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METALLURGICAL EXAMINATION OF FAILED MANTLE HEAD NUT

by

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Mines Branch Investigation Report IR 65-26

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SUMMARY OF RESULTS

A portion of a failed mantle-retaining head nut from the crusher at Carol, Labrador, of the Iron Ore Company of Canada, was examined. The fracture had propagated principally in the brittle mode. The fracture origin was not detected on the sample. A considerable number of crack-like microshrinkage defects were present. Such defects can be expected to materially reduce resistance to crack propagation. Improper heat treatment had resulted in the presence of a considerable amount of lightly tempered martensite, which contributed to diminishing the notch toughness. As a first step to achieving a satisfactory nut it was suggested that metallurgically sound material with tensile properties equal to or somewhat higher than those determined for the sample be utilized. It was also suggested that investigation of any subsequent failures would require the full fracture as well as further information on the mechanical aspects of the application.

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INTRODUCTION

On 20 January, 1965, a portion of a broken mantle head nut from the crusher at Carol, Labrador, of the Iron Ore Company of Canada was received. A covering letter of 6 January, 1965, requested an opinion of the cause of the failure and any suggested alternative alloy selection, together with the recommended heat treatment if required.

It was stated that the nut had been in service from 3 August, 1964, to 15 December, 1964, (133 days) with a throughput of 5,644,000 long tons. During the week preceeding failure, the ambient temperature at Wabush airport had ranged from a low of -37°F and high of -1°F on 9 December, to a low of +9°F and high of +29°F on 14 December, 1964. The material specification for the nut was given as AISI 2345, Extra Low Sulfur and Phosphorus. The crusher was subject during the preceding 7-day period to normal conditions of work although the tonnage crushed during the week was lower than average. It was stated the nut is subject to stresses due to expansion of the mantle under impact and is itself subject to impact. At the time of failure the nut was 5 inches lower than the spider at the top of the crusher.

A blueprint was enclosed with the covering letter from which it was determined that the nut dimensions were 33 inches internal diameter, 5-1/2 inches height and 3-1/2 inches wall thickness. The legend indicated it was a two-piece nut although the joint was not shown. A sketch showing the sectioning of the sample piece was also included. This sketch showed that half of one side of the fracture and half of the opposite of the fracture were to be forwarded to the Mines Branch, the other two portions being forwarded to the original supplier.

VISUAL EXAMINATION

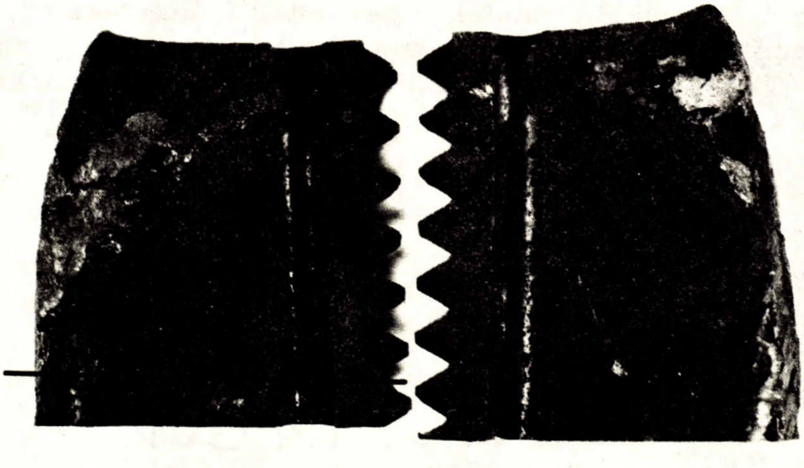
Figure 1(a) shows an over-all view of the sample submitted. The fracture is in the centre of the arc, the outside ends were flame cut. The nut threads are on the opposite side. The bottom surface was saw cut. The sample consisted of only half the height of the nut. The jogs in the line where the fracture plane intersects the top surface match perfectly. The general appearance of the fracture faces is shown in Figure 1(b). Although not visible in the illustration, there are many details in the fracture surfaces which also match perfectly. It is evident that these two sample pieces provide matching fracture faces, hence only half the fracture length is available for examination.

