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EXAMINATION OF CRACKED STEEL CASTINGS

by

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PHYSICAL METALLURGY DIVISION

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Mines Branch Investigation Report IR 59-77

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SUMMARY OF RESULTS

Examination of cracked and uncracked castings (Pattern 182-732-M1) revealed that the failure of the material was due to the formation of cracks during the quenching operation. The cause of cracking was mainly attributed to a high quenching temperature, possibly above 1600°F. The chemical analysis of the cracked castings complied with the SAE Specification 4150 instead of SAE 4140 which is less prone to quench cracks.

It was recommended that the castings be produced from steel of the SAE Specification 4140. It was also recommended that oil-quenching be carried out from within the temperature range of 1550 - 1600°F, as higher quenching temperature would result in crack formation.

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(13 pages, 1 table, 9 illus.)

INTRODUCTION

A request was received from Mr. E. F. Patton, Canadian Unitcast Steel Limited, Sherbrooke, Quebec, in a letter dated June 2, 1959, for an investigation of the cause of cracking of steel castings (Pattern 182-732-M1) made to the SAE Specification 4140. The covering letter stated that before the castings are sent to the customer they are austenitized at 1800°F - 1850°F for about four hours and then furnace cooled. Subsequently they are wheelabrated cleaned and annealed at 1500°F to give a Brinell hardness of 180-220 (Rockwell B 89-97). The castings are shipped in this condition to the customer who carries out the major part of their machining and gives the final heat treatment which consists of quenching in Houghton 4C oil from 1600°F followed by a draw at 1200°F - 1225°F. This treatment gives a Brinell hardness of 255-283 (Rockwell C 25-30).

Regarding the processing carried out by the customer Mr. E. F. Patton has the following to say:

> "I have no idea what rate the castings are heated at or at what temperature they re-enter the furnace for the draw. We have been checking these castings by magnaflux before shipment without finding cracks, so it appears that this is happening somewhere during the heat treating after machining.
>
> I would guess from the casting being returned cracked that we are getting about 30% rejects for this cause".

An interim report in letter form was supplied to Mr. E. F. Patton on July 28, 1959.

In all, four and a half castings were received. Two of these were in the uncracked condition as supplied to the customer, and the remaining were in the machined condition and as heat treated by the customer.

VISUAL AND MAGNAFLUX INSPECTION

Figure 1 shows the castings under investigation. Both the visual and magnaflux examination revealed the presence of a crack on the machined castings (Figure 1), whereas those heat treated by the foundry and supplied to the customer showed no evidence of surface flaw or cracking. As a further check the castings were also examined radiographically. It confirmed the presence of a crack in the machined castings as detected by magnaflux, and showed that there was no other major defect in the body of the castings. It also indicated that there was no shrinkage around the area of the crack.

CHEMICAL ANALYSIS

Drillings taken from one of the cracked castings were chemically analysed. The results are given in Table I. For means of comparison, SAE Specifications 4140 and 4150 are also included.

TABLE I

Chemical Analysis of Cracked Casting

	Composition, Percent		
	Casting	SAE 4140	SAE 4150
Carbon	0.49	0.38 - 0.43	0.48 - 0.53
Manganese	0.80	0.75 - 1.00	0.75 - 1.00
Silicon	0.69	0.20 - 0.35	0.20 - 0.35
Sulphur	0.043	0.04 max	0.04 max
Phosphorus	0.034	0.04 max	0.04 max
Chromium	0.89	0.80 - 1.10	0.80 - 1.10
Molybdenum	0.26	0.15 - 0.25	0.15 - 0.25

It will be seen that the carbon content of the casting does not comply with the SAE Specification 4140, but conforms to SAE 4150. Similarly, the sulphur content is 0.043 percent against the required maximum of 0.040 percent. In this connection it may be pointed out that in steel castings sulphur as high as 0.06 percent is permissible when the metal is made in acid-lined furnaces and 0.05 percent when made in basic-lined furnaces.

