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MEMORANDUM REPORT ARCCB-MR-00007

A FRACTOGRAPHIC STUDY OF A CIRCA AD83 ROMAN NAIL

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MAY 2000

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2000	Final

4. TITLE AND SUBTITLE

A FRACTOGRAPHIC STUDY OF
A CIRCA AD83 ROMAN NAIL

5. FUNDING NUMBERS

PRON No. ALLIANTTECH

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army ARDEC
Benet Laboratories, AMSTA-AR-CCB-O
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER

ARCCB-MR-00007

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Submitted to *Ironmaking and Steelmaking (UK)*

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Results are presented of a scanning electron microscope fractographic study of a circa AD83 iron nail from the Roman fortress at Inchtuthil, Perthshire, Scotland. The fracture surface studied was created under embrittling conditions of low temperature, an added stress raiser, and high strain-rate loading. Fractographic features are discussed in relationship to the classic cataloguing and metallographic examination of the Inchtuthil nails in earlier work by Angus, Brown, and Cleere.

14. SUBJECT TERMS

Scanning Electron Fractography, Roman Nail,
Iron, Roman Fortress

15. NUMBER OF PAGES

10

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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ACKNOWLEDGEMENT

The authors are pleased to acknowledge the help and encouragement of Dr. Anthony P. Parker of Cranfield University, Swindon, England.

INTRODUCTION

The subject nail was from a store of several hundred thousand discovered in a 4-m deep pit at the Roman legionary fortress at Inchtuthil, Perthshire, Scotland. A sample of these iron nails was catalogued and examined in a paper by Angus *et al.* (ref 1). Microstructure, chemical composition, size and configuration, hardness, and methods of manufacture were described in detail in the previous work. However, the publication of Reference 1 in 1962 predated commercially available scanning electron microscopes. At that time, high-resolution fractography could only be accomplished through the tedious task of replication followed by transmission electron microscopy; accordingly, no fractographic illustrations were presented. This current study uses the scanning electron microscope to document the fracture surface of one nail broken under embrittling conditions: low temperature, an added stress riser, and high strain-rate loading.

RESULTS

Measuring about 84-mm long with a disk-shaped head, the nail corresponded to one of group "D" as classified in the previous work. Figure 1 shows the as-received nail at 1X magnification, and reveals the roughly rectangular shape of the nail shank and the surprisingly light surface oxide layers discussed in the previous work.

The nail was rinsed in acetone to remove loose surface debris; however, the red-brown surface oxide seen in Figure 1 persisted. After introducing a transverse notch with a 0.5-mm thick cutting wheel, the nail was submerged in a liquid nitrogen bath until boiling had subsided (indicative of stabilization to liquid nitrogen temperature). It was quickly locked into a vise, and easily broken into two pieces with a light hammer blow. The two sections were immediately placed into a room-temperature alcohol bath to preclude fracture surface oxidation by surface condensate. The notch had a depth of about 0.5 mm, and was located about 19 mm from the nail head, where the rectangular shank cross section measured about 5 mm by 5 mm. This resulted in a notch depth of about one-tenth of the shank thickness.

Figure 2 is a view normal to the fracture surface, and it shows that only a small portion of the laboratory-created fracture surface had initiated at the introduced notch, indicated by the letter "N." Most of the fracture had started at a preexisting transverse corner defect, "C." A preexisting longitudinal fissure, "FF," separates the laboratory-created fracture area that initiated at the corner defect and the area that initiated at the introduced notch. The preexisting corner defect and fissure were coated with a black (high-temperature) oxide, and they have a similar appearance to the internal defects seen in a longitudinal metallographic cross section of a group "D" nail shown in Figure13 of Reference 1. Figures 3 and 4 (from locations shown in Figure 2) are from the oxide covered preexisting corner defect and the "clean" laboratory separation, respectively. The oxide obscures most other features in Figure 3. Figure 4 shows typical low-temperature transgranular cleavage, consistent with cleavage of sound, homogenous steel. Figure 5 is from a region most remote from the crack origin, and again shows transgranular cleavage, and a thin lip of tear dimples, "D."

