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EXAMINATION OF CRACKS IN WABCO AND KNORR DISC BRAKES

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PROJECT MEMORANDUM

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SUMMARY

On December 18, 1978, three AMFLEET brake discs containing thermal cracks were surveyed at the AMTRAK wheel maintenance shops in Wilmington, DE. Two of these discs had been supplied by the Knorr Brake Corporation, and had belonged to the major fleet population. The third was one of approximately forty discs of a different design that had been supplied by the Westinghouse Air Brake Corporation for field testing.

Parts were cut from the three discs and subsequently delivered to the Department of Materials Science and Engineering, Massachusetts Institute of Technology, for metallurgical evaluation.

The Knorr and Wabco disc brakes were examined for the cause of cracking and why there is a difference in the type of cracks found in the two designs. Microstructure, microhardness, hardness, composition, and crack surfaces were investigated. Little difference was noted between the two materials. The crack surfaces had been worn and corroded, and neither the origins of cracks nor directions of crack growth could be accurately determined.

To further assess the performance of the Westinghouse Air Brake Co. disc brake, the tangs that join the disc to the hub in this design were examined for microstructure, microhardness, composition, dimensionals, and visual evidence of wear. The data was compared to the design requirements furnished by the manufacturer. The connecting bolts were also examined for wear, debris, deformation, and/or cracks.

The Wabco tangs and connecting bolts were found to meet the manufacturer's specifications. The tangs and connecting bolts showed no signs of wear, cracking, or deformation. The microstructure and microhardness of the tangs were found to be similar to the metal in the disc region.

1. OBSERVATIONS

Two types of cracks were observed in both the Wabco and Knorr disc brakes. Cracks of the first type were small, ran in a radial direction, and were located in the middle region of the braking surface (Figures 1-3). These cracks are commonly called heat checks and are not unusual in braking surfaces. The density of cracks varied between the two designs (0.5 crack/cm^2 for Wabco; 0.1 crack/cm^2 for Knorr). The Knorr disc had few observable heat checks. Those observed were approximately 4 cm in length and 1 to 2 cm in cross-sectional depth. The Wabco disc had numerous heat checks, with some as long as 10 cm. Their cross-sectional depth was also 1 to 2 cm (Figures 1, 4, and 5).

The second type was a major crack passing through the disc thickness. This type of crack was also found in both designs, but with a difference in location. In the Knorr discs, the major cracks had an open end at the inner radial edge of the disc. The cracks ran across the disc in a nearly radial direction with a crack tip generally located a distance from the outer radial edge, but with some cracks completely crossing the disc (Figures 2, 3, 6 and 7). When the major cracks were opened, the crack surfaces were found to be worn and corroded. No information as to the origin of fatigue could be determined. The fact that all of the major cracks in the Knorr disc had at least one open end at the inner edge suggests the origin was at the inner radial edge (Figure 6). All of the major cracks in the Knorr disc occurred between the disc boss and an adjacent cooling fin (See Figure 8).

The Wabco disc had only one major crack. It was located with an open end at the outer radial edge of the disc. The crack was nearly radial, with the crack tip stopping in the middle of the braking surface (Figure 9). Because of the condition of the crack surface, no additional information was obtained. The major crack branched into the heat checks that crossed its path.

The length of time each disc was in service is unknown. However, the depth of the depressions on the brake disc surfaces indicate that the Knorr disc has lost approximately twice the amount of material as the Wabco disc. The depression is a result of wear caused during braking action (Figures 7 and 8).

The Wabco tangs were found to have no wear debris. Corrosion had occurred on exposed surfaces but no significant damage appeared at the bolt/tang interfaces. No cracks were found in the tangs.

The connecting bolts showed no signs of wear (Figure 10). Scratches on the surface had removed the protective coating which appeared to have been a copper alloy. No debris was detected on the bolt surfaces. The bolts showed no signs of cracking or failure. No apparent damage was observed to have occurred to the nuts or washers.

Measurements were taken of the tang holes in two directions, the rolling and radial directions (Figures 11 and 12), and at the outside and inside surfaces. The acceptable diameter, as stated by Wabco, is between 0.745 and 0.805 inch. All measurements were within these limits (Table 1). The holes appear to have elongated in the radial direction. No major differences were detected between the outside and inside surface measurements.

