

## Failure Analysis of an Automotive Component (Cardan Yoke) by Scanning Electron Microscopy

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**Abstract.** Two SAE 1541 (0.39%C; 1.44%Mn; 0.23%Si; 0.16%Ni; 0.16%Cr) carbon steel cardan yokes that were forged, machined, quenched and tempered, as part of the manufacturing process to ensure long term operation under specific loading conditions, failed during its manufacture. The cardan yokes ruptured in the bearing seat region while these were being straightened by bending. This study deals with fracture analysis that was carried out by visual inspection and scanning electron microscopic examination. The focus of this study was to investigate the fracture mechanism associated with the failures. Fractographs of the broken components indicated that the rupture initiated at the edges of the component, from preexisting cracks, due to the bending stresses during the straightening process. The initial stage of rupture was predominantly intergranular in the tempered martensite surface layer, revealing the brittle nature of the component. Cracks were observed at regions prone to stress concentration. Eventual rupture of the component probably initiated at these cracks. This behavior is probably related to metallurgical processing steps like quenching, that causes the formation of a banded structure and promotes circumferential and radial cracking before the tempering. The fracture surface revealed regions with micro dimples and a large smooth area with some elongated inclusions. The morphology of these inclusions was cellular and originated at the grain boundaries of the primary austenite. These inclusions are probably MnS with a dendrite structure, capable of causing brittle intergranular rupture.

### Introduction

Power transfer systems in vehicles consist of many components that can fail under some loading conditions. The two main reasons for component failures are component design and manufacturing process problems. The cardan yoke is a component of the power transfer system and is made of SAE 1541 (0.39%C; 1.44%Mn; 0.23%Si; 0.16%Ni; 0.16%Cr) carbon steel and its manufacture consists of forging, machining, quenching and tempering. The SAE 1541 carbon steel has good mechanical strength and toughness, with high surface hardness if quenched and tempered. Two cardan yokes failed during the straightening operation due to bending stresses. The mechanism of failure of these cardan yokes was investigated using a scanning electron microscope.

### Failure analysis of cardan yokes

Failure of the two cardan yokes will be discussed separately. Figure 1A shows a general view of the fracture surface of one of the cardan yokes. The initial crack, caused by the heat treatment process occurred at region A. During the straightening process, the crack propagated into region labeled B, which revealed radial marks. The final fracture stage, labeled as C in figure 1A, spread all over the fracture surface, including the periphery, except region labeled A. This final fracture occurred at an angle of approximately 45° with respect to region B. The dark surface in region C is attributable to

the temper heat treatment in a preexisting crack. Figure 1B shows a side view of the failed component and the white lines indicate the 45° angle, mentioned previously. The circumferential cracks, shown within the black rectangle in figure 1B are probably related to the original flaws and responsible for the manufacturing process failure. The black arrows in this figure point at some vertical cracks indicating the fracture path.

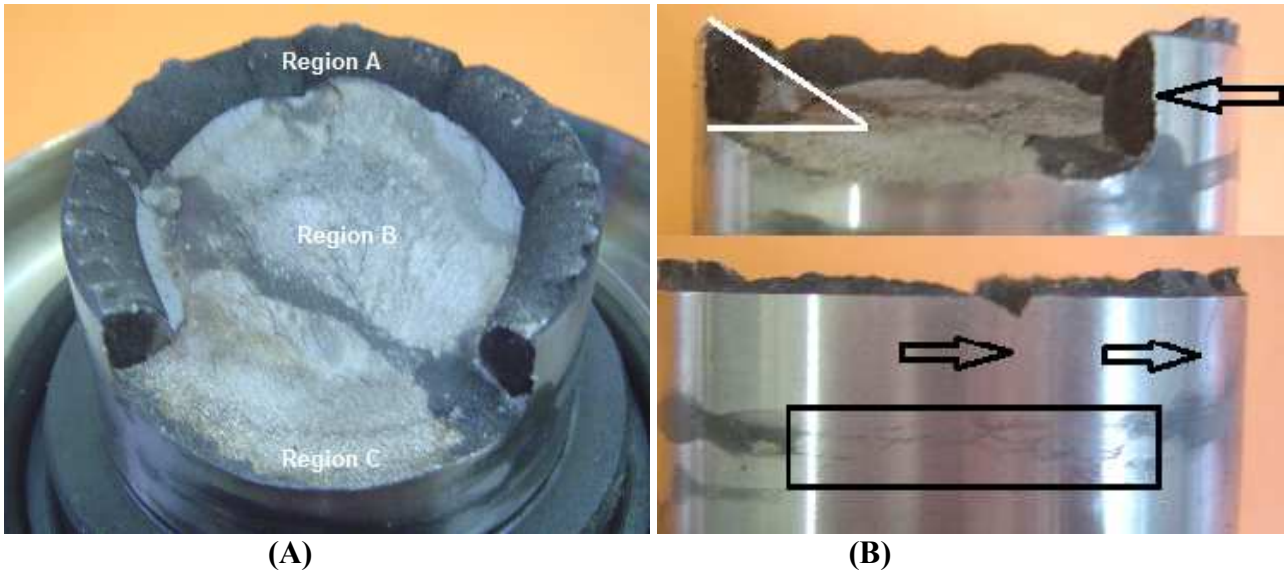


Figure 1: (A) General view of the fracture surface of a cardan yoke. (B) Side views of a fractured cardan yoke.