Figures 6 through 10 are from the laboratory-created fracture surface that initiated at the introduced notch, with the locations of Figures 7 through 10 noted in Figure 6. Figures 7 and 8, at 1000X and 5000X, respectively, show areas of transgranular cleavage immediately adjacent to the notch. Figure 9 shows curved river lines, "R," indicative of transgranular cleavage through preexisting cold worked metal adjacent to the notch, while Figure 10 shows oxide, "O," and small voids, "V," associated with the preexisting longitudinal fissure, "FF."

CONCLUDING REMARKS

This study shows that fracture of this nail under embrittling conditions occurred by typical low-temperature transgranular cleavage, consistent with what would be observed in present-day steel. However, the defects that are present due to poor workmanship during forging, discussed in Reference 1, are seen to have considerable control over the fracture behavior of the nail. These defects could have resulted in the failure of some of these nails by cleavage fracture, especially when improperly driven at low temperature.

REFERENCES

1. Angus, N.S., Brown, G.T., and Cleere, H.F., "The Iron Nails from the Roman Legionary Fortress at Inchtuthil, Perthshire," *Journal of the Iron and Steel Institute*, November 1962, pp. 956-967.

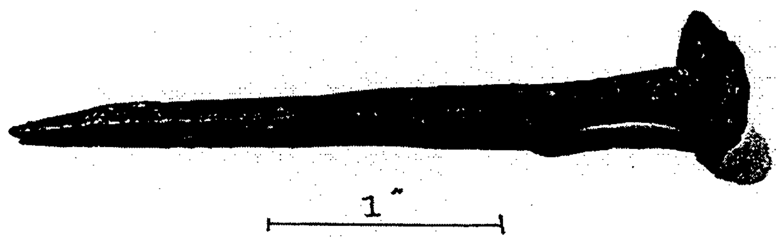

Figure 1. A group "D" nail from the Roman fortress at Inchtuhil (1X).

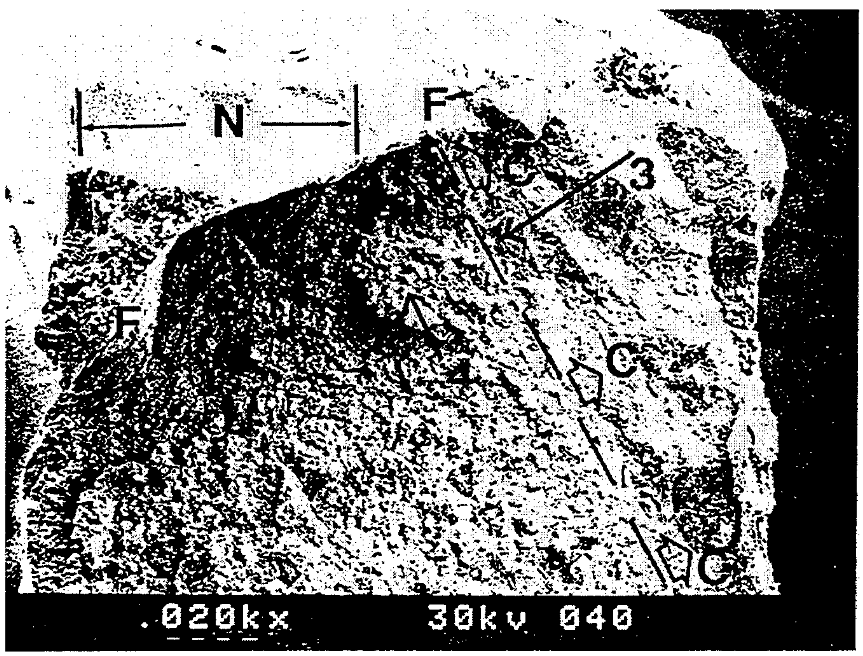

Figure 2. Transverse fracture surface showing notch, corner defect, and fissure (20X).

