Ford Motor Company

**Automotive Safety Office**
**Environmental and Safety Engineering**

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NVS-210
2004 JUN 14 P 3:12
OFFICE OF DEFECTS INVESTIGATION

June 8, 2004

Mr. Richard Boyd, Chief
Medium and Heavy Duty Vehicle Division
Office of Defects Investigation Safety Assurance
National Highway Traffic Safety Administration
400 Seventh Street, S.W.
Washington, DC 20590

Dear Mr. Boyd:

Subject: PE04-010:NVS-214jry

Ford Motor Company (Ford) is providing the attached final report of the material analysis of the fractured axle shaft from the Maryland State Police vehicle (VIN 2FAFP71W53X154365) that was provided to us by your office. Preliminary results were reviewed with a representative of your office in May 2004.

The analysis determined that the axle shaft fractured as a result of a groove worn into the bearing race portion of the shaft. Evidence suggests the fracture occurred while the axle was at a temperature high enough to reform the structure of the shaft material. Analysis conducted outside the fracture area indicates that the axle met specification requirements for effective case depth, core hardening, and chemical composition. The surface hardness outside the fracture area is slightly below specification – it is not known if the heat generated at the fracture location affected the surface hardness elsewhere on the shaft. Ford does not believe the reported axle shaft fracture is related to the measured surface hardness noted above.

If you have any questions concerning this response, please feel free to contact me.

Sincerely,

R.A. Nevi

R. A. Nevi
Manager,
Production Vehicle Safety & Compliance

Attachment

**Central Laboratory**
15000 Century Drive
Dearborn, MI 48120-1267
FAX (313) 322-1614

**Report 40945**

May 25, 2004

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|---|---|---|---|
| ***To:*** | T. Covert | (313) 59-41522 | (313) 84-54023 FAX |
| ***From:*** | R. Van Stratton-Kirk | (313) 24-87844 | |

***Subject:*** Axle Shaft Left
Part Number: 3W1W-4234-
Vehicle Vin: 2FAFP71W63X[redacted]
Specification: Engineering Drawing Provided
Supplier: Visteon

***Received:*** One fractured left axle shaft was received on May 6, 2004.

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***Object:*** Determine the cause of failure. Determine if the shaft meets the print requirements.

***Conclusion:*** The axle shaft fractured through a groove worn into the bearing race. The fracture appears to have occurred by single event ductile torsional shear. Oxidation and reformed structure suggest that the fracture occurred while the axle was at high temperature (~1400°F minimum).

Analysis was done outside the fracture area due to the extreme heat deformation at the fracture site. This analysis indicates that the axle satisfies specification requirements for effective case depth, core hardening, and chemical composition. The surface hardness outside the fracture area is slightly below the specification.

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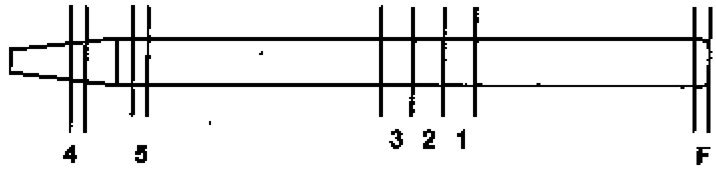
***Data and Analysis:***

<u>Visual Examination</u>

The axle shaft fractured through the bearing race inboard of the flange (Figures 1 through 3). The bearing wore a groove into the shaft approximately 2 mm deep (Figures 2 and 3). The fracture occurred through this groove. The surfaces of the bearing race, groove, and fracture exhibit a blue-grey discoloration suggesting high temperature oxidation (probably from frictional heating). The fracture faces are relatively flat and exhibit circular smeared patterns typical of single event ductile torsional shear (Figures 4 and 5).

Metallographic Analysis
(ASTM E 3, E 45, and E 407)




The drawing above represents the sections taken out of the axle shaft (Figures 6-8).

**F (Fracture)** – Sample was cross-sectioned and the pieces were mounted transversely and longitudinally for microstructure and Microindentation hardness evaluation.
**Part 1** – Sample was cross-sectioned and the pieces were mounted transversely and longitudinally for microstructure and Microindentation hardness evaluation.
**Part 2** – Sample used for elemental analysis.
**Part 3** – Sample used to measure the Brinell hardness in the core.
**Part 4** – Sample used to measure effective case depth by microindentation hardness.
**Part 5** – Sample used to measure surface hardness.