The samples show no gross deformation in fracturing but do show considerable deformation in service prior to fracture, notably that shown in Figure 1(b) where the side of the nut has flowed to a higher level than the top. The maximum wall thickness of the sample is only 2-1/2 inches, representing a decrease of almost 30% from the nominal value. It is not known whether this decrease represents wear or whether the nut failed to conform to the blueprint originally.

None of the fracture surface characteristics which reveal fracture origin or direction of fracture propagation could be observed on the samples submitted.

(a)

Approx. 1/3 Full Size



(b)

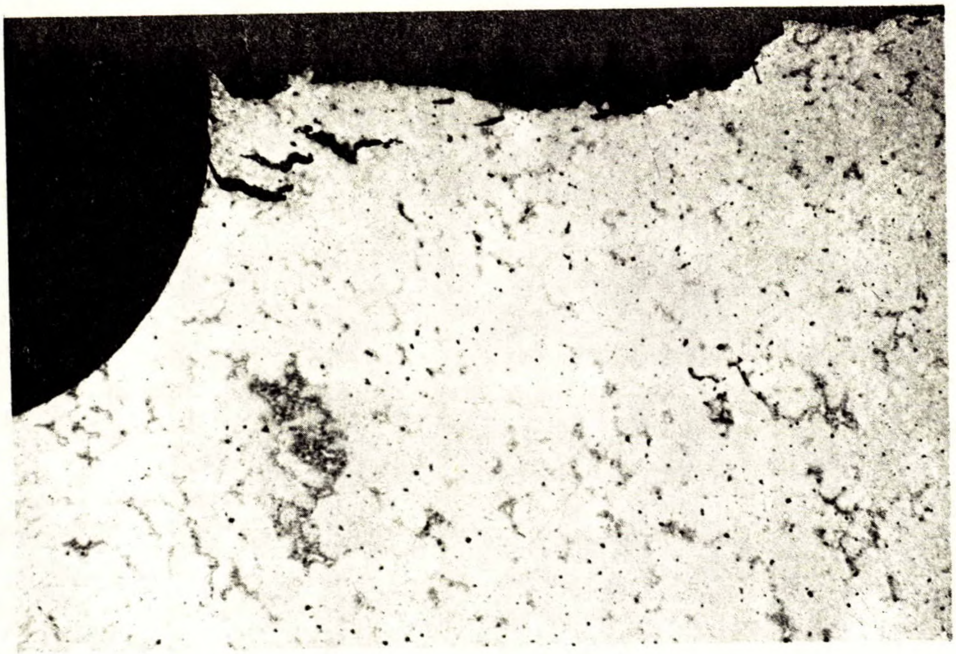
Approx. 4/5 Full Size

Figure 1. (a) General view of sample. Note matching of "steps" where the fracture intersects the top of the nut.

(b) Illustrating matching fracture faces. Ruled line in left hand piece indicates location of section for metallographic examination.

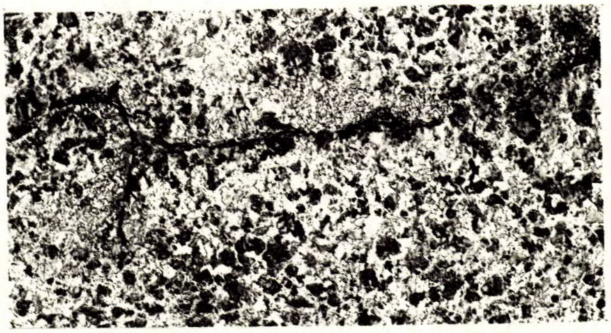
METALLOGRAPHY

A section parallel to the top of the nut, intersecting the plane of fracture, as shown in Figure 1(b), was examined. The fracture mode was mixed, being principally intergranular and transgranular cleavage with minor amounts of shear. There was a considerable amount of microshrinkage, Figure 2. The microstructure was not uniform, there being a great many areas of mixed transformation products in a ferrite-pearlite matrix, Figures 2 and 3. These areas were very often, although not always, associated with microshrinkage, Figure 3. The mixed transformation products consisted principally of lightly tempered martensite with a small amount of bainite and some proeutectoid ferrite, Figures 4 and 5. The pearlite is principally lamellar with some divorced carbide, Figure 4. The configuration of the areas of mixed transformation products as well as their frequent association with microshrinkage, suggests compositional segregation, most probably of nickel, which has persisted from freezing. The modified picral etch specific to temper brittleness did not reveal this condition. This result could be anticipated as the plain nickel steel is not very susceptible to temper embrittlement.



