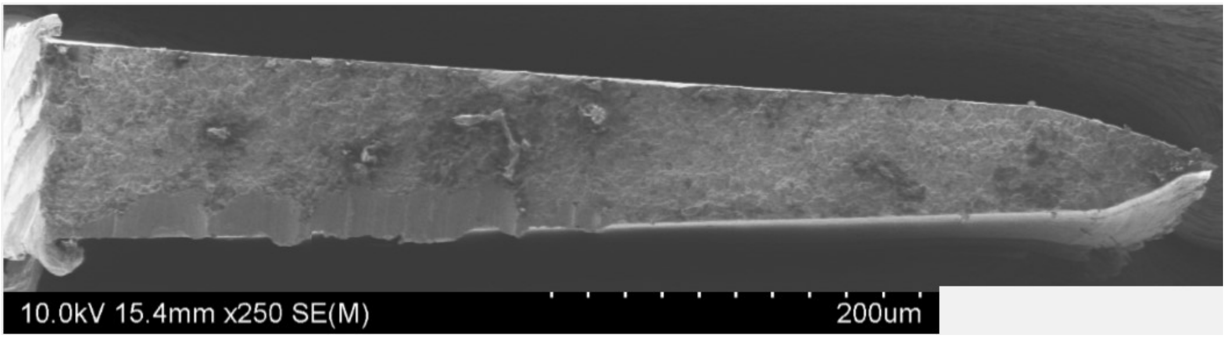


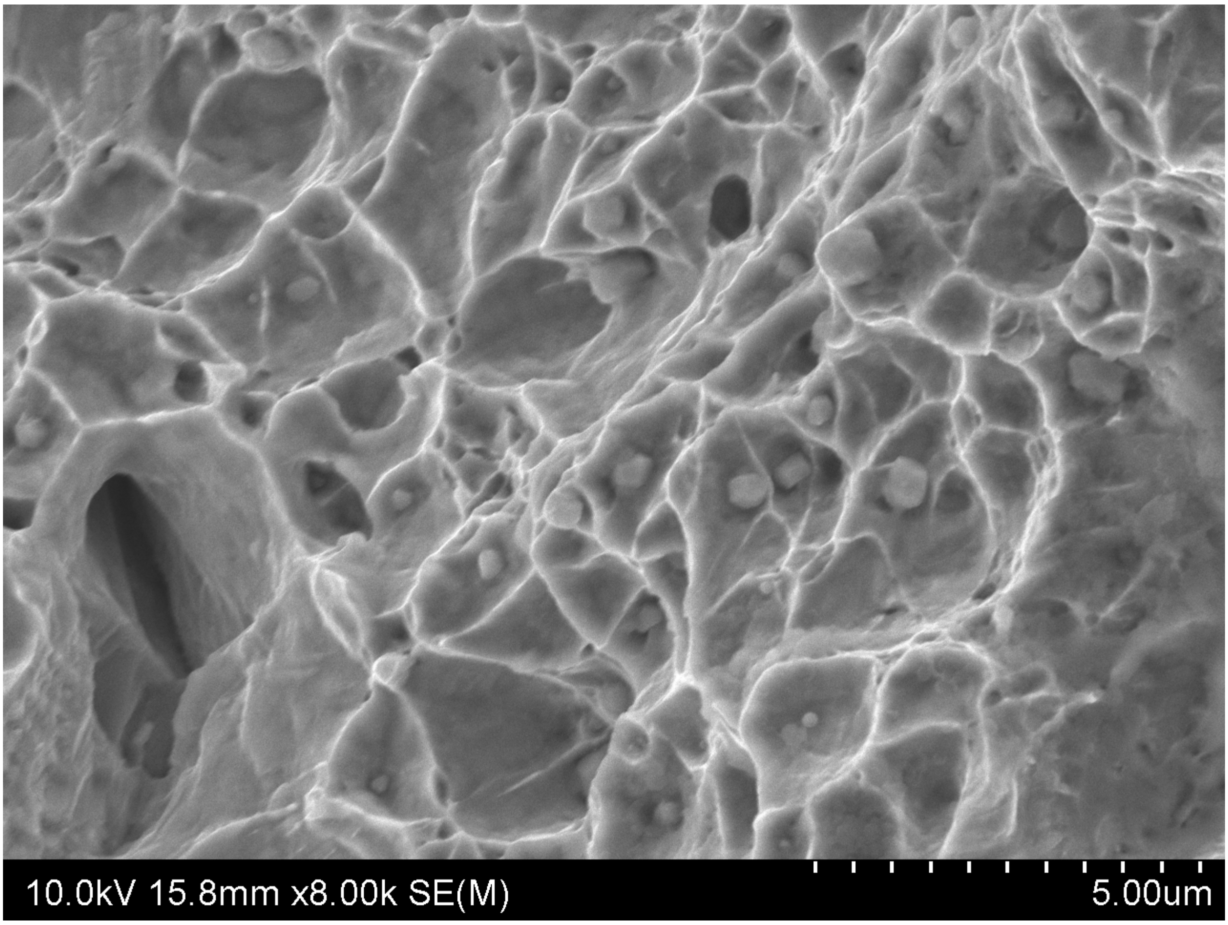

Figure 5: SEM of grain structure

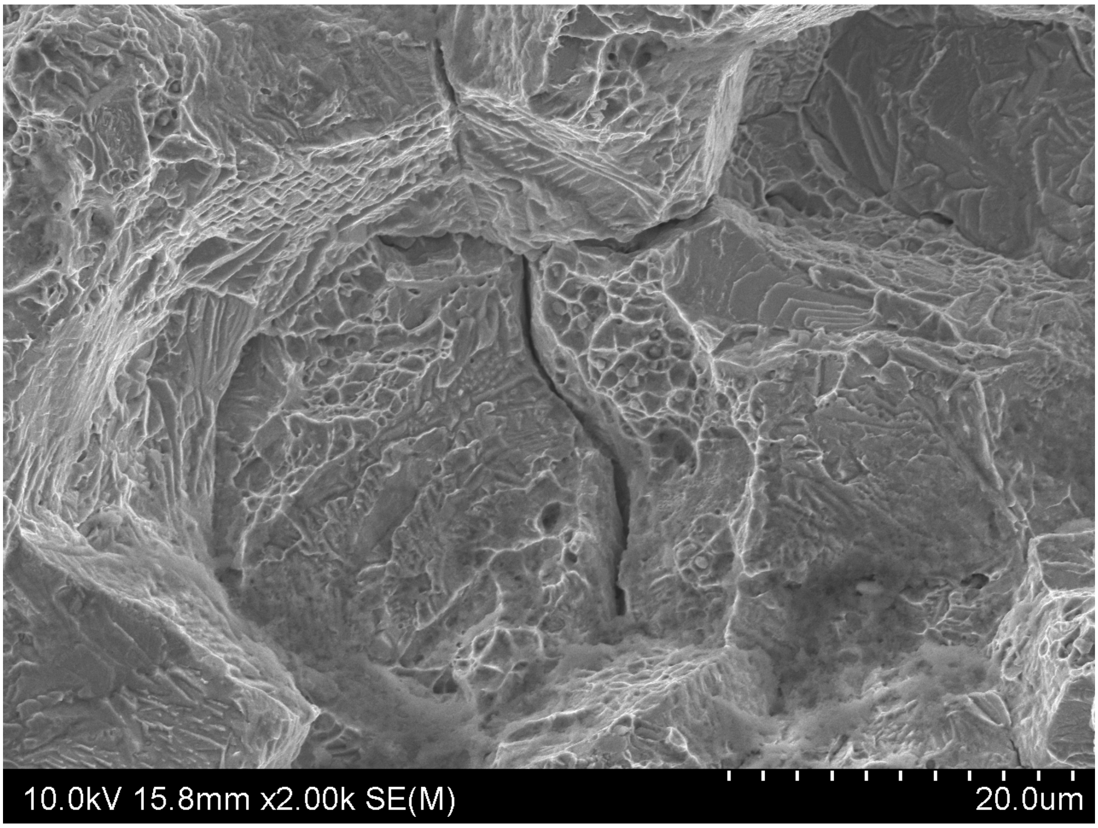
## 6 Conclusions

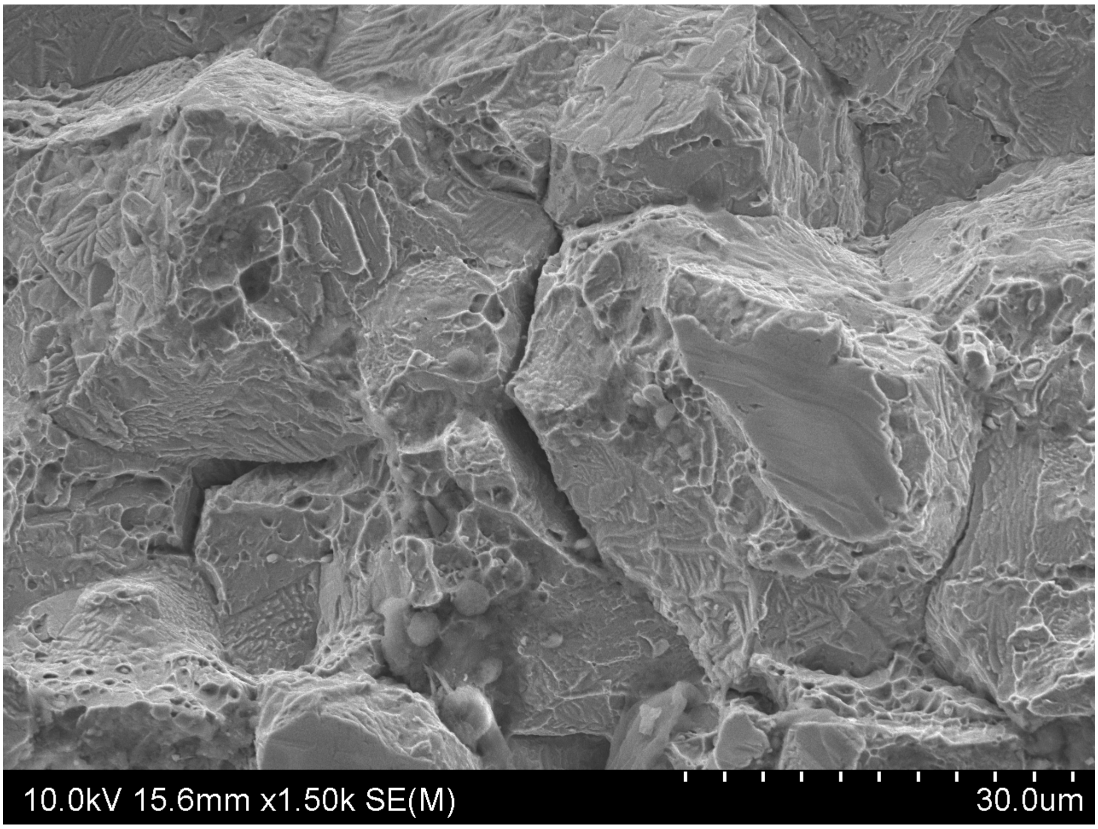
It is justified from the evidence provided, the reason for premature blade failure was most likely due to manufacturing defect because theses knives are mass produced from a forging process so quality matters less than quantity. Although other factors can influence failure such as microscopic scratches and human error by not maintaining the blade to a general standard. A dull knife will require more pressure to cut through food, due to this, the blade edge will get pushed slightly out of alignment. This small misalignment will eventually cause the fracture as seen in the specimen. To avoid premature failure, it is advised the knife be safely stored in a knife block, buy a good quality knife that is laser cut, not put it into a dishwasher and to do due diligence by maintaining such as sharpening the blade.