Regarding the silicon content of 0.69 percent in the casting it may be mentioned that a relatively high silicon content (about 0.65 percent) is permitted as it is desirable in making steel for castings to deoxidise the metal as thoroughly as possible. This element, up to 0.65 percent, exerts but little influence on the casting and mechanical properties, but a slight increase in strength, hardness and hardening capacity are conferred without adverse effect on the ductility.

MICRO EXAMINATION

Sections were cut from each casting and metallographically examined after suitable preparation. Unetched sections showed the presence of micro-shrinkage (Figure 2) and of sulphide inclusions (Figure 3) slightly in excess of the normal count. The microstructure of the castings heat treated by the foundry i.e. those shipped to the customer, consisted of ferrite and lamellar pearlite (Figure 4), and recorded a hardness of Rockwell C 22 (240 Bhn) compared with the required range of Rockwell B89-97 (180-220 Bhn).

The microstructure of the castings as heat treated by the customer showed coarse tempered martensite (Figure 5) with the hardness of Rockwell C 38 (352 Bhn) against the desired level of Rockwell C 25-30 (255-283 Bhn). Presence of coarse tempered martensite is indicative of a high quenching temperature.

Metallographic examination of a section including the cracks (Figures 6A and 6B) showed that there was no decarburization along the crack area and that the cracks were of duplex nature following both inter- and trans-granular paths. The cracks did not extend for the full thickness of the casting, but tapered out from the surface inwards (Figure 7). Furthermore, they were sharp-ended type, typical of those formed by sudden cooling or quenching of steel.

DISCUSSION

During the course of the investigation, it became increasingly clear that the failure of the castings was mainly due to the severity of quenching. The steel was about six points higher in carbon than the amount called for in SAE 4140, and showed distinctly coarse grained tempered martensite in the final heat treated condition. Another undesirable feature, not uncommon in cast-steels, was the presence of randomly distributed micro-shrinkage and a slightly high sulphur content (0.043 percent). All these factors together with the type of crack, indicate that cracking was a result of thermal stresses set up in the casting during the quenching operation.

In order to examine the crack susceptibility of the material one of the unmachined castings as shipped to the customer, was quenched in Houghton 4C oil at 1600°F after being soaked for 3/4 hr. It was then tempered at 1200°F for the same length of time. The hardness of the casting in this condition was found to be Rockwell C 34 (313 Bhn), and there was no indication of cracking as evinced by both the visual and magnaflux examinations.

The same casting was later on oil-quenched at 1675°F. This treatment gave a hardness of Rockwell C 58 (587 Bhn). As anticipated the casting formed a typical quenching crack which, when opened with a hammer blow, showed characteristic brittle fracture as shown in Figure 8.

The crack formation may therefore be attributed to an unduly high quenching temperature which produces not only a grain coarsening effect, but also lowers the critical rate of cooling or the Ms* point of steel. A lowering of the critical cooling rate increases the hardenability of steel which in turn produces sharp volume changes in carbon and low-alloy steels from the surface to the interior. It may be added that an increase in carbon content would have the added effect of lowering the critical cooling rate of the casting.

Chapman and Jominy did some work on engineering steels (Metal Progress, September, 1953) using a special crack test specimen, and found that as the (calculated) Ms point of steel was reduced, or the carbon content increased up to eutectoid compositions**, so the propensity of cracking during quenching

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*Ms point: The temperature at which transformation of austenite to martensite starts during cooling.

**0.9 percent carbon.

increased. Figure 9 summarizes their results. It will be seen that SAE 4140 steel with the Ms point at 594°F is appreciably less prone to cracking than SAE 4150 steel. One of the important deductions from Figure 9 is that the lower the temperature of martensite formation in the steel, the more likely it is to crack, because at lower temperatures there is less possibility of plastic flow to relieve stresses resulting from the expansion occurring during the martensite formation.

