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INVESTIGATION OF FAILURE OF TIMKEN ROLLER BEARINGS

by

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SUMMARY

Microscopic examination and hardness testing revealed that the failure of one of the bearings and possibly both was primarily due to the presence of retained austenite. The decomposition of the austenite in service caused considerable distortion. This distortion was responsible for the fretting corrosion of the outside diameter of the cup and the spalling of the raceways. The passage of the spalled fragments around the raceways caused the numerous small indentations in the raceways.

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(28 pages, 3 tables, 27 illustrations)

INTRODUCTION

Two roller bearings were received following a letter dated November 8, 1957 from Dr. F.W. Smith of the Fuels and Lubricants Laboratory, National Research Council, concerning the failure of such bearings by spalling. An examination for any metallurgical evidence of the origin of failure was requested. Illustrative pictures of defects, and an examination of the corrosion product on the outside diameter of the cup, were also requested.

VISUAL EXAMINATION

Bearing No. 1

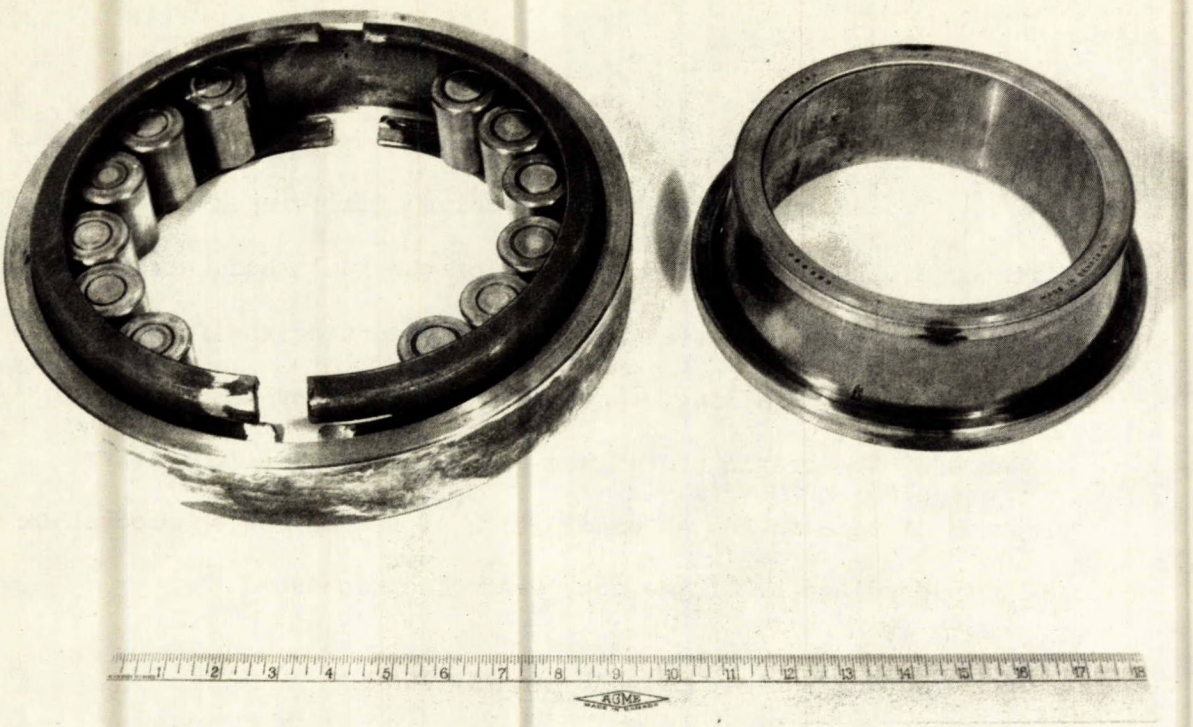
A view of bearing No. 1 is shown in Figure 1. The important visual observations concerning this bearing were summarized by Dr. Smith as follows:

1. The outside diameter of the cup showed two relatively rough, dark areas surrounded by polished regions.

2. The raceway of the cup had two shallow spalls and a large number of small, smooth-bottomed depressions. The spalls were in the same section of the cup as the larger of the dark areas on the outside diameter.

3. The raceway of the cone showed severe spalling at the flange edge of the raceway. Numerous small smooth indentations were also present.

4. The rollers showed many small, smooth depressions, but no spalling was evident.



(Approx. X.3)

Figure 1 - Bearing No. 1. Shows dark patches on outside diameter of cup (at left), two spalls on raceway of cup (12 o'clock), and large spall on raceway of cone (7 o'clock on right-hand part).

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Bearing No. 2

The visual observations made by Dr. Smith were summarized as follows:

1. The damage was similar to that of bearing No. 1, in that a dark, rough area on the outside diameter of the cup corresponded to a spalled region on the raceway.

2. Considerably more mechanical damage was visible on the outside diameter of the cup. This was felt to be due to rotation of the cup in the housing.

3. There were a greater number of corrosion spots on the rollers and raceways, including marks on the cone raceway made by corrosion of the points of contact with four of the rollers while the bearing was at rest.

4. There was a"bell mouthing" of the cup at the widest point of the raceway. This had caused a polished strip about 1/16-inch wide.

5. More wear of the rollers had occurred at the points where they touched the ends of the case pockets than in the case of bearing No. 1.

Only the cone and rollers of bearing No. 2 were available for examination by the writer. The visual observations on these coincided with those made by Dr. Smith. A photograph of the cone is shown in Figure 2.

(Approx. X.34)

Figure 2 - Cone No. 2. Illustrates three spalled areas (circled) on the raceway of the cone. Spall at right (5 o'clock) was sectioned for microscopic examination.