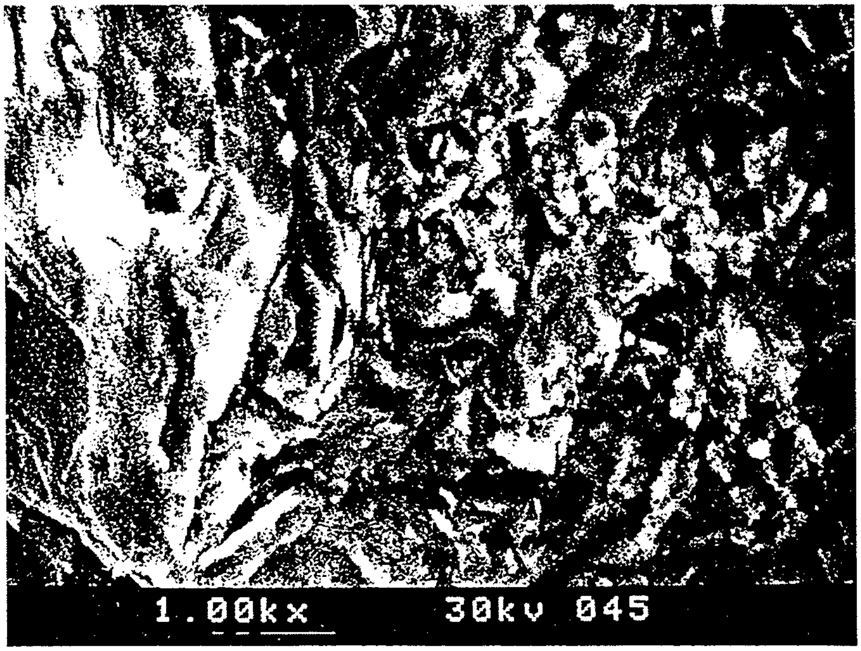

Figure 3. Oxide layer on preexisting corner defect (1000X).

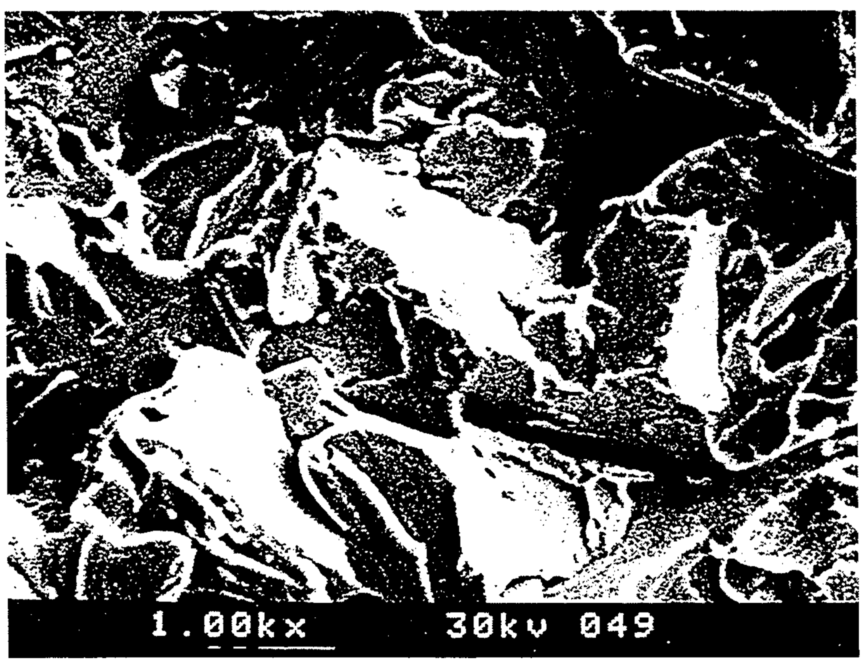

Figure 4. Low-temperature transgranular cleavage near crack origin (1000X).