CONCLUSIONS

1. Chemical analysis of the casting showed that it complied with the SAE Specification 4150 instead of SAE 4140.

2. The castings showed the presence of micro-shrinkage and the sulphide inclusions. However, their mode and extent of distribution were not in excess of the amount usually associated in cast steels.

3. There was no decarburization along the crack area and the nature of the cracks appeared to be duplex, following both inter- and trans-granular paths.

4. The microstructure of the customers' heat treated material consisted of coarse tempered martensite indicative of a high quenching temperature. The hardness was Rockwell C 38 (352 Bhn) against the required range of Rockwell C 25-30 (255-283 Bhn).

5. The failure of the material is attributed to the development of cracks during quenching, and this in turn is related to a high quenching temperature, possibly in excess of 1600°F.

Recommendations

In order to avoid the reoccurrence of similar trouble in future, it is recommended that:

(a) the chemical composition of the castings be maintained within the SAE Specification 4140 which has an appreciably lower crack susceptibility than SAE 4150,

(b) all precautions be taken to ensure a good heat treatment procedure, and

(c) quenching temperature be maintained in the range of 1550°F - 1600°F as higher temperatures lower the adverse effect of depressing the Ms point, or increasing the critical rate of cooling resulting in crack formation.

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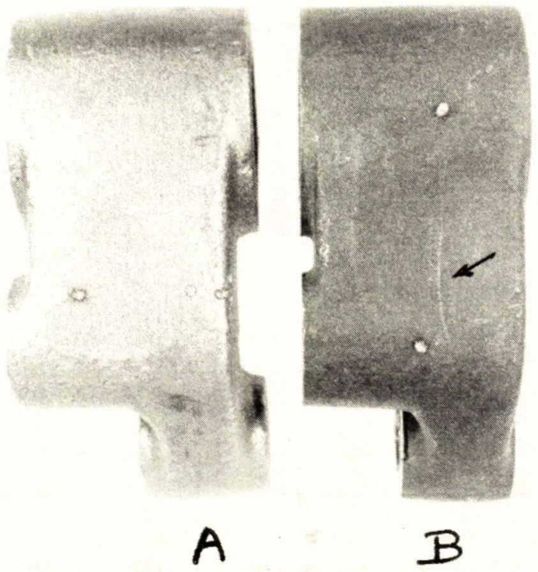
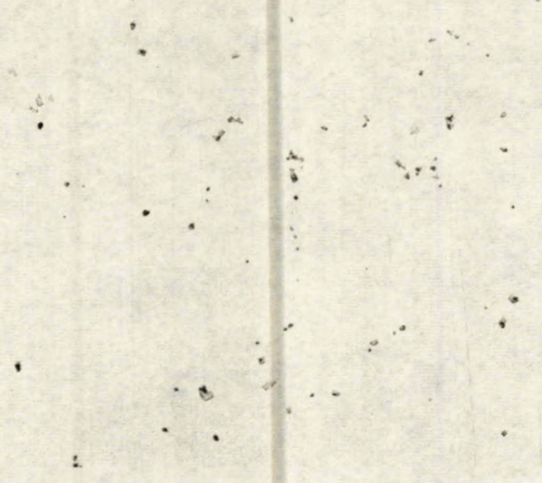
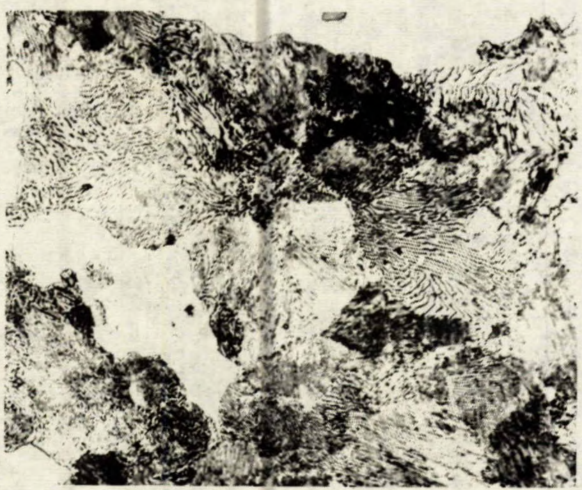


(Approx. 2-1/4 actual size)
Figure 1. - Photograph of unmachined (A) and machined (B) castings. Note the presence of crack (arrow) on machined casting.