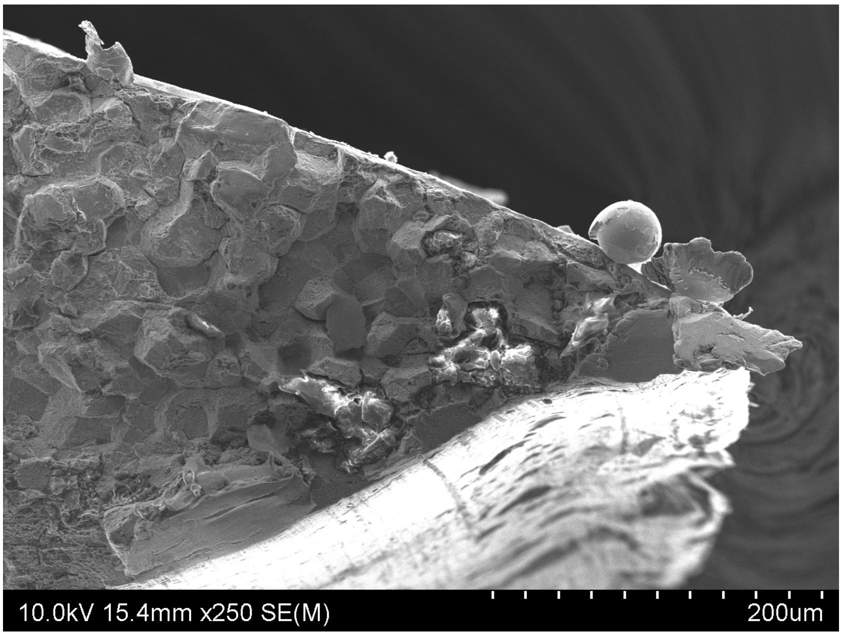
# 7 Appendix

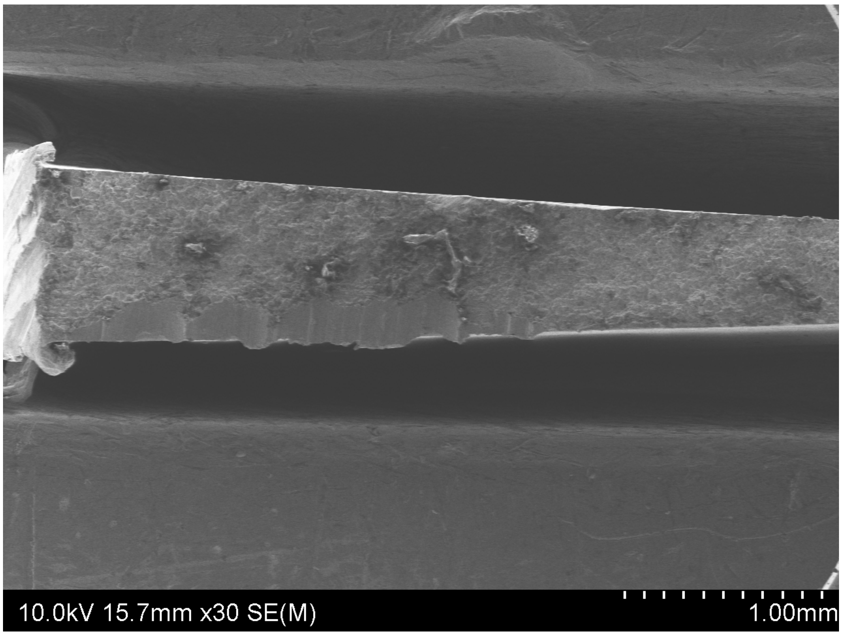


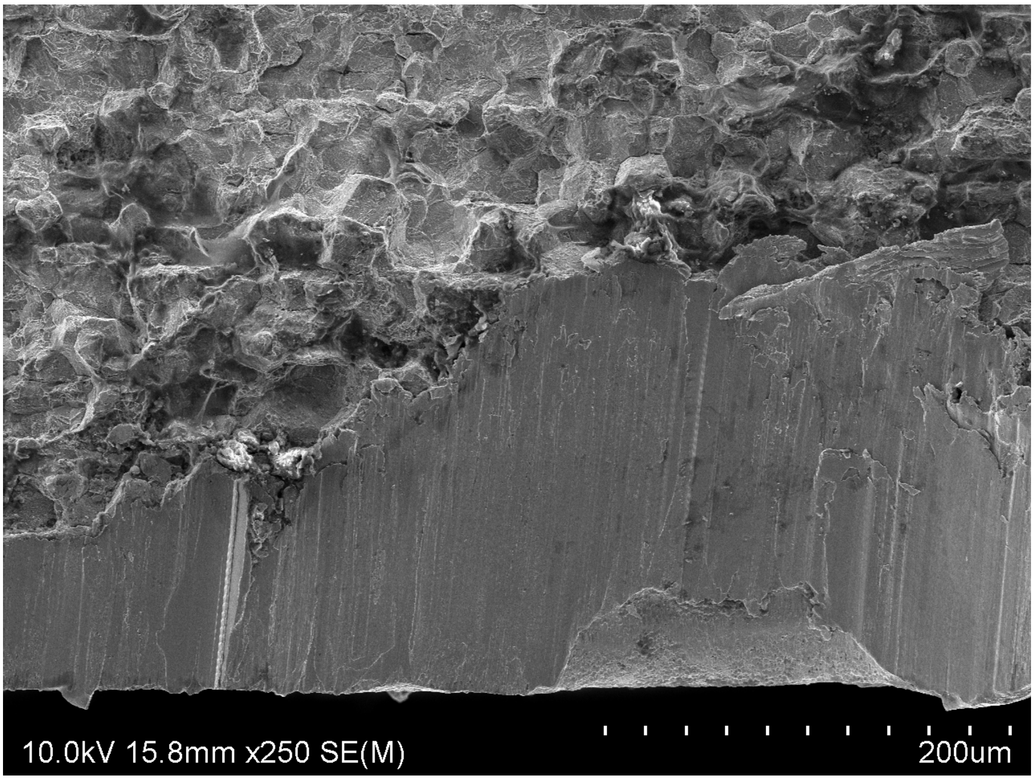



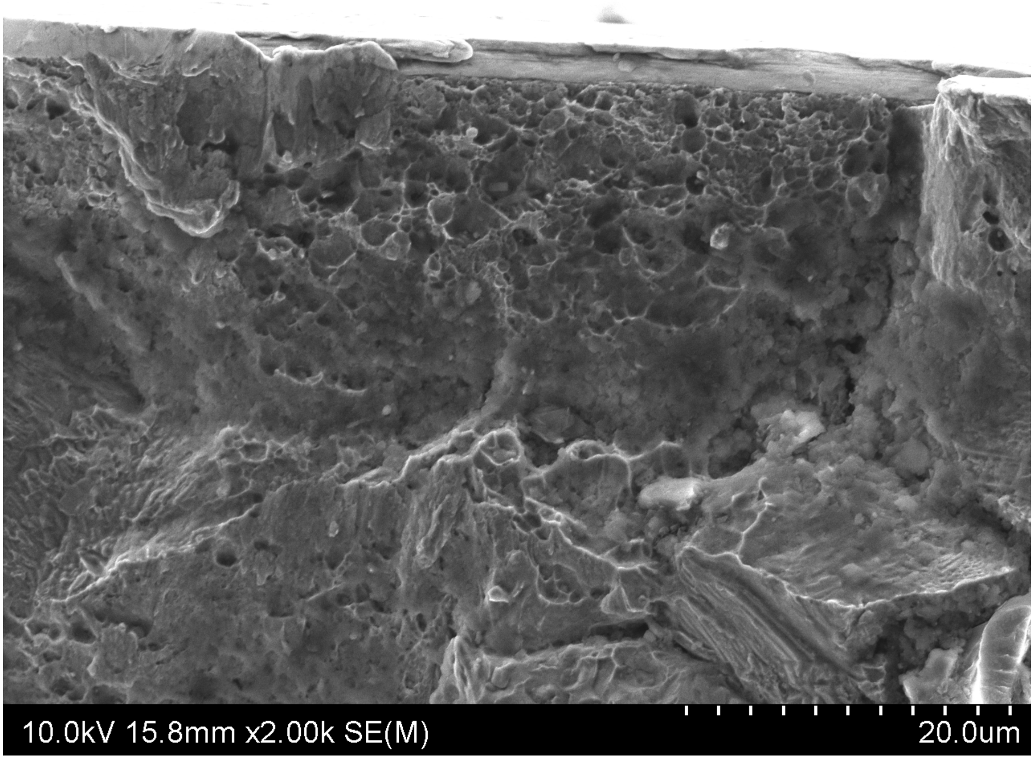

10.0kV 15.8mm x2.00k SE(M)
20.0um

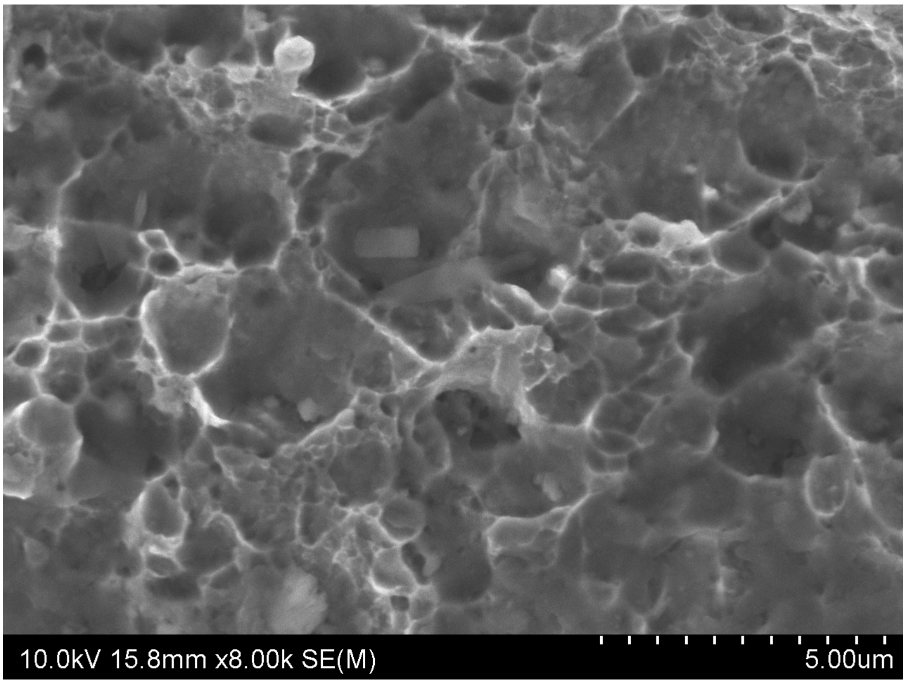

10.0kV 15.6mm x1.50k SE(M)
30.0um

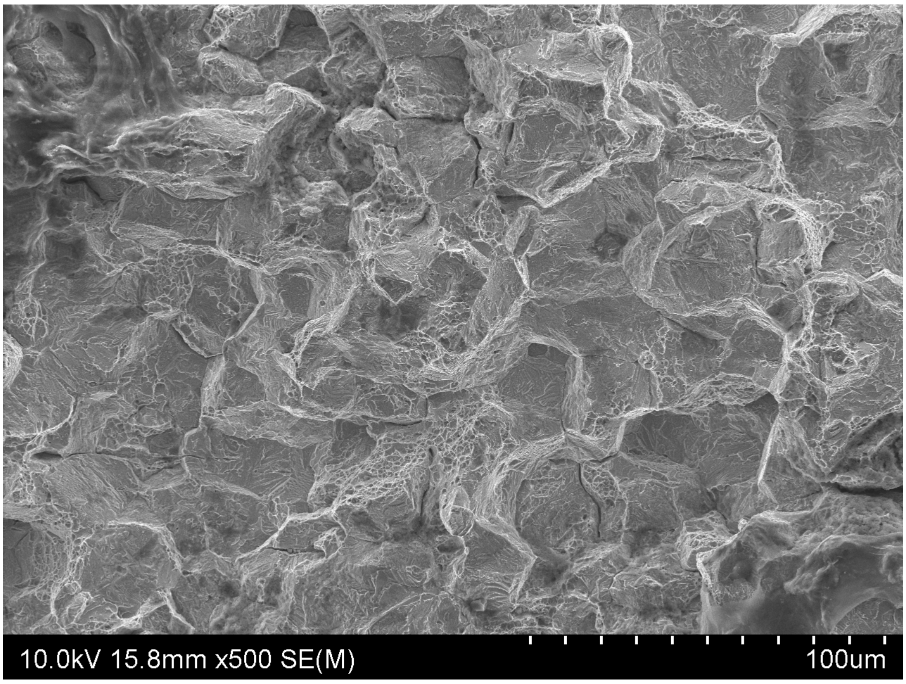

10.0kV 15.4mm x250 SE(M)
200um


10.0kV 15.7mm x30 SE(M)