Table 1 (Figure 9): Inclusion Rating

| | Worst Field Inclusion Rating (ASTM E 45, Method A) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Type A | | Type B | | Type C | | Type D | |
| | Thin | Heavy | Thin | Heavy | Thin | Heavy | Thin | Heavy |
| **Part 1** | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Fracture** | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

There are worked-in oxides below the surface of the worn in groove (Figures 10-11). Oxide layers are present along the fracture face and surfaces near the fracture (Figures 12-13), but not on the surfaces away from the fracture (Figure 14).

The Fracture and Part 1 were etched in 3% Nital for microstructure analysis. The induction-hardened microstructure of Part 1 consists of martensite (Figures 15-16). The microstructure of the core of Part 1 consists of banded ferrite and pearlite (Figure 17-18). The surface and core in the area of the fracture exhibits microstructures of ferrite and pearlite (Figures 19-23). There is no evidence of the induction hardened zone left. This suggests that the fracture area had been heated above the austenization temperature (~1400°F minimum) and cooled.

The presence of oxide layers on the worn surface and fracture face, along with the reformed structure suggest that the fracture occurred while the shaft was at high temperature (~1400°F minimum).

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Mechanical and Microindentation Hardness Testing[1]
(ASTM E 384, E 140, E 18, E 10)

Brinell and Rockwell hardnesses were measured on Parts 3 and 5. Part 3 was used to determine a measurement of the core hardness, while Part 5 was used for a measurement of the surface hardness.

Table 2: Core and Surface Hardness

| | Hardness Reading | Specification |
|---|---|---|
| **Part 3** | 293, 285 HB | 207-341 HB |
| **Part 5** | 58*, 57*, 57*, 56*, 58*, 57* HRC | 60 HRC |

*does not meet the specification requirement

A Clemex Vision image analysis system was used to perform a microindentation hardness traverse ($HK_{500}$) on Parts 1 and 4 to determine the effective case depth at 40 HRC. The hardness 50 µm below the surface was also measured using the Clemex system.

Table 3: Surface Hardness and Effective Case Depth

| | Hardness 50µm below the surface | Effective Case Depth (in) |
|---|---|---|
| **Part 1** | 52* HRC | ~0.181 |
| **Part 4** | 57* HRC | ~0.185 |
| **Specification** | 60 HRC | 0.120-0.350 |

*does not meet the specification requirement

[1] Statement of Precision and Accuracy: The error of $HK_{500}$ readings, as defined by ASTM E 384, has been determined to be -3% when the average of 45 readings performed on a standard test block was compared to the published average for that block. The variability of these readings has been determined with 95% confidence (±2s) to be ±3%.

Elemental Analysis, weight percent
(ASTM E 415)

Table 4: Elemental Analysis

| | Axle | Variability #[2] | Specification |
|---|---|---|---|
| Carbon | 0.51 | 0.02 | 0.47—0.55 |
| Manganese | 0.93 | 0.03 | 0.8—1.10 |
| Phosphorus | 0.02 | 0.005 | 0.030 max. |
| Sulfur | 0.02 | 0.006 | 0.035 max. |
| Silicon | 0.28 | 0.03 | |
| Copper | 0.02 | 0.01 | |
| Nickel | 0.01 | 0.02 | |
| Chromium | 0.08 | 0.02 | |
| Vanadium | <0.01 | 0.002 | |
| Molybdenum | 0.05 | 0.01 | |
| Aluminum | 0.03 | 0.004 | |
| Titanium | <0.01 | 0.002 | |
| Zirconium | <0.01 | 0.002 | |
| Niobium | <0.01 | 0.006 | |
| Tin | <0.01 | 0.001 | |
| Lead | <0.01 | -- | |
| | | | |
| Iron | Base | | Base |

*Note: Manganese requirement has been modified.*

Concur: [signature]

Allen Radke, Supervisor
Metallurgy & Mechanical Testing

By: [signature]

Rachel Van Stratton-Kirk (RVANSTRA)