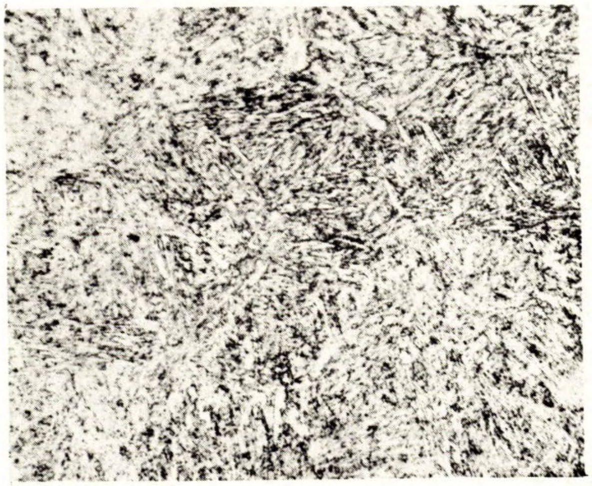
(Unetched; magnification X100)
Figure 2. - Photomicrograph showing micro-shrinkage (black) and sulphide particles (grey).



(Unetched; magnification X100)
Figure 3. - Particles of sulphide inclusions (grey)

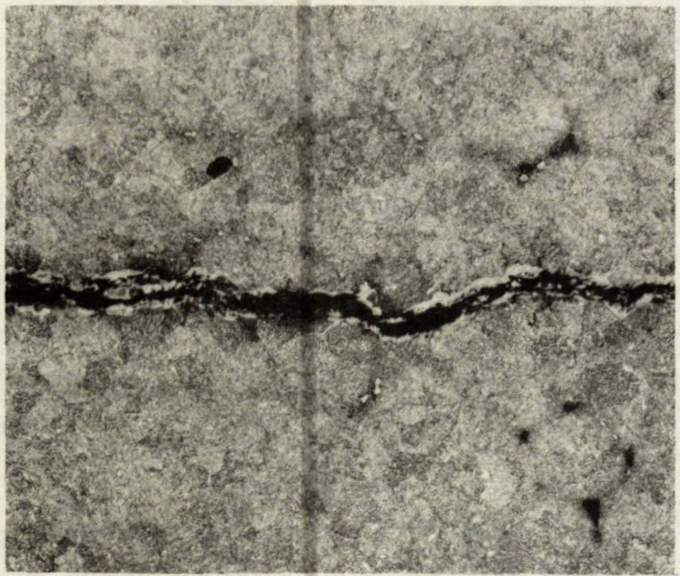


(Etched 2% nital; magnification X500)
Figure 4. - Microstructure of the casting as heat treated by the foundry. Hardness: Rockwell C 23 (240 Bhn).