CHEMICAL ANALYSES

The results of chemical analyses carried out on drillings taken from the cup and cone samples are shown in Table 1. The steels were within the chemical limits of SAE 3310 except for the slightly high nickel content of cone No. 1.

Table 1

Percent Chemical Analyses

Element	SAE 3310 Limits	Cup No. 1	Cone No. 1	Cone No. 2
C	.08/.13	.12	.12	.13
Mn	.45/.60	.44	.44	.49
Si	.20/.35	.33	.38	.36
S	.025 max.	.014	.020	.022
P	.025 max.	.014	.015	.011
Ni	3.25/3.75	3.40	4.12	3.45
Cr	1.40/1.75	1.48	1.49	1.37
Mo	-	.11	.08	.09
V	-	.005	.01	.04

EXAMINATION OF CORROSION PRODUCT

Photomicrographs showing some of the corrosion product found at the outside diameter of cup No. 1 are shown in Figures 3 and 4. The results of an X-ray identification carried out on samples of the corrosion product are shown in Table 2.

Table 2

X-ray Identification of Corrosion Products

Material	Magnetic Properties	Major	Minor	Trace
Black material in cavities	Magnetic	Spinel (probably Fe_3O_4). + amorphous	Fe_2O_3	$Fe_2O_3.H_2O$ + iron + unidentified
Dark brown surface film	Magnetic	Spinel (probably Fe_3O_4) + amorphous	Fe_2O_3	iron

(Mag. X100; 2% Nital)

Figure 3 - Shows scale and surface roughness at outside diameter of cup.

(Mag. X500; 2% Nital)

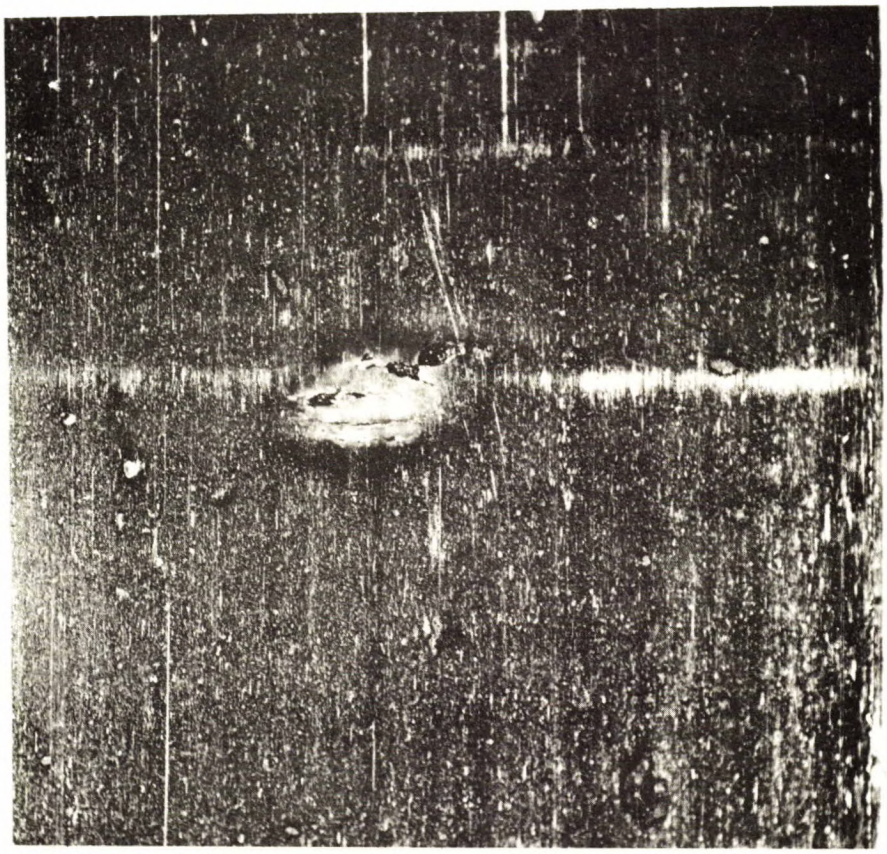
Figure 4 - Shows same area as in Figure 3.

MACROSCOPIC EXAMINATION

Several of the spalls are shown in Figures 5 to 8 at a magnification of 8 diameters. Spalls which were sectioned for further examination are so noted.

(Mag. X8)

Figure 5 - Multiple spall on raceway of cone No. 1 (7 o'clock in Figure 1). Note transverse cracking at upper surface. Arrow indicates suspected direction of rotation.

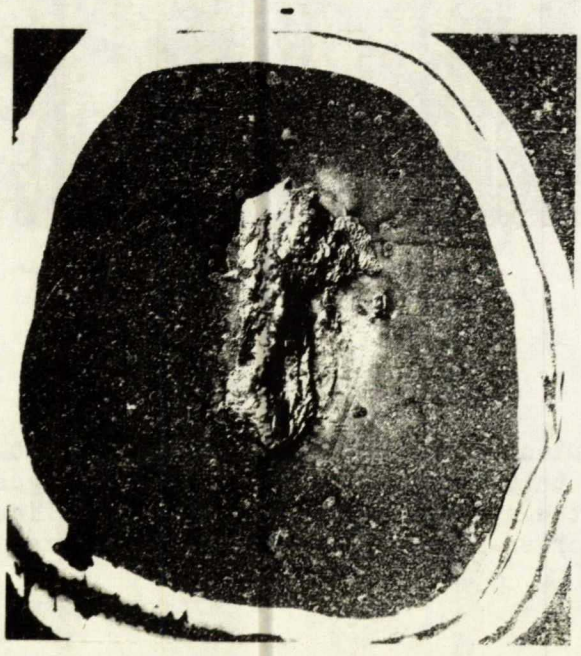


(Mag. X8)

Figure 6 - Incipient spalling on raceway of cone No. 1 at same distance from thick rim as spalling shown in Figure 5. This spall is located at 11 o'clock as oriented in Figure 1. This defect was cross-sectioned for microscopic examination.