The bolts, not having a standard orientation with respect to the tang, were measured with respect to a "B" marking on the bolt head (Figure 13). Measurements were made along lines down the shaft of the bolt in line with the "B" and at 90° from the "B". The bolt/shafts were measured at three locations along the lines: next to the bolt head, next to the threads, and halfway between. The acceptable range for bolt diameter is 0.74 to 0.75 inch. The average (over eight bolts) of each measurement is presented in Table 2. All averages were within the acceptance range. However, two of the bolts had measurements that exceeded the maximum by .002 inch, while one bolt was below the minimum by .011 inch.

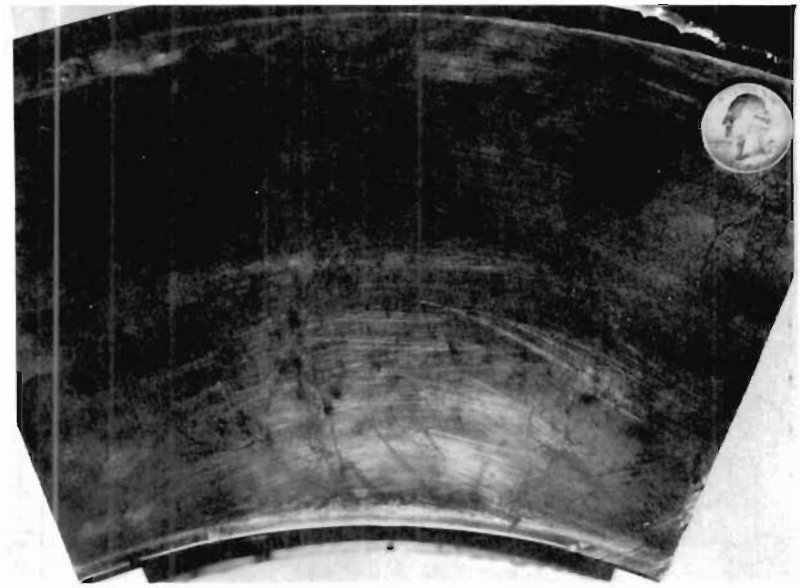

FIGURE 1. WABCO DISC BRAKE WITH HEAT CHECKS IN MIDDLE OF DISC. THE CRACKS RUN RADIALLY ACROSS THE BRAKING SURFACE

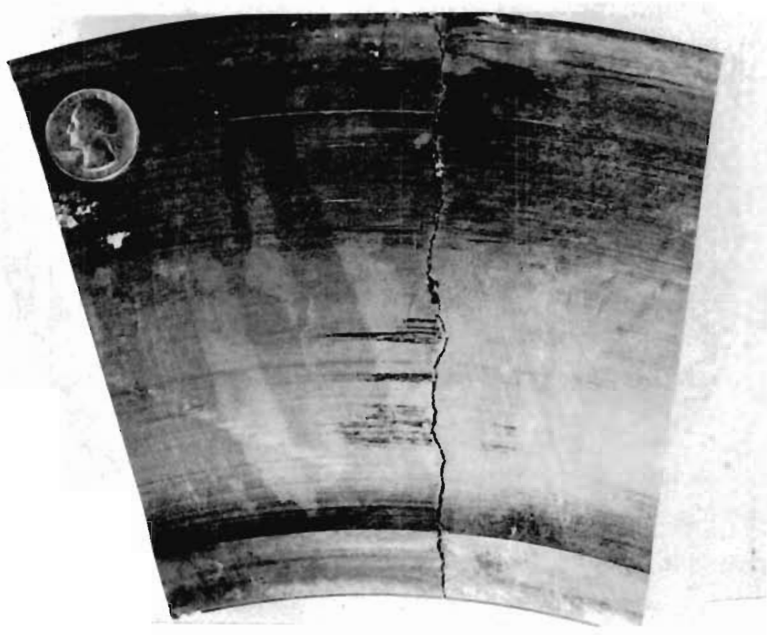

FIGURE 2. KNORR DISC BRAKE WITH HEAT CHECKS (minor cracks) AND MAJOR CRACKS. THE CRACK RUNS FROM THE INNER RADIAL EDGE (lower part of photograph) TO THE OUTER RADIAL EDGE (upper part of photograph).

FIGURE 3. KNORR DISC BRAKE WITH MAJOR CRACK WITH OPEN END AT THE INNER RADIAL EDGE.