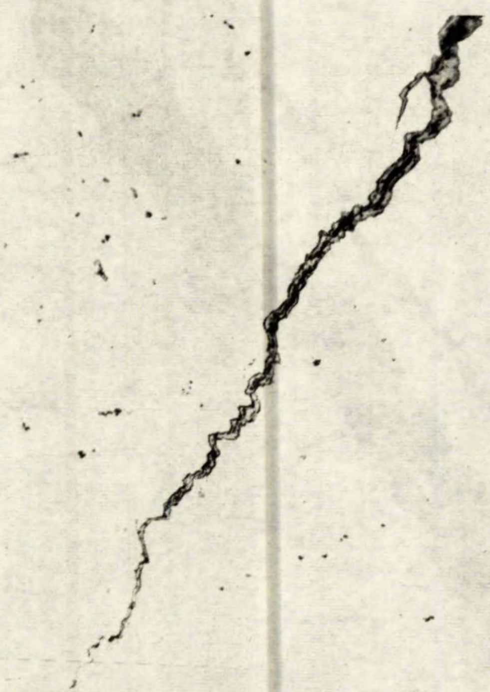


(Etched 2% nital; magnification X500)
Figure 5. - Microstructure after the customers' heat treatment. Hardness: Rockwell C 38 (352 Bhn).

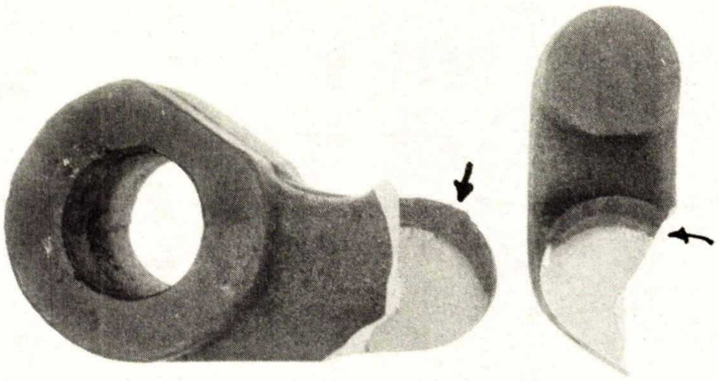
(Unetched; magnification X100)
Figure 6A. - Photomicrograph showing crack area. Fine particles are sulphide.



(Etched 2% nital; magnification X100)
Figure 6B. - Photomicrograph showing absence of decarburization along the crack area.



(Unetched; magnification X100)
Figure 7. - Photomicrograph of the bottom position of the major crack shown in Figure 6A.



(Approx. 2-1/4 actual size)

Figure 8. - Cracked casting after being quenched in oil from 1675°F. Note the black rim (arrow) showing the area penetrated by oil after the crack formation.

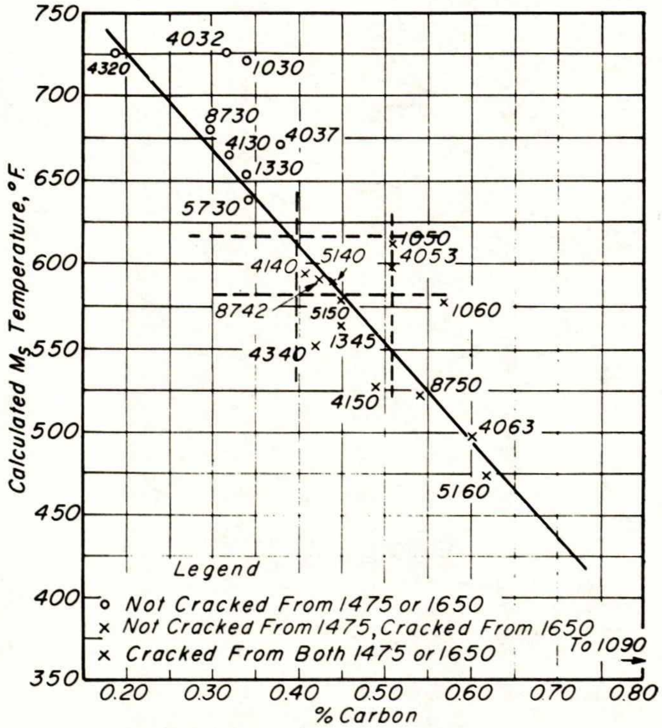


Figure 9. - Cracking tendency as related to Ms temperature and carbon content when quenched from 1475°F to 1650°F.