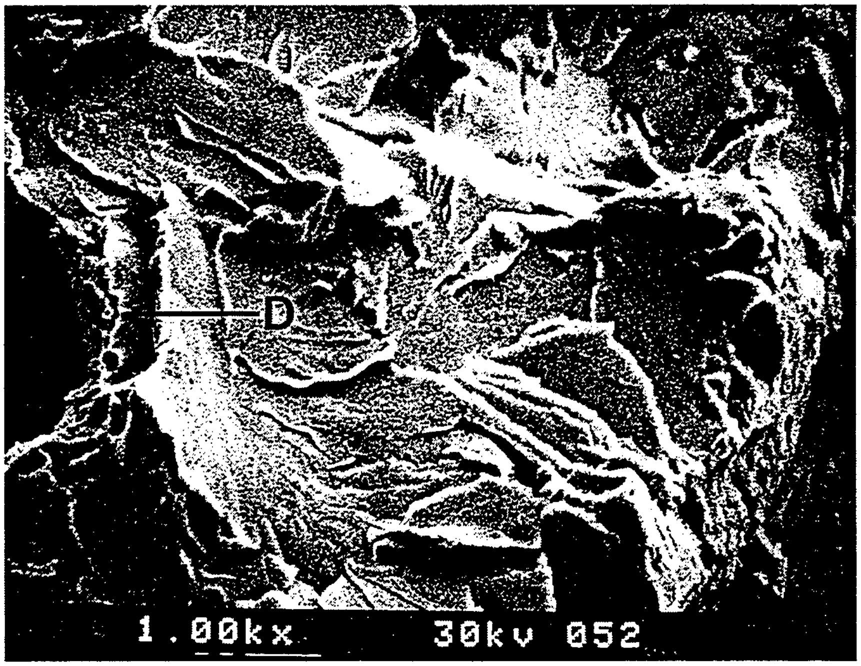

Figure 5. Low-temperature transgranular cleavage remote from crack origin (1000X).

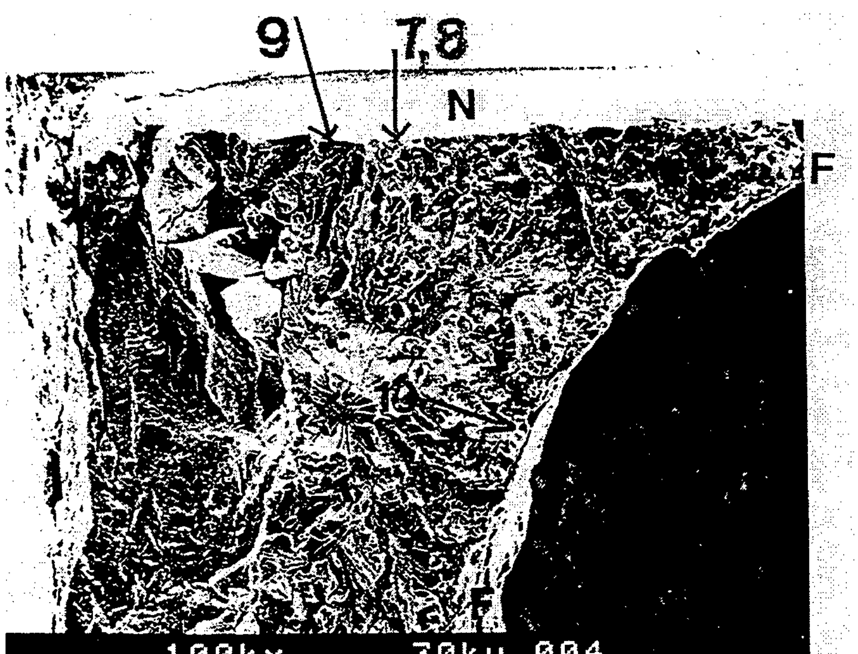

Figure 6. Transverse fracture surface near the laboratory-induced notch (100X).