(Mag. X8)

Figure 7 - Spalls on raceway of cup No. 1. See 12 o'clock position in Figure 1. Microspecimens were cut at, and adjacent to, these defects.



(Mag. X8)

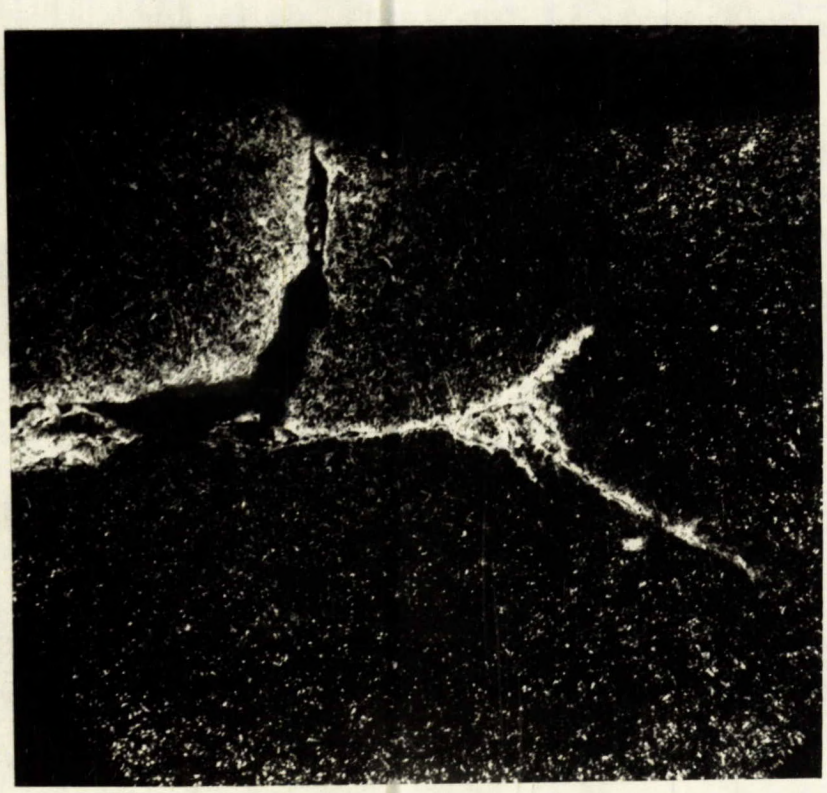
Figure 8 - Spall shown at 5 o'clock position of cone No. 2 (Figure 2). This defect was cross-sectioned for microscopic examination.

MICROSCOPIC EXAMINATION

Examination of the microspecimens of both cone samples revealed a normal carburized - quenched structure. Figures 9 to 13 show views of their structures at cross-sections cut through spalls. Figures 14 to 26 show the variation in structure and several views of spalling defects as seen in cup No. 1 (the only cup sample available).

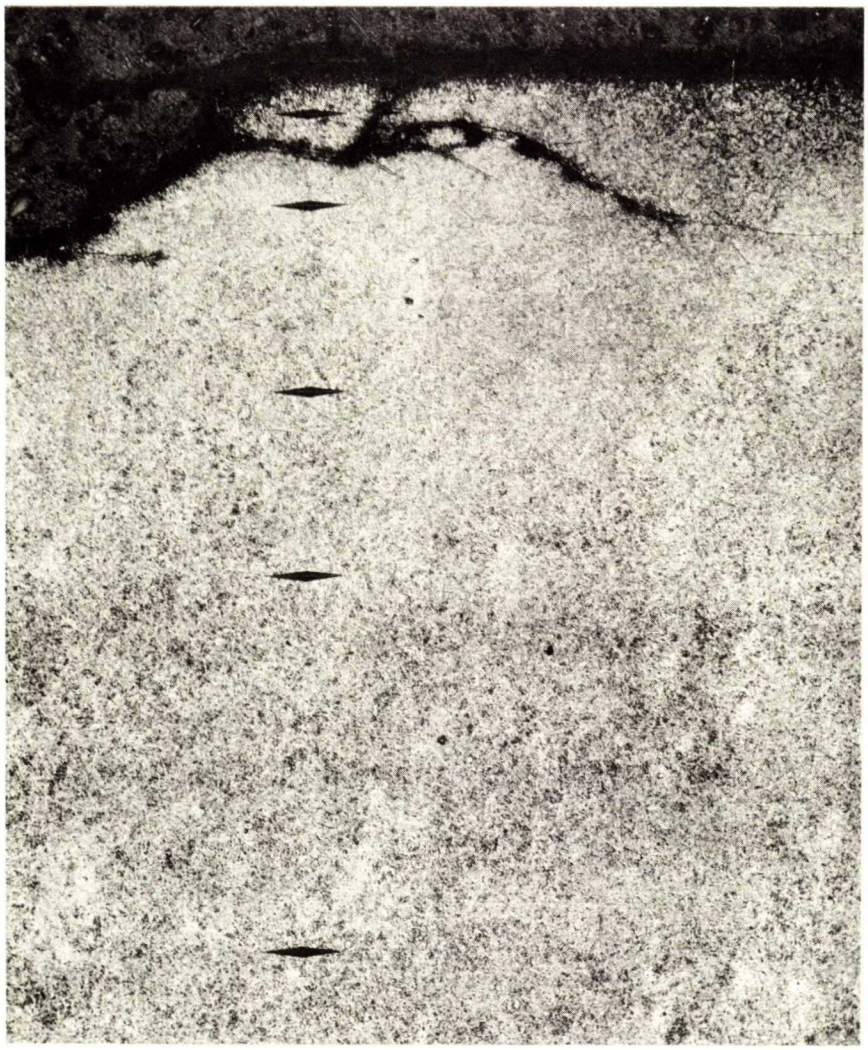
(Mag. X250; As Polished)

Figure 9 - Cross-section at incipient spall shown in Figure 6. (Cone No. 1).