Etched in 2% nital X10

Figure 2. Section through fracture (at top). Note segregation and microshrinkage.

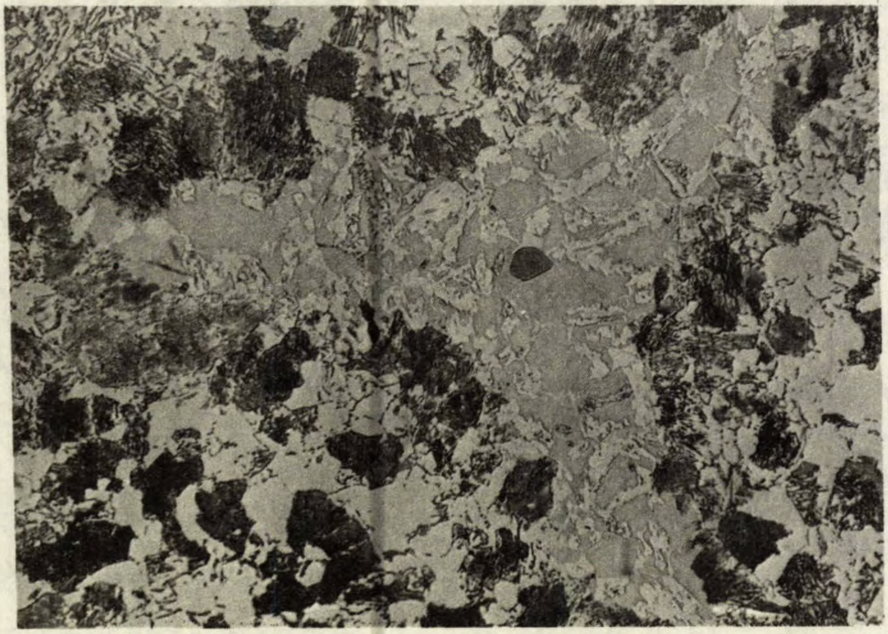


Etched in 2% nital X100

Figure 3. Illustrating general microstructure and microshrinkage.

Etched in 2% nital X1000

Figure 4. Illustrating the microstructure in the segregated area to consist of lightly tempered martensite with a small amount of bainite and some pro-eutectoid ferrite. Also showing the matrix pearlite to be predominantly lamellar with some divorced carbide.



Etched in 2% nital X500

Figure 5. Illustrating segregation at a triple point, probably between dendrites of the original as-cast microstructure.

CHEMICAL ANALYSIS

Drillings were obtained from one piece and analyzed with results shown in Table 1, along with the specification values for AISI 2345.

TABLE 1

Chemical Composition

	Per Cent of Element								
	C	Mn	Si	S	P	Ni	Cr	Mo	V
Sample	0.36	0.85	0.45	0.018	0.019	3.06	0.08	0.02	Tr.
AISI 2345	0.43/ 0.48	0.70/ 0.90	0.20/ 0.35	0.04 max	0.04 max	3.25/ 3.75	-	-	-

The sulphur and phosphorus contents are low, as called for by the Iron Ore Company. However, both nickel and carbon contents are below specification values. The discrepancy in nickel content is not very great and probably is not important but the carbon content corresponds to only AISI 2335 rather than AISI 2345. This would result in a somewhat lower tensile strength than anticipated for any specific heat treatment. The silicon content is high but the specification values shown refer to wrought material. The silicon content of 0.45% is not out of line for casting practice. Chromium, molybdenum and vanadium are present in residual amounts only and are considered to have had no significant effect on the properties of the material.