1.00mm

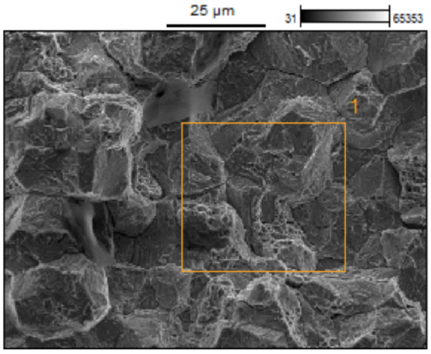

10.0kV 15.8mm x250 SE(M)
200um


10.0kV 15.8mm x2.00k SE(M)
20.0um

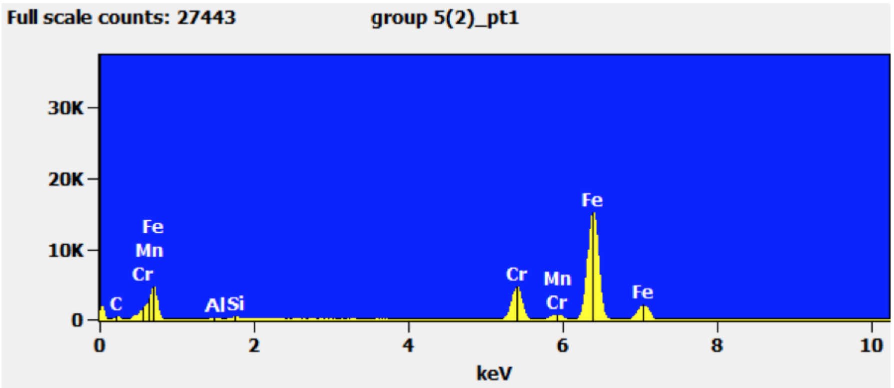

10.0kV 15.8mm x8.00k SE(M)
5.00um


10.0kV 15.8mm x500 SE(M)
100um

group 5(2)




| | |
|---|---|
| Image Name: | group 5(2) |
| Image Resolution: | 512 by 384 |
| Image Pixel Size: | 0.21 µm |
| Acc. Voltage: | 20.0 kV |
| Magnification: | 1200 |




Net Counts

| | C | Al | Si | Cr | Mn | Fe |
|---|---|---|---|---|---|---|
| ***group 5(2)_pt1*** | 1944 | 575 | 2306 | 73635 | 1844 | 275163 |

Weight %

| | C | Al | Si | Cr | Mn | Fe |
|---|---|---|---|---|---|---|
| ***group 5(2)_pt1*** | 2.87 | 0.14 | 0.41 | 13.85 | 0.51 | 82.23 |

Atom %

| | C | Al | Si | Cr | Mn | Fe |
|---|---|---|---|---|---|---|
| ***group 5(2)_pt1*** | 11.89 | 0.26 | 0.72 | 13.28 | 0.46 | 73.39 |

## References

[1] Manufacturing Process 1.
https://www.kai-group.com/global/en/kai-factory/process/kitchen-knives/. 2020.

[2] Manufacturing Process 2 and 3.
https://www.popsci.com/story/technology/how-quality-knife-blades-are-made/. 2020.

[3] Stainless Steels.
https://www.aperam.com/what-stainless-steel. 2019.