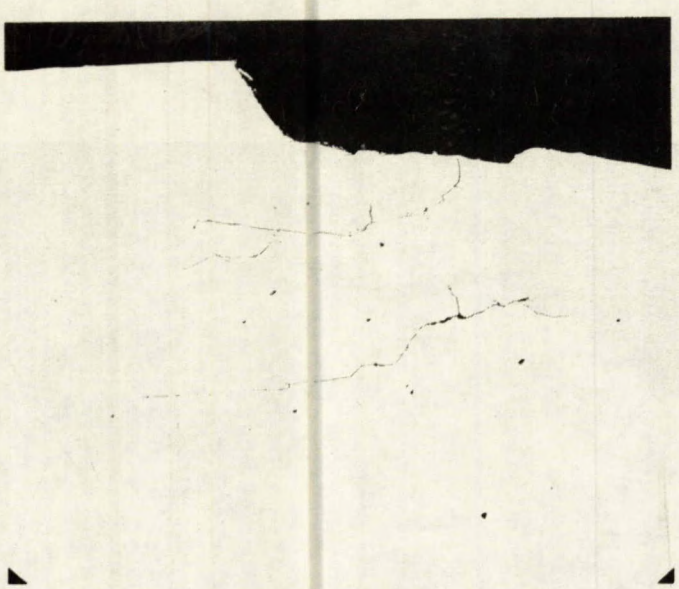
(Mag. X250; Etched in 2% Nital)

Figure 10 - Same field as in Figure 9. (Cone No. 1).



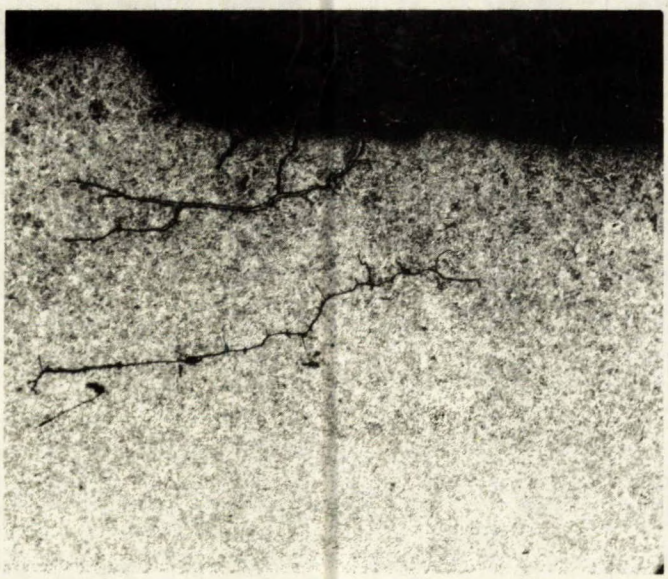
(Mag. X100; Etched in 2% Picral)

Figure 11 - Cross-section at edge of largest pit seen in Figure 6. Shows single spall developing into multiple spall. Hardness impressions shown indicated Rc hardnesses of 61, 57, 57, 56 and 60 from the edge inward.



(Mag. X100; As Polished)

Figure 12 - Cross-section at the edge of the spall shown in Figure 8. (Cone No. 2).

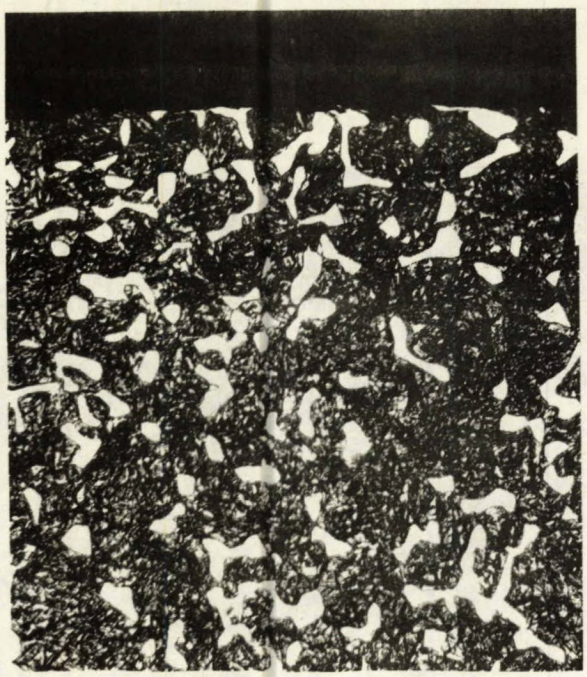


(Mag. X100; Etched in 2% Nital)

Figure 13 - Etched view of the same field shown in Figure 12. (Cone No. 2).

(Mag. X100; Etched in 2% Picral)

Figure 14 - Shows varied microstructure through case. Photomicrograph taken at outer surface of cup. Hardness values from surface inward are Rc 56, 56, 56, 55, 56 and 55. The core hardness was Rc 42. (Cup No. 1).