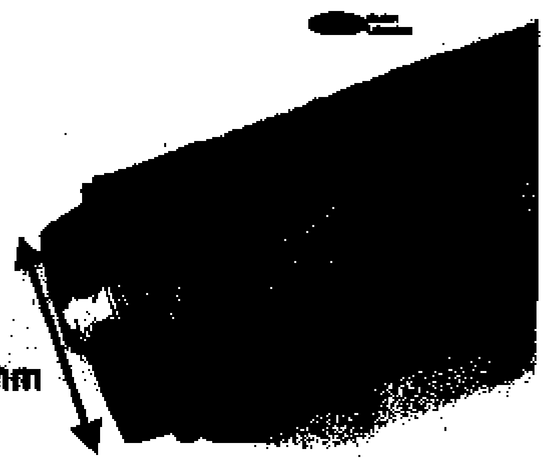
Enclosures: Figures 1-23

*Note: Fracture mount given to NHTSA*

2 Variability is ± 3 standard deviations of >100 measurements of NIST-traceable standards.

*As Received*

*Figure 1: Shaft as received*




*As Received* *~1.06x*

*Figure 2: Worn surface on the shaft near the fracture*

Note: Nominal magnifications given for photomicrographs.

*As Received*

*Figure 3: Fracture surface and worn area*

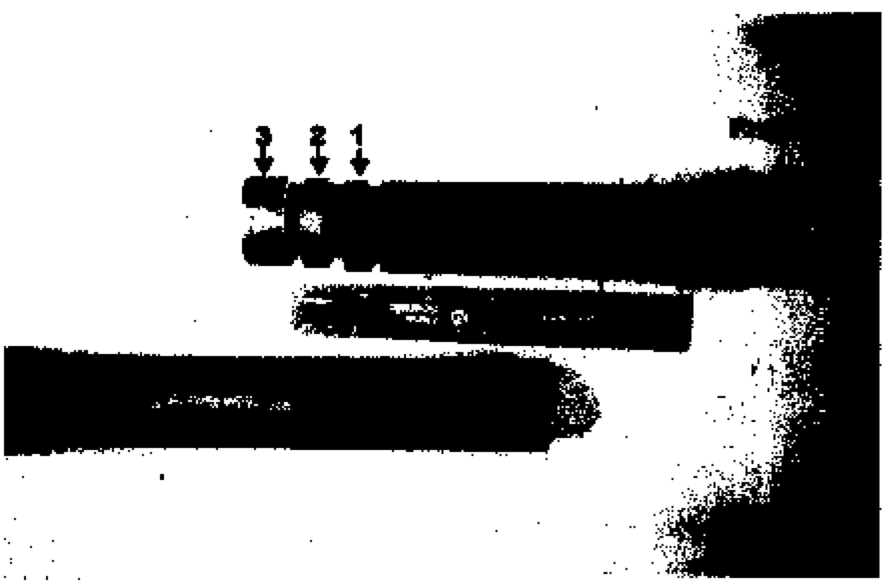
*As Received*

*Figure 4: Fracture surface*

Note: Nominal magnifications given for photomicrographs.