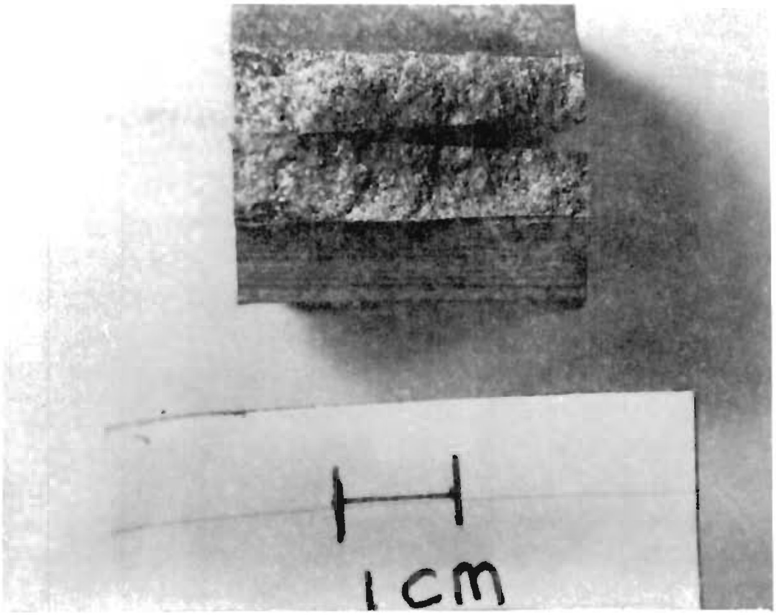

FIGURE 4. WABCO DISC BRAKE HEAT CHECK CRACK. THE CRACK WAS OPENED TO REVEAL THE CRACK SURFACE. THE DARK REGION IS THE CRACK, THE BRIGHTER REGION IS THE REGION FRACTURED TO OPEN THE CRACK. THE DARK MATERIAL IS CORROSION PRODUCTS.

FIGURE 5. CROSS SECTION OF HEAT CHECK IN KNORR DISC BRAKE. THE MAGNIFICATION IS 50X. THE BLACK SEGMENTS IN THE METAL ARE THE GRAPHITE FLAKES.

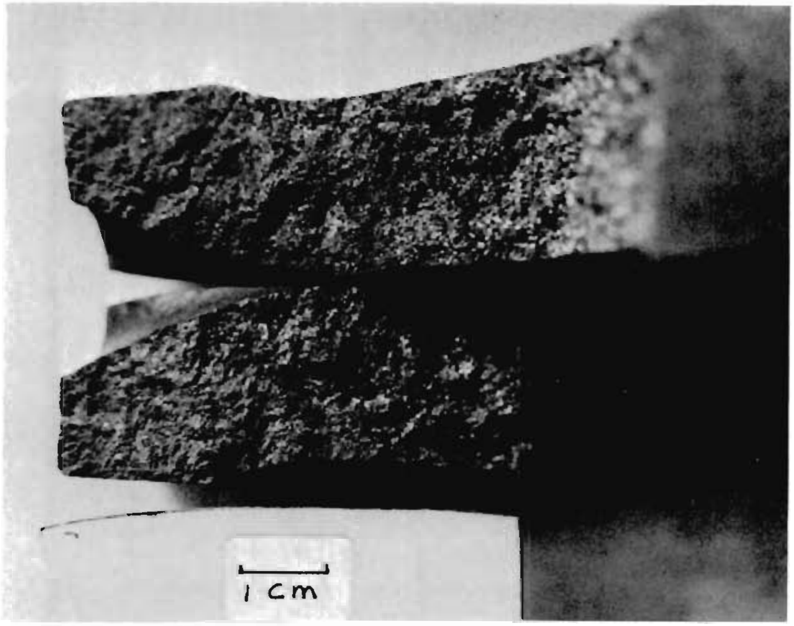

FIGURE 6. CRACK SURFACE OF KNORR NEAR INNER RADIAL EDGE. THE BRAKING SURFACE IS THE TOP EDGE OF THE UPPER PART AND THE BOTTOM EDGE OF THE LOWER PART. THE REGION TO THE LEFT LACKING LUSTER IS THE ORIGINAL CRACK SIZE; THE REST OF THE CRACK SURFACE IS FROM THE OPENING OF THE CRACK. THE DEPRESSION THAT FORMS ON THE BRAKING SURFACE IS A RESULT OF WEAR.

