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EDGE CHIPPING OF ROTARY SLICER STEEL KNIVES

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

A metallurgical examination was carried out on a rotary knife in an attempt to determine the reason for the cutting edge chipping in service.

Metallographic examination, and a hardness survey of the cutting edge, revealed that it was in a hard, brittle microstructural condition which could be susceptible to chipping, i.e., it was composed of martensite which had not been tempered any higher than about 350/400°F.

Cause of failure was probably attributable, therefore, to the omission of sufficient tempering treatment after hardening. It was recommended that the knives should be tempered at a higher temperature to promote greater toughness.

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INTRODUCTION

In a letter dated July 4th, 1966, Mr. L.J. Marion, District Manager of the Toledo Scale Company of Canada, Limited, Ottawa, requested assistance from the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, on a problem concerning circular steel knives used in their rotary meat-slicing machines. On a prior visit to the Physical Metallurgy Division, Mr. Marion related that the sharp, ground cutting edge of the knives was chipping in service. This was not an irregular occurrence but was common with all their knives. One of the chipped blades was submitted for examination in order that the cause of edge chipping might be determined, and a remedy recommended.

VISUAL EXAMINATION

The blade, as shown in Figure 1, measured approximately 1-1/2 in. wide, x 11-1/2 in. diameter, with an angled ground edge of about 1/8 in. The bright surface appearance suggested that the steel had been plated. The cutting edge had been ground very sharp, and was clean enough such that it did not show any obvious signs of corrosive attack. Chipping of the edge had occurred randomly around the blade, and examination under the stereomicroscope revealed the fracture surfaces to be very brittle in appearance.

In order to determine whether improper grinding had perhaps caused surface cracks to occur, the edge of the blade was etched in cold, dilute acid. Careful scrutiny, however, showed it to be free of any such defects.

CHEMICAL ANALYSIS

A piece of the blade was stripped of the plating and softened by annealing to allow drillings to be taken for chemical analysis. Another section was submitted for spectrographic analysis to identify the type of plating. The following results were obtained:

Composition (Per Cent)

C	Si	Mn	S	P	Cr	Ni	Mo	V
1.10	0.21	0.44	0.045	0.027	1.18	0.10	0.02	0.02

The plating was identified as chromium.

METALLOGRAPHIC EXAMINATION

A section for micro-examination was cut through the blade at a point where the edge was still sound. After polishing and etching, examination under the microscope revealed three zones of different microstructure consistent with an edge-hardening heat treatment having been carried out on the knife after machining, i.e., the hardened zone at the cutting edge, the original soft-structured area of the body of the knife unaffected by the hardening treatment, and a zone of transitional microstructure separating the two. This is seen in the low magnification photomicrograph of Figure 2. The dark-etching band of transitional microstructure indicates the depth to which the blade was hardened; this depth was noted at approximately 1/2 in.

The microstructure of the hardened zone, shown in Figure 3, consisted of carbides set in a matrix of martensite, and a Tukon microhardness survey, carried out along the length of the zone, gave consistent readings of Rockwell 62C. This is very hard, and suggested that the martensite had been tempered only slightly. Concomitant with the sulphur content of 0.045%, many elongated sulphide inclusions were present, as shown in Figure 4. It was noted that these inclusions were aligned at right angles to the vertical axis of the knife, i.e., across the width of section, and, in the very thin sections of the extreme outer edge, a considerable proportion of the width would sometimes be made up of the length of an inclusion.

The microstructure of the body of the knife was typical of the spheroidized annealed condition that renders high-carbon steel soft enough for machining. This is also the best condition for a successful hardening treatment that will produce a long-lasting edge. As shown in Figure 5, this machinable structure consisted of spheroidized carbides set in a matrix of ferrite. A hardness of Rockwell 96B was obtained.

DISCUSSION

The results of the chemical analysis showed the knife to be made of high-carbon, low-alloy steel, similar to the AISI 51100 grade, and would seem to be an acceptable composition for the purpose. The sulphur content of 0.045% is a little higher than normal, but this may have been intentional in order to make machining easier. It is well known that the machinability of a steel increases when the sulphur content is increased. However, it should be kept in mind that when sulphide inclusions are present in very hard, brittle structures, the steel becomes more susceptible to failure.