(Mag. X500; Etched in 6% Nital)

Figure 15 - Shows microstructure present at the corners of the cup. Free carbides in a matrix of martensite. (Cup No. 1).

(Mag. X500; Etched 10 minutes in boiling alkaline sodium picrate)

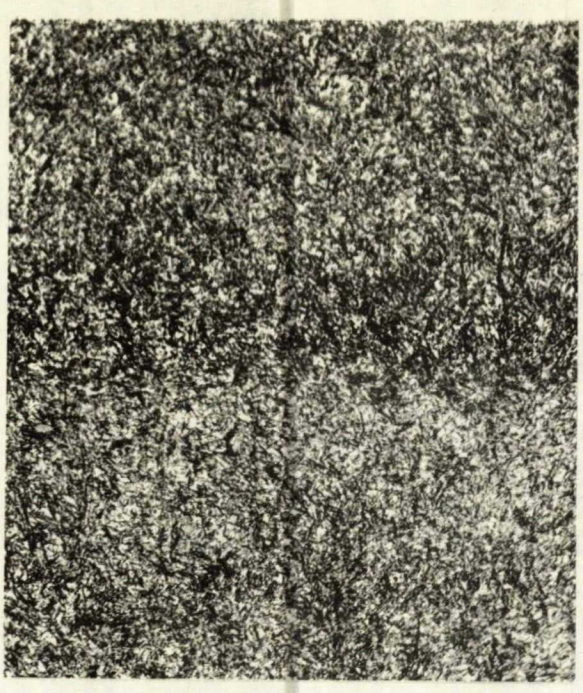
Figure 16 - Shows carbides are removed by etchant. (Cup No. 1).

(Mag. 500; Etched in 6% Nital)

Figure 17 - Shows structure in region of 3rd and 4th hardness impressions (approximately 0.01-inch below surface) of Figure 14. Structure is retained austenite in a matrix of martensite. This area averages about 0.02 inches in depth but varies between 0 and 0.05 inches. (Cup No. 1).

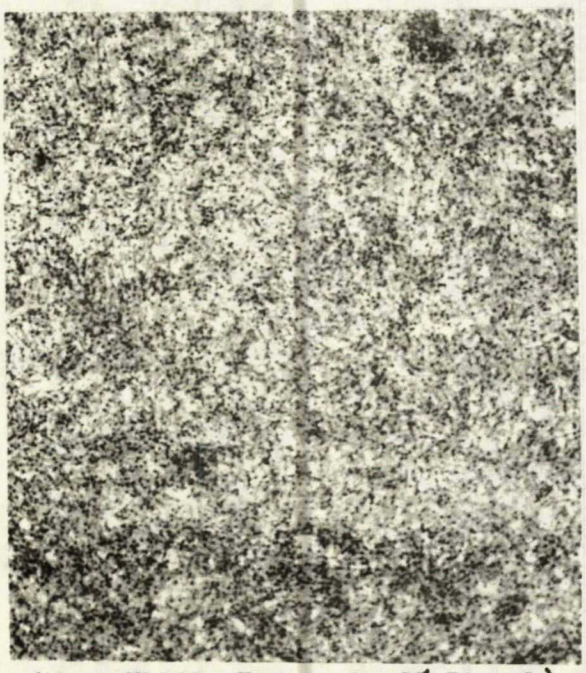
(Mag. X1000; Etched in 2% Picral)

Figure 18 - Shows structure at same depth as Figure 17. The retained austenite in some areas appears to have begun to decompose into martensite (lighter gray plates). (Cup No. 1).



(Mag. X500; Etched in 6% Nital)

Figure 19 - Shows structure at about 0.04-inch below surface (near 6th impression in Figure 14). Structure appears to be tempered bainite. (Cup No. 1).



(Mag. X1000; Etched in 2% Picral)

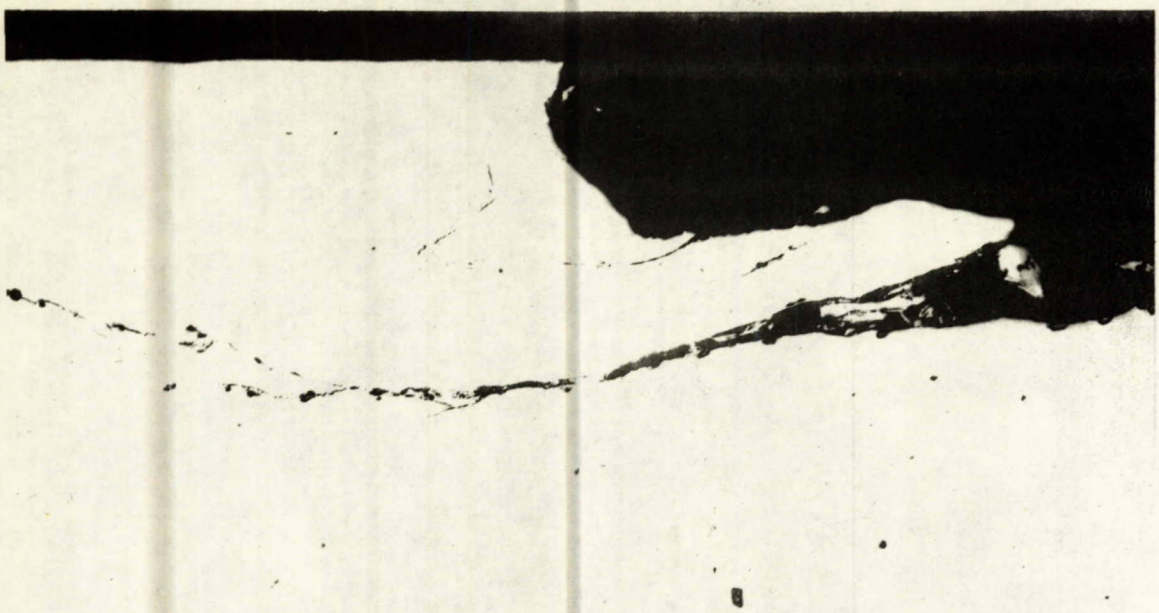
Figure 20 - Shows structure at same depth as Figure 19. (Cup No. 1).