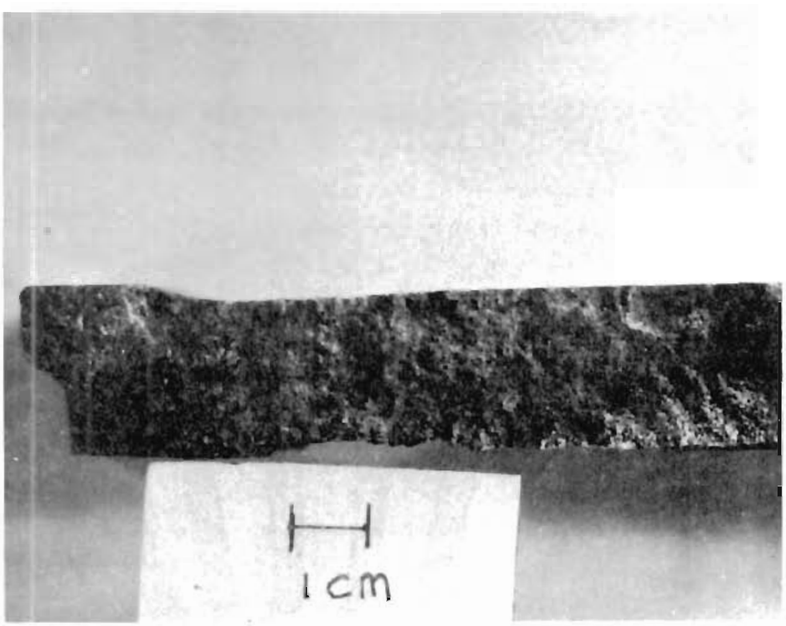

FIGURE 7. CRACK SURFACE OF KNORR MAJOR CRACK. THE DARK REGION IS THE CORRODED AND WORN AREA. THE UPPER EDGE IS THE BRAKING SURFACE. NOTE THE WEAR DEPRESSION.

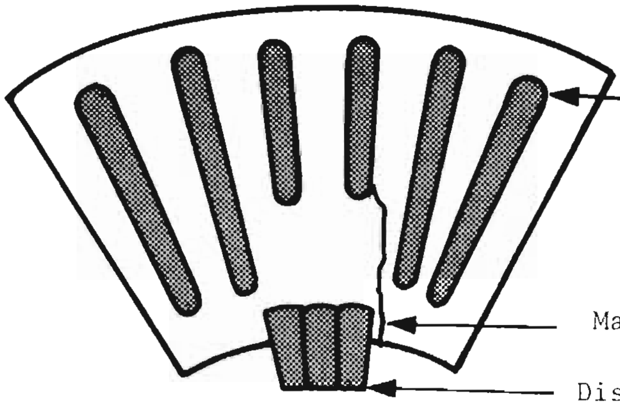

FIGURE 8. KNORR DISC CROSS-SECTION SHOWING LOCATION OF MAJOR CRACK NEAR HUB-DISC CONNECTION.