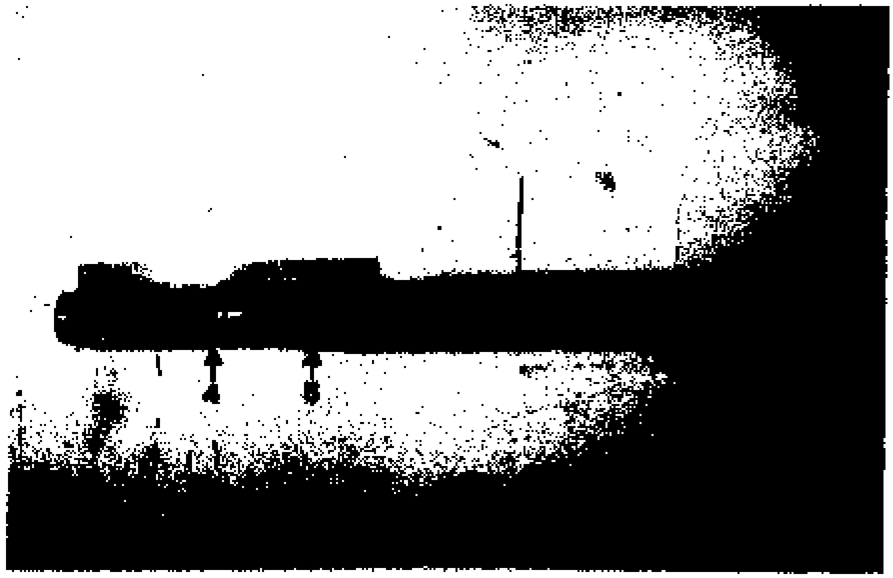
*As Received*

*Figure 5: Fracture surface*




*As Received*

*Figure 6: Sections taken out of the shaft: F (Fracture), 1, 2, & 3.*



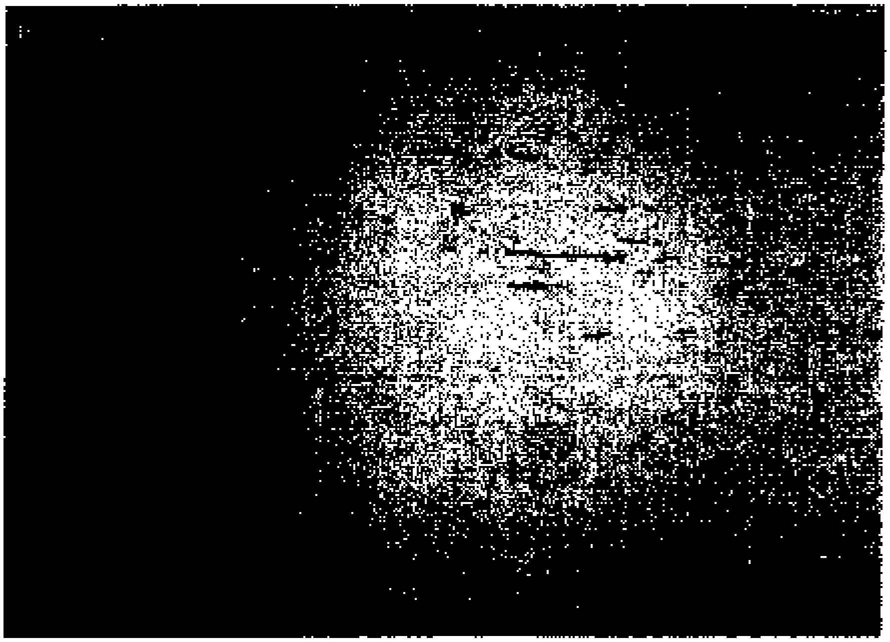

*As Received*

*Figure 7: Sections taken out of the shaft: 4 & 5.*

*As Received*

*Figure 8: Parts sectioned for microstructure analysis. The left piece is the shaft Fracture surface and the right piece is Part 1.*

Note: Nominal magnifications given for photomicrographs.



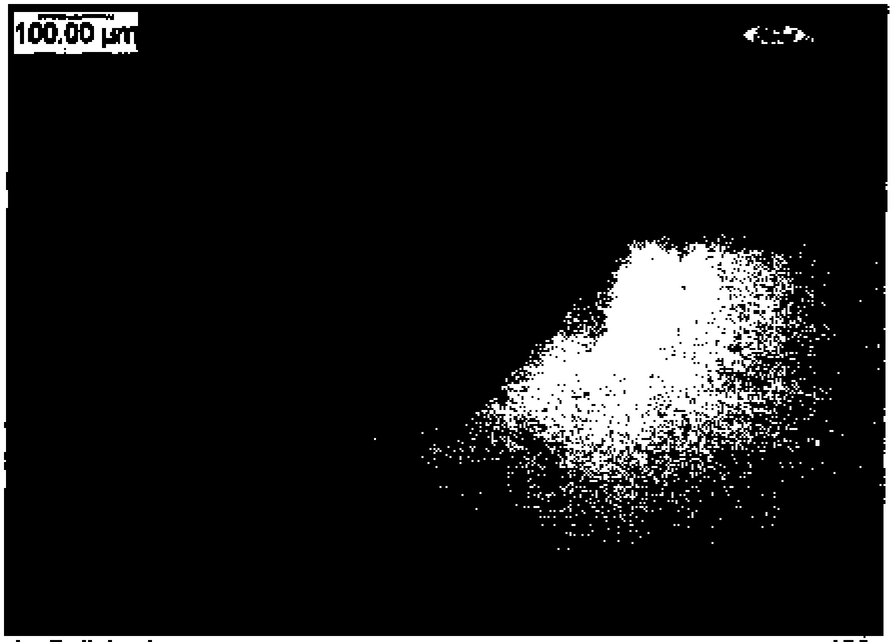
*As Polished*

*Figure 9: Photo showing the inclusions in the shaft from Part 1.*


*As Polished* *~1.6x*

*Figure 10: Photo of cross-section of the Fractured area showing the worn surface.*

Note: Nominal magnifications given for photomicrographs.