Metallographic examination of the cutting edge identified martensite in the microstructure, and the hardness value of Rockwell 62C suggested that only a light tempering treatment had been carried out on the knife or perhaps it had even been left in the as-quenched condition. Data available on this steel shows that the ideal as-quenched hardness is in the region of Rockwell 65/67 C, and a drop in hardness to 62C would be obtained with a tempering temperature around 350/400°F, which is rather low. Ideal as-quenched hardness, however, is not always achieved in production practice; it is possible that the blade could have been put into use in the completely untempered state, losing the few hardness points down to Rockwell 62C as a result of treatment received in service, and during processing of the metallographic sample, on which this hardness was registered. In any event, the hardness indicated that the martensite was in a relatively untempered condition and hence lacked toughness. The most obvious reason for the chipping, therefore, would appear to be that the cutting edge, being so thin in section, and composed of hard, brittle material, was unable to stand up to impact loading during service. The presence of the many sulphide inclusions, and the manner in which they were aligned across the thin cutting edge, probably aided failure. With the knife in a tougher condition, however, the detrimental effect of the inclusions would decrease and it is probable that, for the type of service involved, the present sulphur content would not cause trouble.

It was mentioned earlier that the knife had been chromium plated. This suggests perhaps another cause of chipping arising from the possibility of hydrogen embrittlement of the steel during the plating process. Normally this would not be considered on account of the very thin section involved, but since susceptibility to such embrittlement is very much greater at high hardness, the possibility of this causing chipping of the edge should be kept in mind.

The most likely explanation for the chipping, however, as indicated by the results of the examination, appears to be the lack of toughness in the thin cutting edge section, due to insufficient tempering. The remedy lies in tempering at a temperature high enough to give the desired level of toughness. This would reduce the hardness of the cutting edge, and it probably would not retain its sharpness for as long, but this may be acceptable since each slicing machine has a device which allows the knife to be sharpened at any time. The appropriate tempering temperature then, depends on how much hardness can be sacrificed for a gain in toughness. In order to determine the relationship between hardness and tempering temperature, three specimens were cut from the knife and each was tempered for 1 hour at 500°F, 750°F, and 1000°F respectively. The resulting hardness of these specimens is given in Table 1.

TABLE 1

Hardness

Tempering Temperature - °F	Tukon Conversion Hardness
As-received	62 Rockwell C
500	59 " "
750	51 " "
1000	45 " "

These results show the amount of hardness reduction with tempering, but an exact recommendation on the hardness to which the knives should be tempered is something best left up to those more directly concerned and experienced with this particular situation. Suffice to say that the more hardness that can be sacrificed, the more chance there will be of eliminating the chipping, although it sometimes happens that sufficient toughness can be achieved with only a drop of two or three points in hardness.