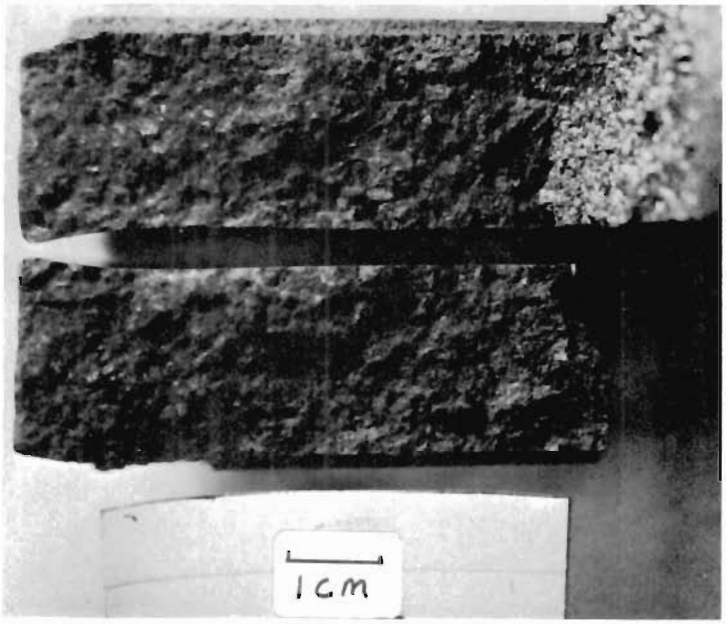

FIGURE 9. WABCO MAJOR CRACK NEAR THE OUTER RADIAL EDGE. THE DARK MATERIAL IS THE CORRODED AND WORN REGION. THE BRAKING SURFACES ARE THE MIDDLE EDGES. THE DEPRESSION IN THE BRAKING SURFACE IS A RESULT OF WEAR.

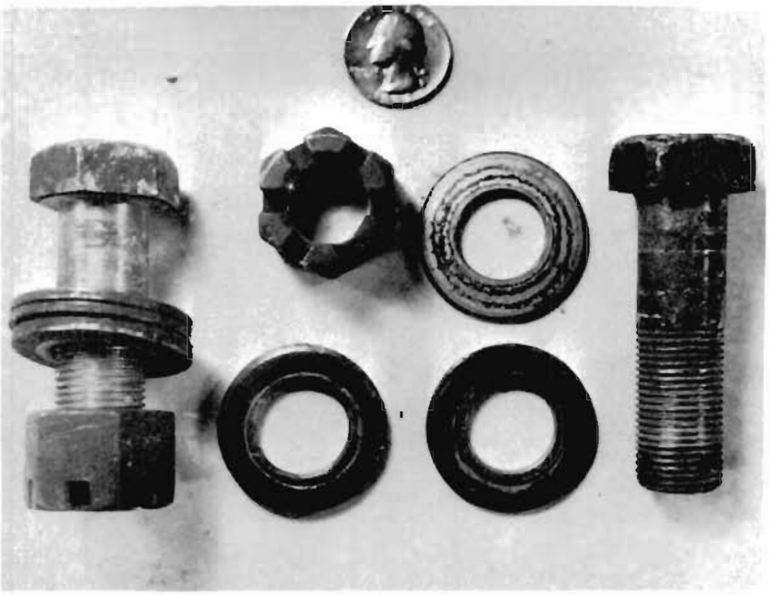

FIGURE 10. WABCO BOLTS AS RECEIVED. NOTE SURFACE CONDITION BEING FAIRLY SMOOTH WITH NO APPARENT WEAR.

FIGURE 11. WABCO BRAKE DISC TANGS AS RECEIVED. SHOWN ARE THE STAMPED (left) AND PAINTED (right) SIDES OF HOLES NUMBER 2 AND 3. THE SIDE WITH THE LARGE PAINTED THREE IS THE OUTSIDE SURFACE WHILE THE OTHER HOLE SHOWS THE SURFACE THAT WAS IN CONTACT WITH THE HUB.