(Mag. X500; Etched in 6% Nital)

Figure 21 - Shows martensitic structure at depth of about 0.08-inch. (Cup No. 1).

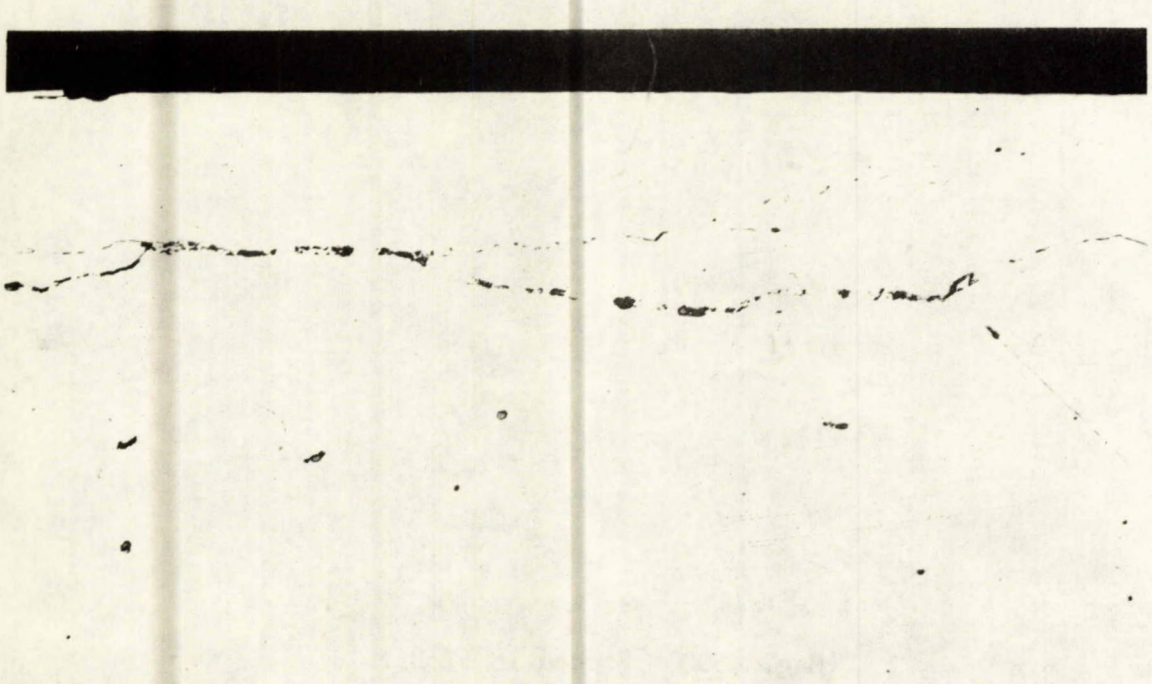
(Mag. X500; Etched in 6% Nital)

Figure 22 - Shows low carbon martensitic structure in core. Picture is at a depth of about 0.25-inch. (Cup No. 1).



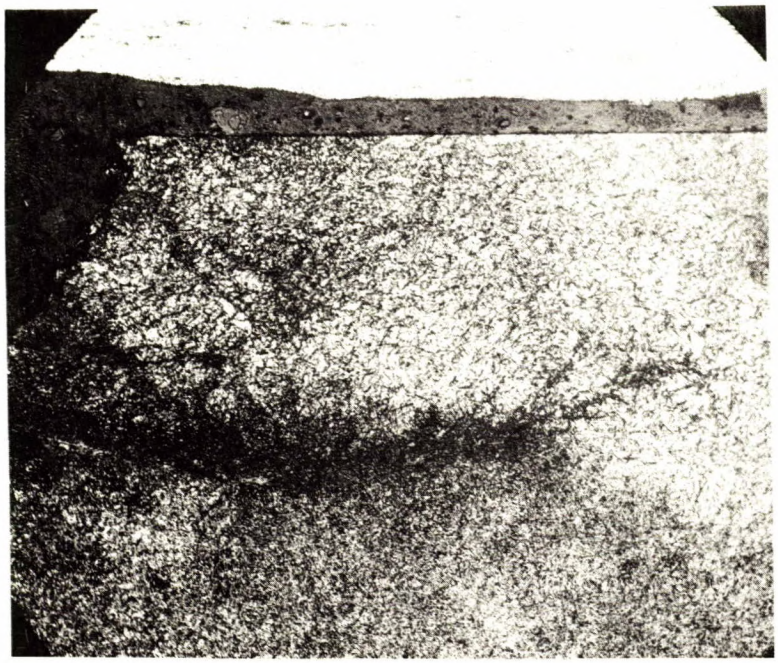
(Mag. X100; As Polished)

Figure 23 - Shows appearance of partial unetched cross-section at the side of the larger spall on the cup race (as in Figure 1 and enlarged in Figure 7). (Cup No. 1).