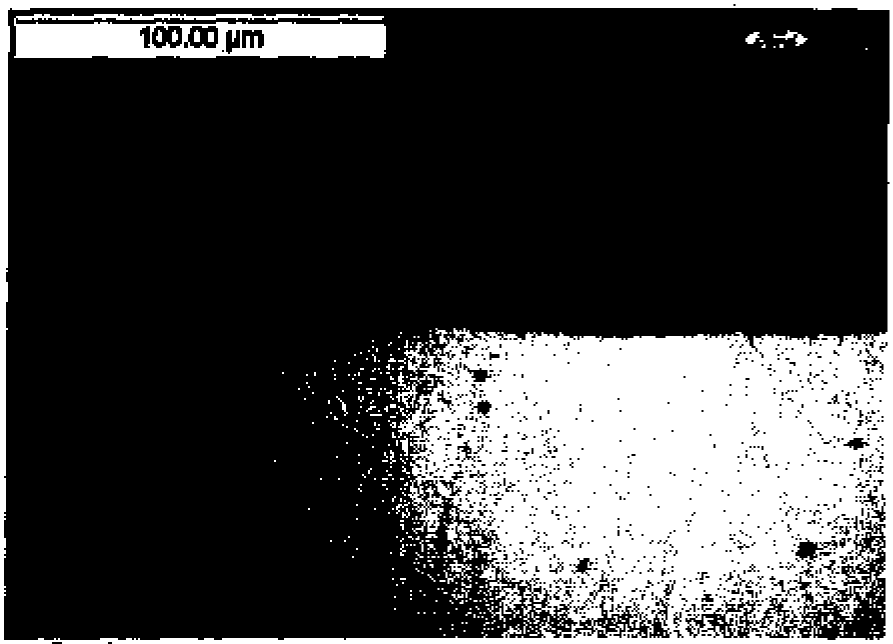

*As Polished* *100x*

*Figure 11: Magnified view of the worn surface.*


*As Polished* *100x*

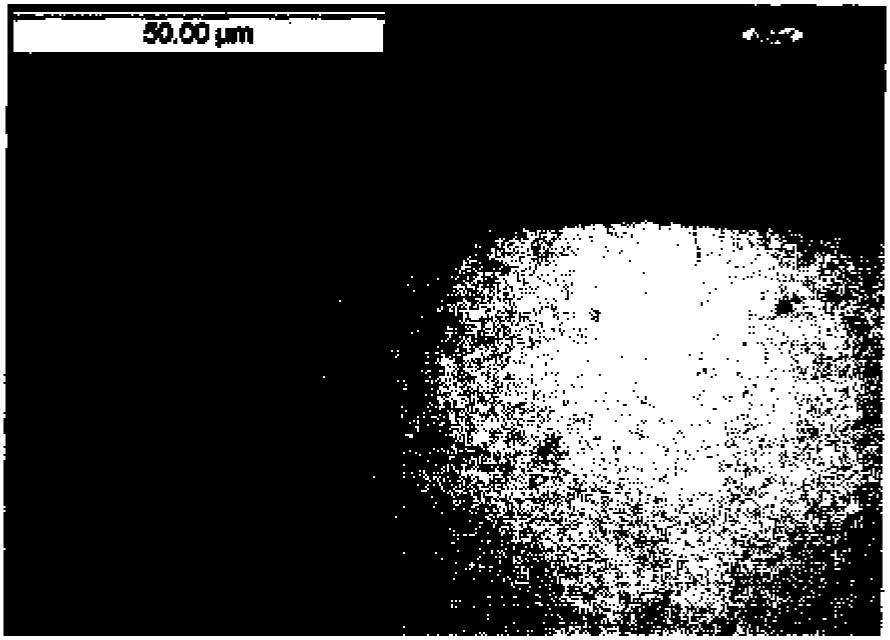
*Figure 12: Photo of the Fracture surface showing the oxides present.*

Note: Nominal magnifications given for photomicrographs.




As Polished 500x

Figure 13: Worn surface showing oxides present.