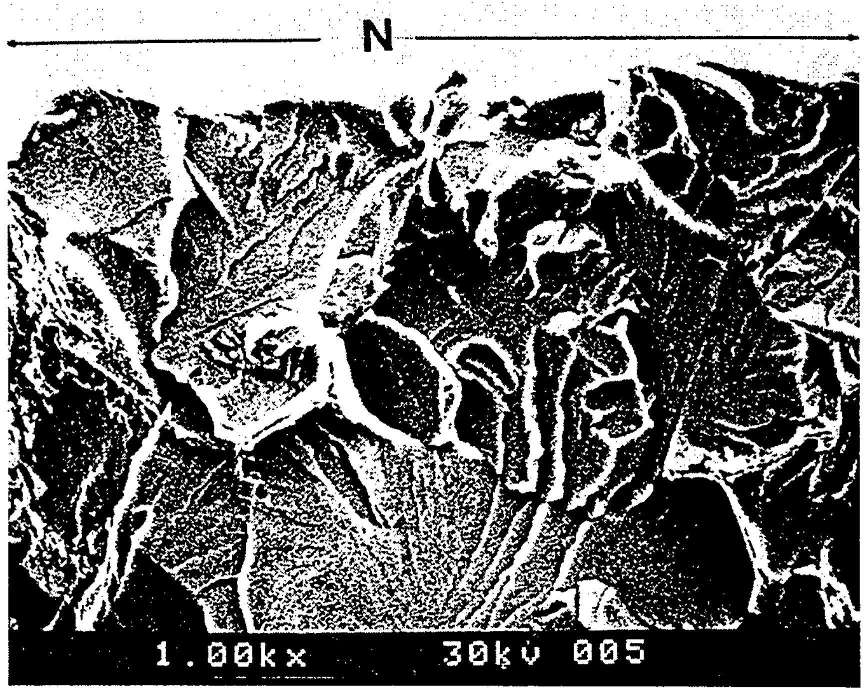

Figure 7. Low-temperature transgranular cleavage adjacent to notch (1000X).

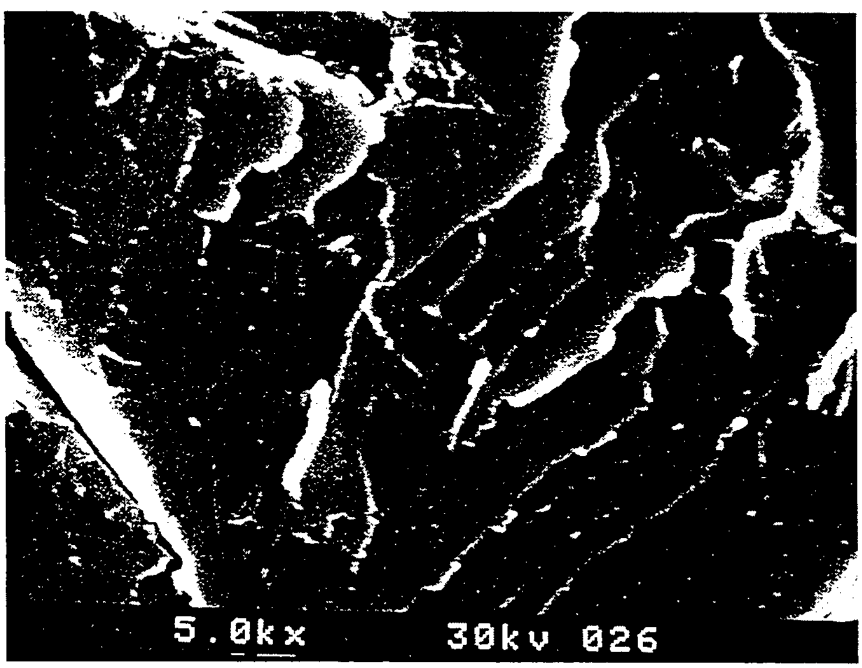

Figure 8. Low-temperature transgranular cleavage adjacent to notch (5000X).