CONCLUSIONS

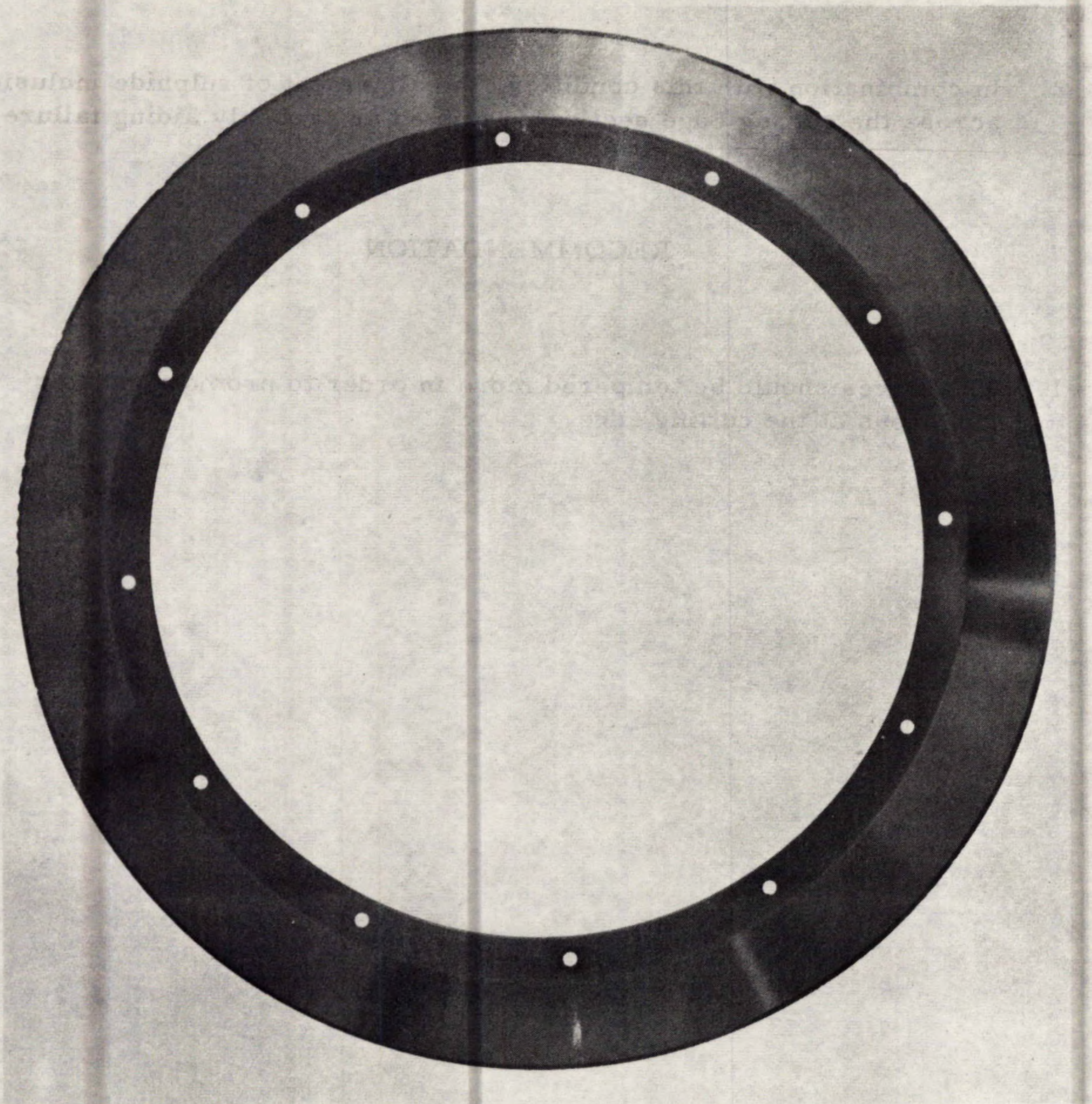
1. The results of the examination suggested that chipping of the thin cutting edge was caused by it being in a microstructural condition that lacked sufficient toughness to resist impact loading during service.

2. In combination with this condition, the alignment of sulphide inclusions across the cutting edge section was noted as probably aiding failure.

RECOMMENDATION

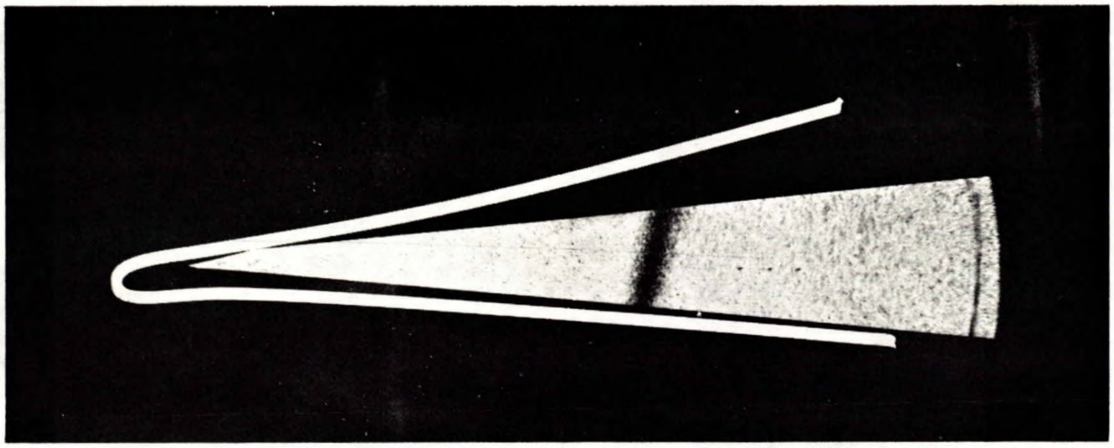
1. The knives should be tempered more in order to promote greater toughness at the cutting edge.