MECHANICAL PROPERTIES

Room temperature tensile tests were carried out on two, 0.25 inch gauge diameter, 1 inch gauge length, test bars taken in the tangential orientation. Results are shown in Table 2.

TABLE 2

Results of Tensile Tests

	UTS kpsi	Yield Point kpsi	% El. in 4XD	% R.A.
Sample 1	113.0	71.2	23.0	39.7
Sample 2	113.2	71.2	23.0	35.4

Charpy V-notch impact tests were carried out on standard size test specimens taken tangentially, notched normal to the top surface so that the fracture plane of the Charpy specimens paralleled the service fracture plane. Tests were carried out on material, both as-received and after tempering at 1200°F for 1 hour. Results are shown in Table 3.

TABLE 3

Charpy Impact Test Results

Test Temperature -°F	Energy Absorbed - ft-lb	
	As-Received	Tempered
0	-	6, 8
32	-	20, 14
75	12, 8, 8	26, 26
140	21, 14, 14	34, 38

Hardness tests on the Charpy V-notch specimens showed a relatively slight drop in hardness on tempering to Rockwell B95 from the as-received hardness of Rockwell B98.

DISCUSSION

From the results of the Charpy impact tests on the as-received material it is apparent that the transition temperature is above 75°F. Hence, crack propagation by brittle fracture would be expected in a service failure at winter temperatures in Labrador. The fracture origin could not be located on the sample submitted and the probable cause of fracture initiation could not be established.

From a comparison of the results of the Charpy tests on material before and after tempering in the laboratory, it is clear the presence of lightly tempered martensite contributed significantly to the susceptibility to brittle fracture. The presence of this brittle constituent is due to improper heat treatment. More than one sequence of heat treating could result in mixed microstructure and the actual heat treatment is unknown. It is, however, probable that the final tempering temperature was too high, leading to re-austenitization in the segregated areas with subsequent transformation to bainite and auto-tempered martensite on air cooling. Ideally, the as-cast alloy should receive a high-temperature homogenization treatment to reduce segregation. This alloy should be austenitized at 1450°F to 1550°F for normalizing or quenching. The tempering temperature should not exceed 1225°F maximum, and probably not 1200°F in commercial practice.

The poor results of the Charpy impact tests after laboratory tempering are probably due in large part to the presence of the crack-like microshrinkage defects. There is little doubt that such defects lower resistance to crack propagation. Such defects are very difficult to eliminate in normal commercial casting practice, short of using vacuum degassed metal, and it would appear that use of forged steel is indicated as a means of improving metallurgical soundness. Although such material would probably be more expensive initially it is quite probable that increased service life would compensate.

As the primary cause of failure was not established, it is not known whether a radical change in material properties, hence in alloy and heat treatment, is required. In any event, the use of sound material of equivalent tensile properties would be a step in the right direction.

It is quite possible that AISI 2345, forged or rolled, might not be readily available. If so, consideration should be given to a machinery grade such as Ultimo 4, produced by Atlas Steel Company. This particular alloy, in a 4 inch section, air quenched from 1600°F and tempered at 1200°F has a yield strength of 96,000 psi compared to 71,200 psi for the sample submitted. The toughness of a forged or rolled bar at this strength level would be expected to exceed that of the cast sample examined by a considerable margin. In addition, the higher yield strength would result in a lower ratio of working stress to yield strength in comparison with the failed material. This would be of especial significance if the service fracture origin were found to lie in a fatigue crack.

In the event of further unsatisfactory performance, it is suggested that a sample incorporating the full fracture be submitted for examination along with blueprints and/or sketches sufficient to show the design, location, and function of the nut in some detail.

CONCLUSIONS

1. Crack propagation was by brittle fracture.
2. Service temperature was well below the ductile to brittle transition temperature of the material.
3. The material was improperly heat treated as shown by the presence of lightly tempered martensite.
4. The brittle lightly tempered martensite was deleterious to notch toughness.
5. The notch toughness of the material was further degraded by the presence of considerable microshrinkage.
6. The carbon content was low, which would result in a somewhat lower tensile strength than anticipated for a specific heat treatment.

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