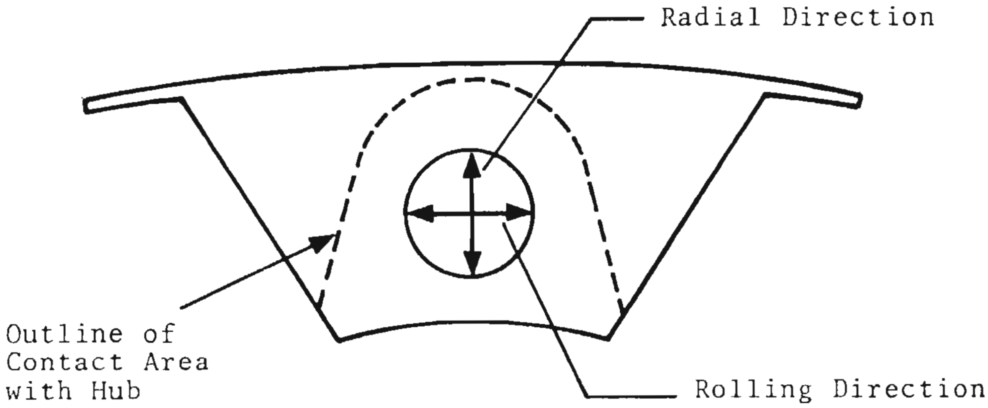

FIGURE 12. DIAGRAM OF WABCO DISC BRAKE TANG

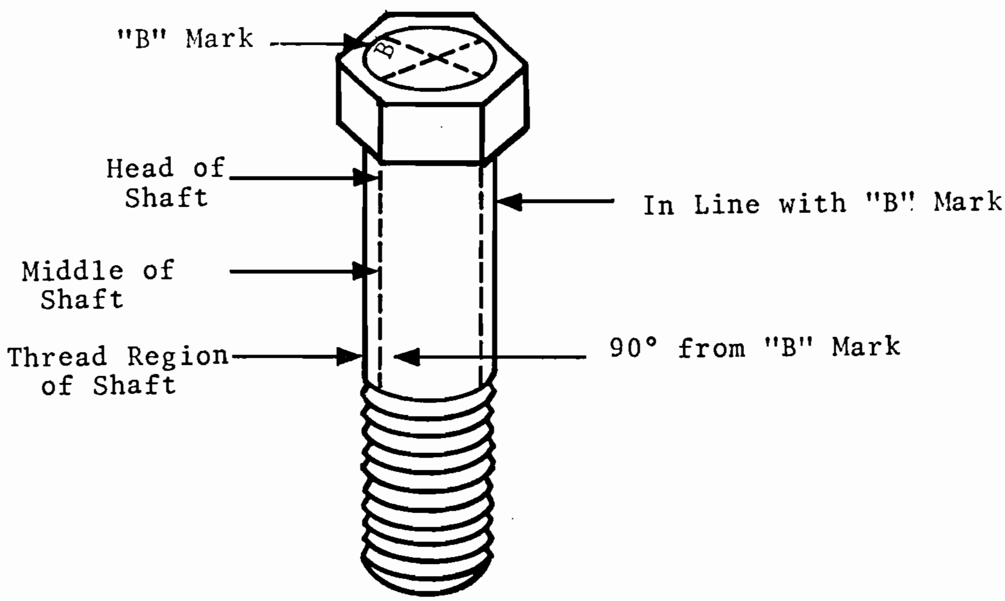

FIGURE 13. DIAGRAM OF CONNECTING BOLT

TABLE 1. MEAN MEASUREMENT AND STANDARD DEVIATION FOR TANG HOLES

	ROLLING DIRECTION	RADIAL DIRECTION
OUTSIDE SURFACE	.761 $\pm$.0007	.790 $\pm$.0008
INSIDE SURFACE	.761 $\pm$.0009	.790 $\pm$.0011
AVERAGE	.761 $\pm$.0008	.790 $\pm$.0009

TABLE 2. MEAN MEASUREMENT AND STANDARD DEVIATION FOR CONNECTING BOLTS

	IN LINE WITH "B" MARK	90° FROM "B" MARK
HEAD OF SHAFT	.746 $\pm$.0012	.748 $\pm$.0013
MIDDLE OF SHAFT	.744 $\pm$.0062	.749 $\pm$.0025
THREAD REGION OF SHAFT	.744 $\pm$.0060	.749 $\pm$.0018
AVERAGE	.745 $\pm$.0044	.749 $\pm$.0019

2. COMPOSITION

Samples of both the Knorr and Wabco disc brakes were analyzed for the following elements: carbon, silicon, manganese, sulfur, phosphorus, chromium, molybdenum, and tin. The results are given in Table 3, together with the results from previous analyses for the Knorr disc and the specifications set by Wabco.

The major difference between the composition of the Knorr disc and Wabco disc was the amount of molybdenum present. Molybdenum is added to gray cast irons to increase wear resistance (References 1 and 2). Some difference in the amount of chromium was also noted. Chromium also increases wear resistance, but its presence increases brittleness (Reference 2).

Because of the similarities between microstructure and hardness of the Wabco disc and tang, a specific analysis was not done for the tangs. The composition should be valid for both the Wabco tangs as well as the Wabco disc.

1. The Making, Shaping and Treating of Steel, published by U.S. Steel, 1067 - 1071, Ninth Edition, 1970.

2. Metals Hardbook, Volume 1, Properties and Selection: Iron and Steels, Published by A.S.M., 25-28, Ninth Edition, 1978.