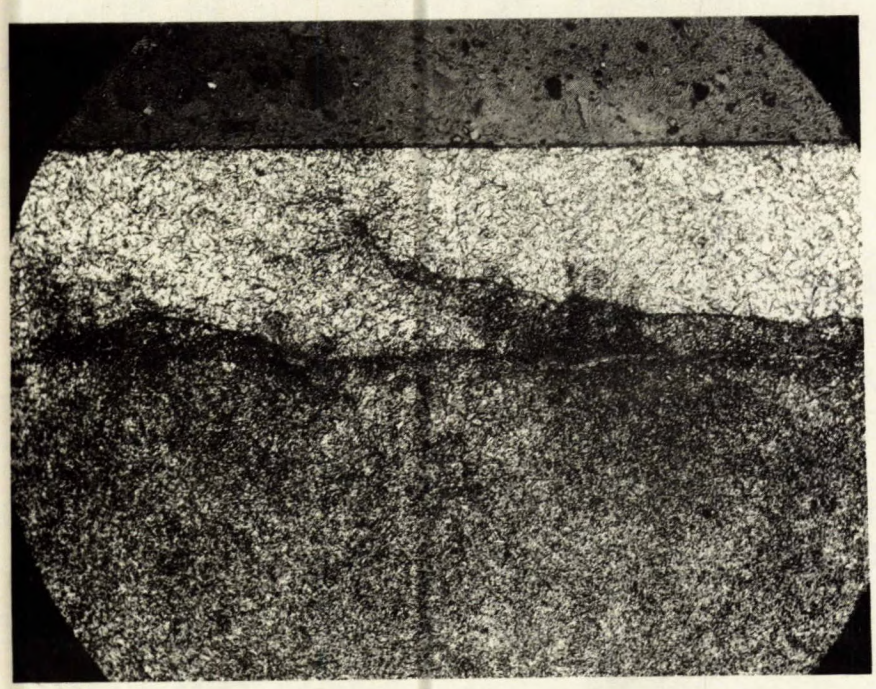
(Mag. X100; As Polished)

Figure 24 - Shows appearance of partial unetched cross-section close to the smaller spall on the cup race. (Cup No. 1).



(Mag. X100; Etched in 2% Nital)

Figure 25 - Shows edge of largest spall. Spall depth seems to be equal to the depth of the retained austenite zone, and cracking seems to follow the layer where the microstructure changes. (Cup No. 1).



(Mag. X100; Etched in 2% Nital)

Figure 26 - Shows area close to smaller spall on cup race. Cracking tends to follow layer where the microstructure changes, i.e. below the zone containing retained austenite. (Cup No. 1).

MAGNAFLUX EXAMINATION

Cup No. 1 was examined by magnaflux techniques to attempt to determine if there was any evidence of overheating during grinding which could explain the presence of retained austenite. No sign of cracking could be found to support this theory.

HARDNESS TESTS

Knoop hardness surveys were carried out on the microsections taken from cones No. 1 and 2, cup No. 1, and a randomly selected roller from bearing No. 1. For this purpose the Tukon Hardness Tester was used with a load of 1000 grams. The results of these surveys (converted to Rockwell "C" units) are plotted in Figure 27.