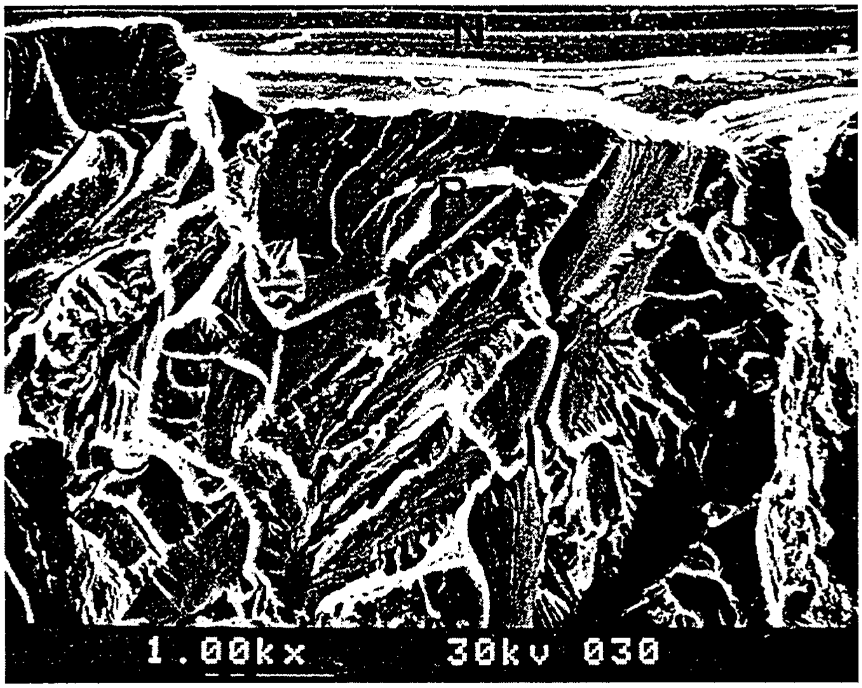

Figure 9. Curved 'river lines' indicating cold-worked metal (1000X).

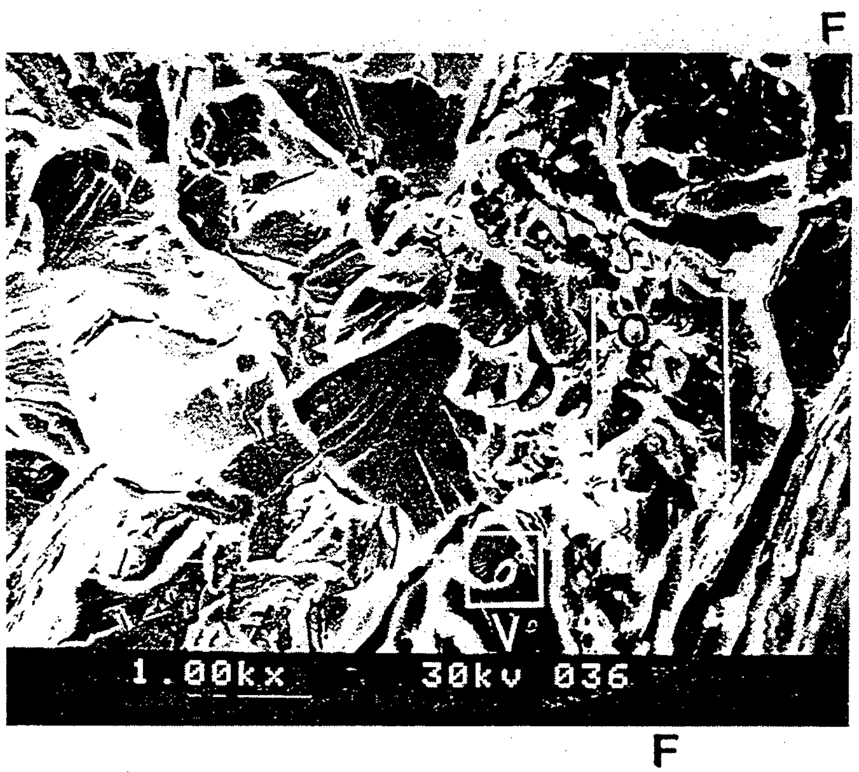

Figure 10. Oxide and voids indicating the preexisting fissure (1000X).

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