TABLE 3. KNORR AND WABCO DISC COMPOSITIONS

	KNORR	KNORR PREVIOUS	WABCO	WABCO SPECIFICATIONS
	%	%	%	%
Carbon	3.38	3.48	3.43	3.10 - 3.40
Silicon	1.92	1.80	2.35	1.90 - 2.30
Manganese	.69	*	.54	0.60 - 0.90
Sulfur	.076	*	.058	.15 Max.
Phosphorus	.071	*	.017	.15 Max.
Chromium	.25	*	.41	0.10 - 0.50
Molybdenum	.025	*	.35	0.10 - 0.50
Tin	.008	*	.080	.10 Max.

The above table is based on the results of chemical analysis done by Luvak, Inc.

*(Not analyzed in previous analysis.)

3. MICROSTRUCTURE

The microstructures of the Knorr and Wabco disc brakes (Figures 14 and 15) were typical for gray cast iron: a matrix of gray cast pearlite with graphite flakes randomly distributed throughout the structure. The grain size, microhardness, flake density, and Rockwell "B" hardness versus the location on the disc are given in Table 4.

Because of the large density of graphite flakes, which affects the microhardness, the Knoop hardness numbers reported do not reflect the true physical properties of the discs. The Knoop hardness numbers do show relative microhardness between locations and between brake disc designs.

The data indicate that the Wabco disc fell within the company's specifications minimum tensile strength of 30,000 psi and Brinell hardness of 170 to 217. An approximation of the tensile strength, based on the Rockwell "B" hardness number, gave a tensile strength of 96,000 psi with a Brinell hardness of 167 to 200.

The graphite flake type for both brake designs was type A. This means that the graphite flakes are randomly oriented and randomly distributed. The average pearlite colony size of the Wabco disc was approximately 1.5 times that of the Knorr disc (Table 4). The graphite flake density was higher in the Knorr disc.

Microhardness tests were made approximately 0.02 cm from the tang hole surface and in the middle of the cross section of the tang. The microstructure, having a large number of graphite flakes, influenced the apparent Knoop hardness number readings such that they could not be directly related to the tensile strength. However, as was done for the discs per se, a relatively good estimate of the tensile strength can be made based on the Rockwell "B" hardness number, which was 89 for the tang. The disc and tang would, therefore, have similar tensile strengths, roughly 90,000 psi.

The relative Knoop hardnesses between its hole surface and tang interior were 280 and 270, respectively. The increase in hardness at the surface may be a result of work hardening by the bolt or because of a microstructure change due to the cooling rate in manufacturing.

The microstructure of the tangs consisted of pearlite colonies with randomly distributed and oriented graphite flakes (Figure 16). This is typical of a gray cast iron. The microstructure of the tangs was very similar to that of the disc region of the brake (Figures 16 through 18). The graphite flake density for the tangs was $2.8 \times 10^4/cm^2$, while in the disc it was 2.3×10^4 flakes/cm^2. The average colony size in the tangs was 40 μm while in the disc it was 35 μm. These differences could account for the differences in microhardness between the disc and tangs.

TABLE 4. MICROSTRUCTURE AND HARDNESS MEASUREMENTS

DISC TYPE	RADIAL LOCATION	AVERAGE COLONY DIAMETER (μm)	GRAPHITE FLAKE DENSITY $\times 10^4/cm^2$	KNOOP HARDNESS NUMBER	ROCKWELL "B" NUMBER
	INNER	19	2.5	273	93.5
Knorr	MIDDLE	19	3.0	232	93.2
	OUTER	27	2.8	355	92.5
	INNER	35	2.3	304	86.8
Wabco	MIDDLE	31	2.2	299	92.7
	OUTER	33	2.3	275	87.5
Wabco Tangs		40	2.8	275	89