As Polished 1000x

Figure 14: Photo showing the surface of the axle shaft away from the fracture.


*Nital* *~1.6x*

*Figure 15: Photo showing induction-hardened area on Part 1.*

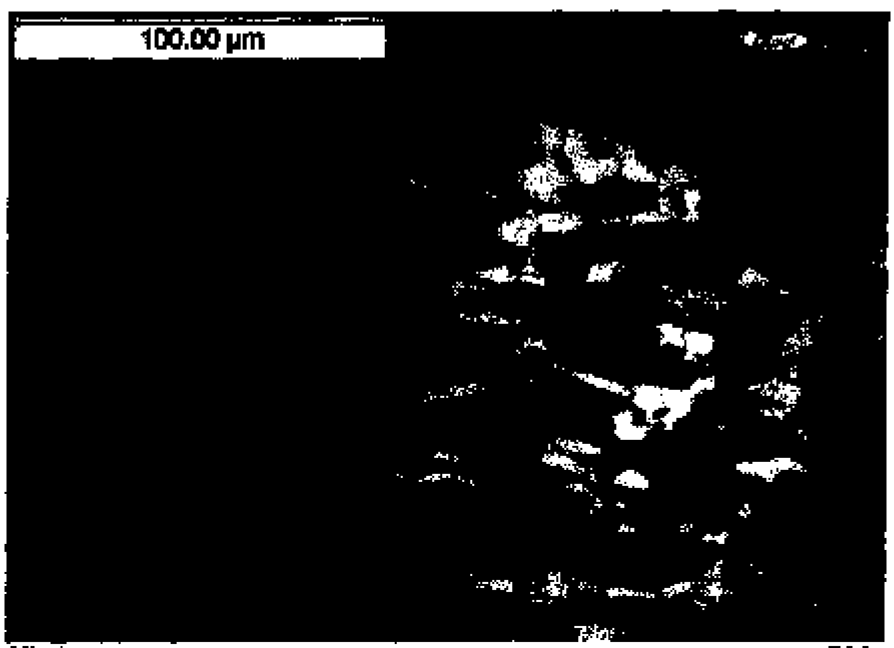

*Nital* *200x*

*Figure 16: Microstructure of the induction-hardened area from Part 1.*

Note: Nominal magnifications given for photomicrographs.