WMC:DAM:bb



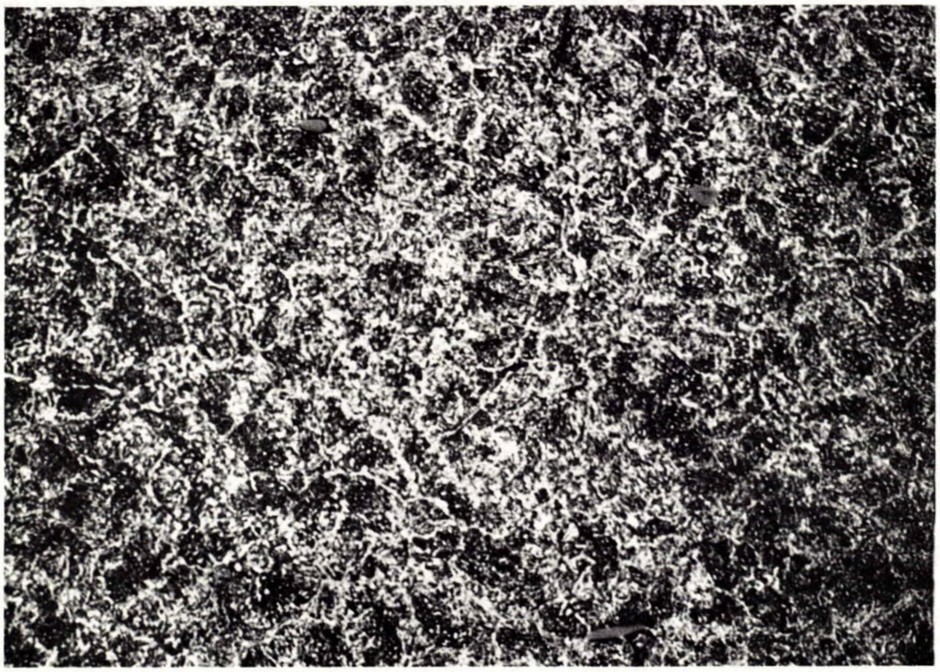
(approx. 1/2 size)

Figure 1. Photograph of rotary slicer knife showing chipping at the edge of the blade.



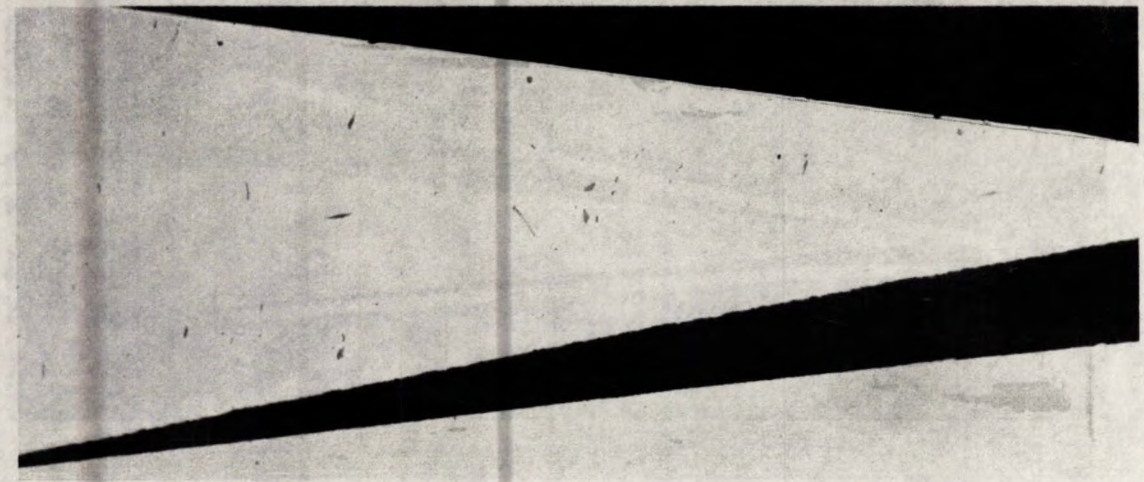
Approx. 6X Magnification Etched in 2% Nital

Figure 2. Photomacrograph of a cross-section of the blade, through the cutting edge, showing the depth of hardening as delineated by the dark-etching band of transitional microstructure. (The white band is a metal strip used to protect the edge of the specimen during polishing.)



X500 Etched in 2% Nital

Figure 3. Photomicrograph showing the microstructure of the hardened zone of the blade. This consisted of carbides in a matrix of martensite - Rockwell Hardness 62C. The white edge is the chromium plating.



X100 As-polished

Figure 4. Photomicrograph of a section through the cutting edge of the blade, showing sulphide inclusions.

X500 Etched in 2% Nital

Figure 5. Photomicrograph showing the microstructure of spheroidized carbides and ferrite in the unhardened body of the blade - Rockwell Hardness 96B.