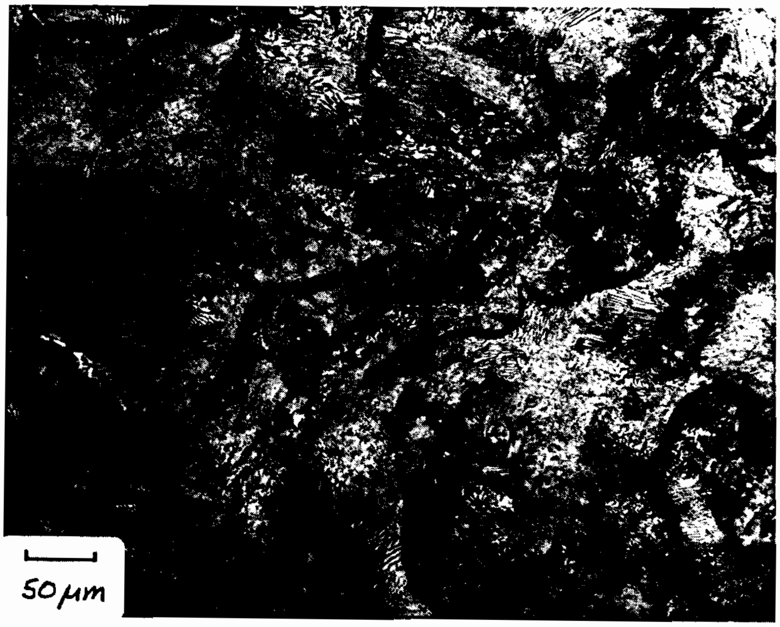

FIGURE 14. MICROSTRUCTURE OF WABCO DISC BRAKE. THE SAMPLE WAS TAKEN NEAR THE INNER RADIAL EDGE. MAGNIFICATION 200X

FIGURE 15. MICROSTRUCTURE OF KNORR DISC BRAKE. THE SAMPLE WAS TAKEN NEAR THE OUTER RADIAL EDGE. MAGNIFICATION 200X

FIGURE 16. MICROSTRUCTURE OF WABCO DISC BRAKE TANG. THE SAMPLE WAS TAKEN NEAR THE HOLE SURFACE. MAGNIFICATION 560X.

FIGURE 17. MICROSTRUCTURE OF WABCO DISC BRAKE TANG. NOTICE THE SIMILARITY TO THE MICROSTRUCTURE OF THE DISC FIG. 18. MAGNIFICATION 200X

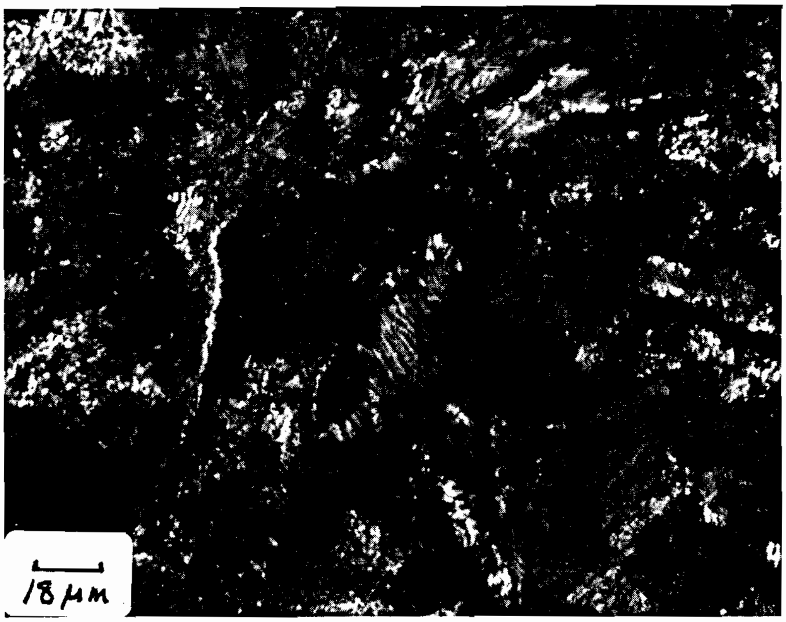

FIGURE 18. MICROSTRUCTURE OF WABCO DISC BRAKE FROM DISC SURFACE REGION. MAGNIFICATION 200X.

4. DISCUSSION AND CONCLUSIONS

The higher wear resistance of the Wabco disc as a result of higher concentration of molybdenum may be the reason for its greater number of heat checks. If the time in service of both discs is assumed to be nearly equal, then the wear rate of the Knorr disc is higher than that of the Wabco discs. As heat checks formed in the Knorr disc, the wear rate may have been high enough to remove the microcracks at the surface. This would result in fewer surface cracks seen on the Knorr disc. When a crack did form in the Knorr disc, it would have formed at its weakest point which, based on observations, was near a point near the hub-disc connection. The major crack in the Wabco disc could be a result of a material defect or a heat check growing by fatigue. The observations and measurements made for the Wabco tangs and bolts indicate that these components had not experienced any incipient fatigue or fretting failure.