Detailed fracture surface micrographs obtained with a scanning electron microscope can be seen in Figures 2 to 5. Figures 2 and 3 are micrographs of region A of figure 1A. The scanning electron micrographs in figure 2 were taken from the edge of the initial crack. This reveals an intergranular cracking process with some dimples caused by some intergranular precipitates (figure 2B). Figure 3 shows a micrograph of region A, and reveals an intergranular fracture mode, but with grain size smaller than that seen at regions where fracturing started.

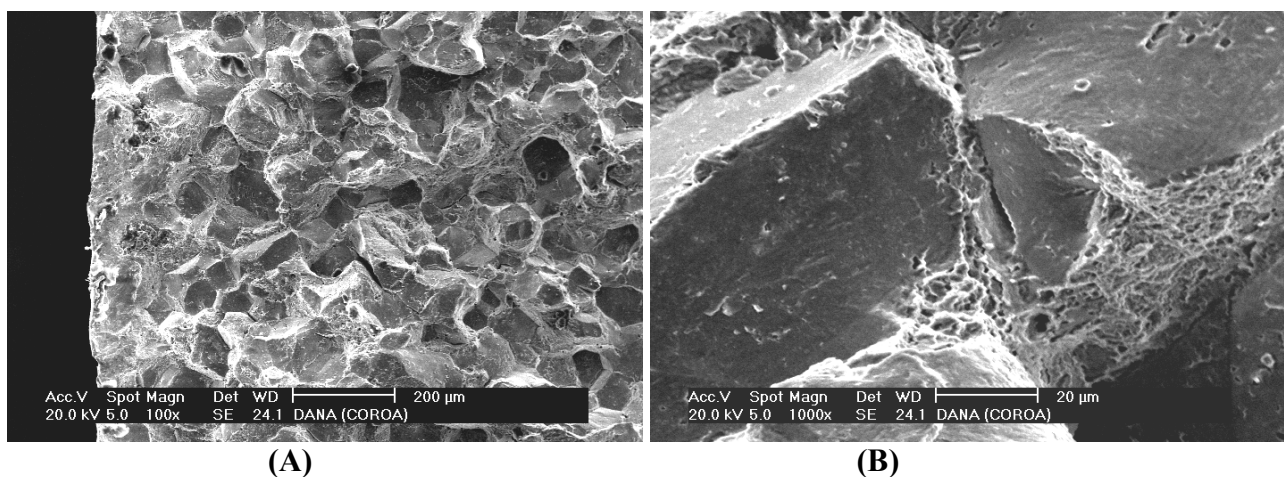


Figure 2: Scanning electron micrographs of the initial crack region of a cardan yoke fracture surface.

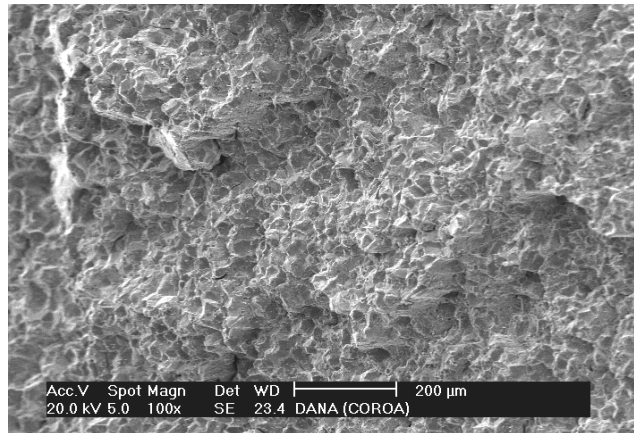


Figure 3: Scanning electron micrograph of an area close to the initial crack region on a cardan yoke fracture surface.

Fracture features of region B (of figure 1) are shown in figure 4. Figure 4A reveals that the fracture path followed different planes. Figure 4B reveals a micrograph illustrating a mixed mode fracture mechanism, with a dimpled area that could be attributed to a quasi-cleavage fracture. Figure 5 is a micrograph of region C, and reveals an intergranular fracture pattern, similar to that in region A.