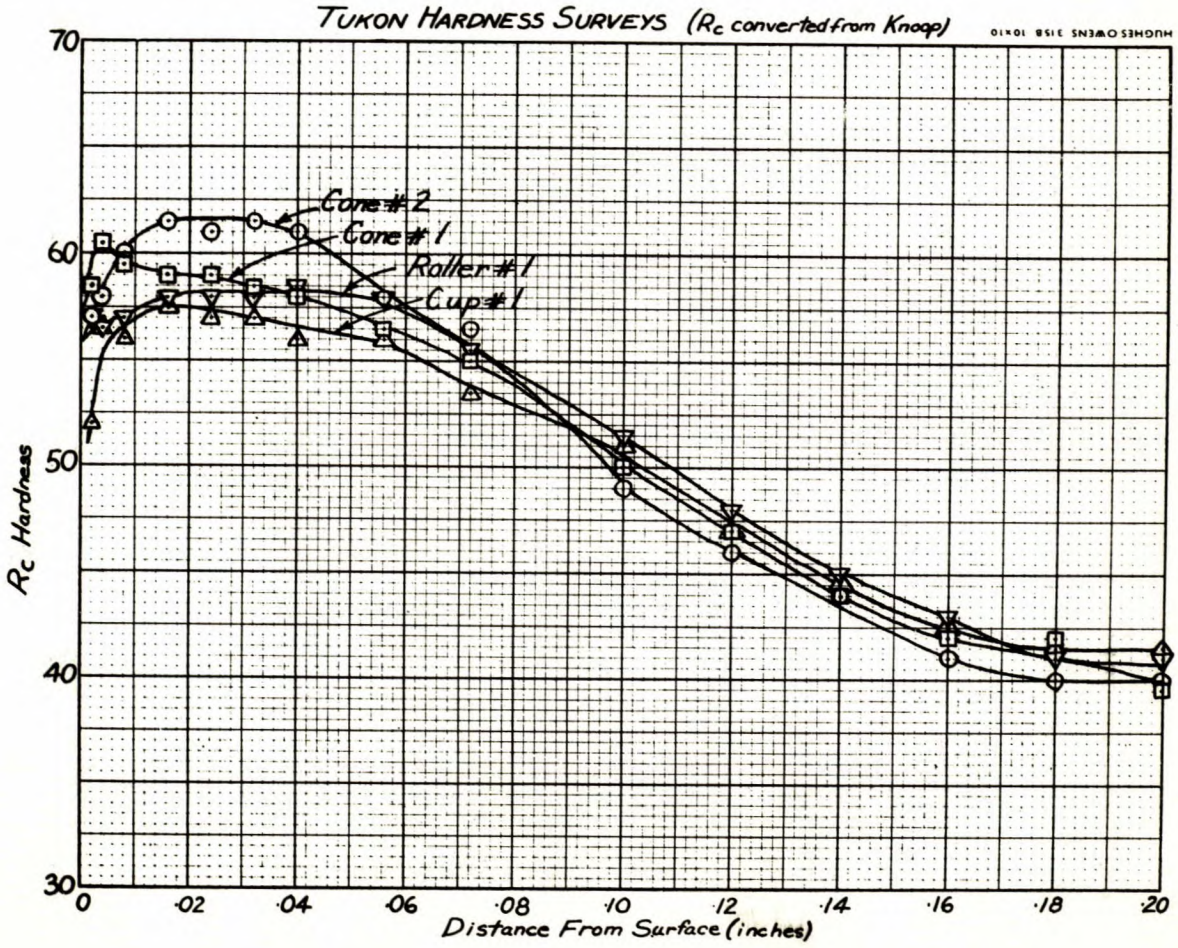


Figure 27 - Results of hardness surveys.

Other samples of cup No. 1 were given hardness surveys after various tempering treatments, and after temper - liquid nitrogen quench treatments. The hardnesses near the surface (0.002-inch below), the hardness peaks, and the indicated core hardnesses are given in Table 3 (converted to Rc units). The distance below the surface at which the hardness peak occurred varied due to variations in the depth of the zone containing retained austenite.

Table 3

Summarized Results of Hardness Surveys on Tempered And Tempered and Liquid Nitrogen Quenched Samples

Sample	Rockwell "C" Hardnesses		
	Hardness near surface	Hardness peak	Core hardness
As received	52	57.5	41.5
As received (B)	56	59	41.5
As received -Q (B)	57	59	
220°F (B)	57.5	59	42
220-Q (B)	61	63	
300°F (B)	54.5	57	42
300-Q (B)	61	62	
400°F (B)	54	58	42
400-Q (B)	57.5	59	42
700°F (B)	50	53	40.5
700-Q (B)	50	53	

NOTE: - Tempering time - ½ hour
- Q - Quenched in liquid nitrogen
(B) Mounted in bakelite, and therefore subjected to about 300°F for around 2 minutes.

DISCUSSION

Chemical analyses of the parts revealed them to be within the chemical limits of SAE 3310 steel, except for the slightly high nickel content of cone No. 1. This high nickel content is of no significance regarding the reason for failure.

The general appearance of the corrosion product on the outside diameter of the cup was similar to that found when fretting occurs. X-ray identification showed the corrosion product to be a typical fretting product. The outside diameter appeared to have been roughened considerably at the areas showing the corrosion product.

No microstructural damage was associated with numerous smooth-bottomed indentations seen in the raceways. The formation of fragments, rather than seizing, is characteristic of the failure of hard materials in such applications. The writer concurs with Dr. Smith's opinion that the indentations are due to the debris travelling in the raceways.

The metallographic examination and hardness surveys for both cone samples and the representative roller sample revealed normal carburized - quenched structures. The spalling and cracking was not related to the microstructures of these parts.

The examination of the one cup sample available showed it to have an abnormal microstructure. The presence of excess carbides at the corners of the part (Figure 15), and the absence of this condition in the cone samples, indicated that the cup may have been carburized to a higher surface carbon content. The presence of a layer, of varying depth, of retained austenite (Figures 17, 18) was the major microstructural difference. Examination of Figure 18 reveals some light etching, untempered martensite, as well as the dark etching needles. The light etching

martensite probably formed by decomposition of some of the retained austenite some time after the final fabrication, probably in service. Such an effect would be responsible for considerable distortion. Under this circumstance spalling and cracking can be definitely related to the microstructure of the case. The spalls tend to penetrate in depth, to the junction of the retained austenite zone with the area having a normal microstructure. Figures 25 and 26 illustrate that the cracks related to the spalling in general follow the above junction.

Negative results in magnaflux tests made on the cup indicate that the retained austenite was present in the original part and not caused by faulty grinding or overheating in service.

The hardness surveys showed the cup sample to have the softest case. This softer case was shown to result from the presence of the soft austenite phase. Hardness surveys after tempering, and temper - liquid nitrogen quench treatments, demonstrated a hardness increase due to the quench even after tempering for ½ hour at 400°F. Up to this tempering temperature there was no change in the core hardness. Thus, tempering the part at 300 or 400°F would have made the structure much more stable with no sacrifice in hardness. The increase in hardness caused by tempering at 220°F for ½ hour, or even the tempering due to mounting the sample in bakelite, show that the part was probably put into service in the as-quenched condition with little or no stress relief.

CONCLUSIONS

The results of the investigation indicate that the primary cause of the spalling, at least in the case of bearing No. 1, was the presence of retained austenite in the microstructure. This retained austenite started to transform to martensite subsequent to manufacture

of the bearing and caused sufficient distortion of the cup so that, fretting on the outside diameter, and spalling of the raceways occurred. The spalled fragments then travelled in the raceways and caused the numerous small indentations.

The reason for the presence of retained austenite is not clear from the results of this investigation. No details of the processing of the part were available. It is probably due to a difference in the carburizing or quenching treatment applied. It would appear that tempering the part at 400°F would have stabilized the structure considerably with no sacrifice in hardness.

The presence of retained austenite in carburized components for this service should be avoided, or minimized by adequate stress relief subsequent to hardening of the case.

RFK:lh