*Nital* *200x*

*Figure 17: Core microstructure of Part 1.*

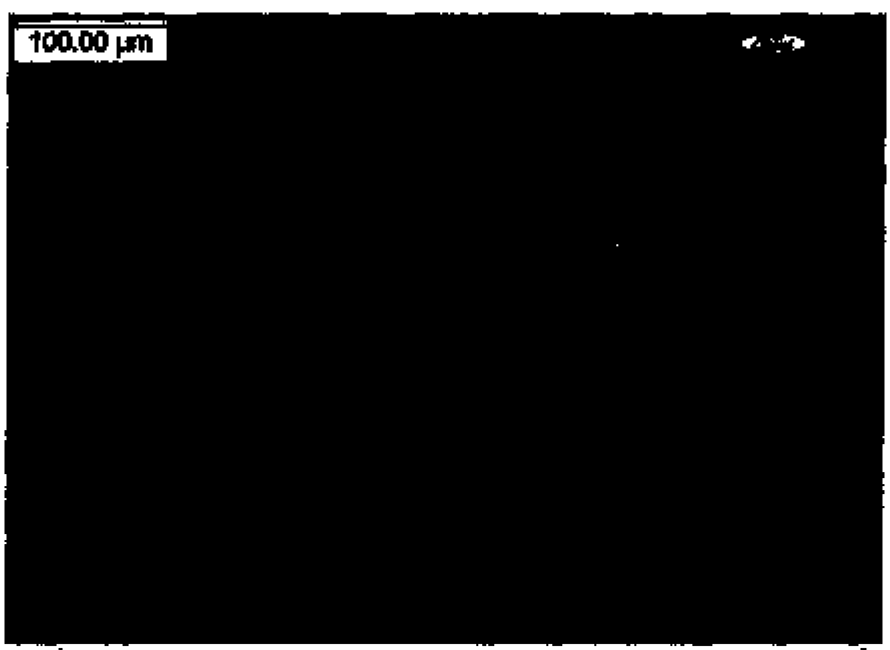



*Nital* *500x*

*Figure 18: Core microstructure of Part 1.*


Nital ~1.6x

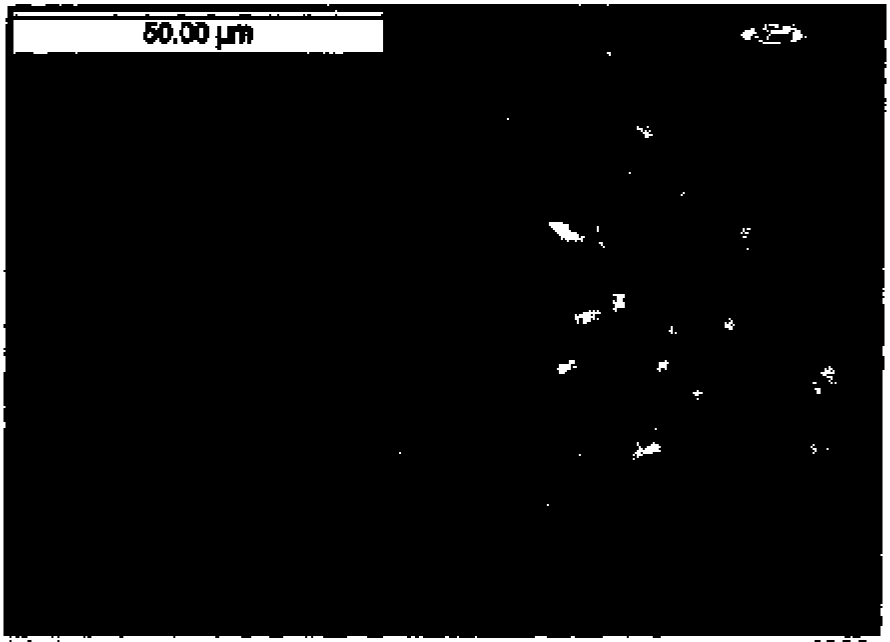
*Figure 19: Photo showing that there is no longer an induction hardened area near the Fracture surface.*




Nital 200x

*Figure 20: Photo showing the microstructure near the Fractured surface.*

Note: Nominal magnifications given for photomicrographs.



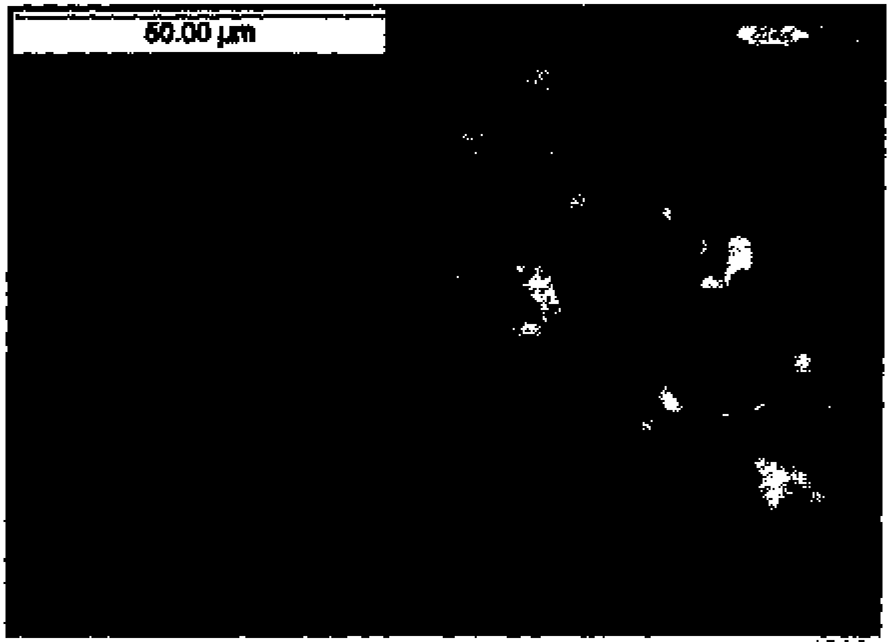

*Nital* *1000x*

*Figure 21: Photo showing the microstructure near the Fractured surface.*


*Nital* *20x*

*Figure 22: Photo showing the core microstructure of the Fractured part.*

Note: Nominal magnifications given for photomicrographs.




Nital 1000x

*Figure 23: Photo showing the core microstructure of the Fractured part.*