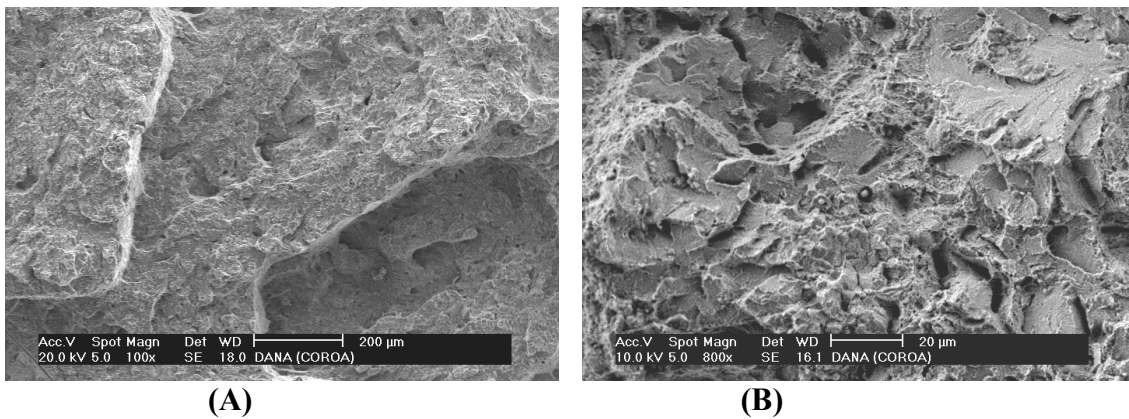


Figure 4: Scanning electron micrographs of the central region of a cardan yoke fracture surface.

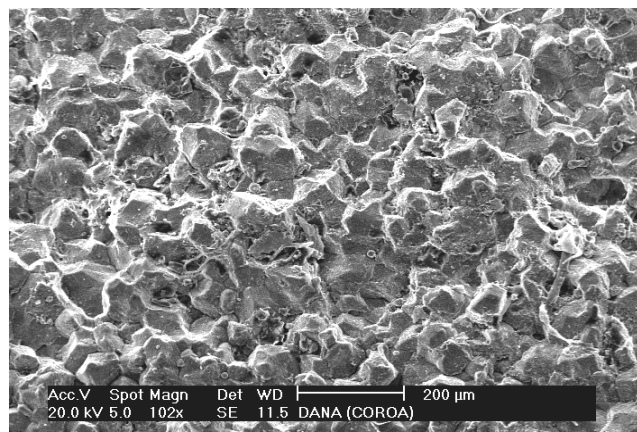


Figure 5: Scanning electron micrograph of the region of a cardan yoke fracture surface where cracking terminated.

Figure 6 presents fracture surface features of region C. Figure 6A shows just the presence of microvoids. Figure 6B shows a large flat region with some inclusions, adjacent to the region with the microvoids. In figure 6C elongated inclusions and microvoids with cellular morphology can be seen. An optical micrograph of a cross section of the fractured area is shown in Figure 7. The

microstructure in the induction hardened area, close to the surface, shows a tempered martensite structure. Further inside, the structure becomes bainitic as shown in figure 7B. Elongated sulfide inclusions can be observed in both micrographs. A banded structure can be seen in the other region (figure 8).

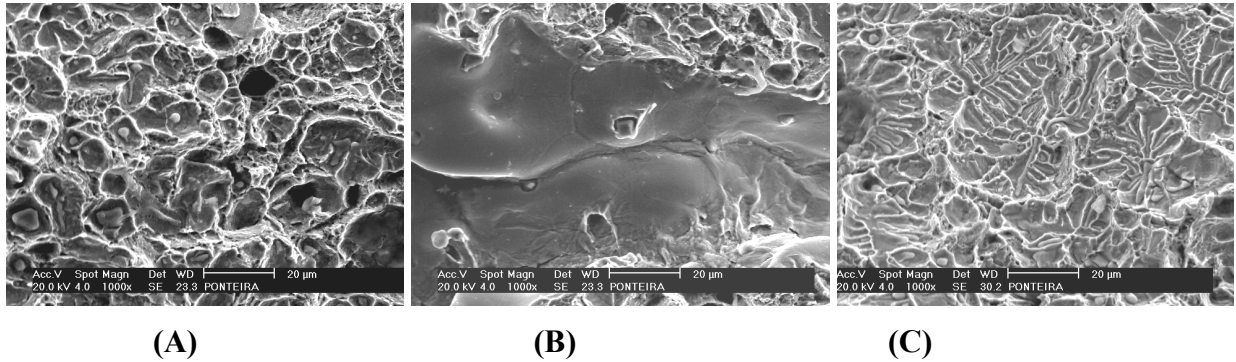


Figure 6: Scanning electron micrographs of the central region of a cardan yoke fracture surface. (Region C in figure 1A).

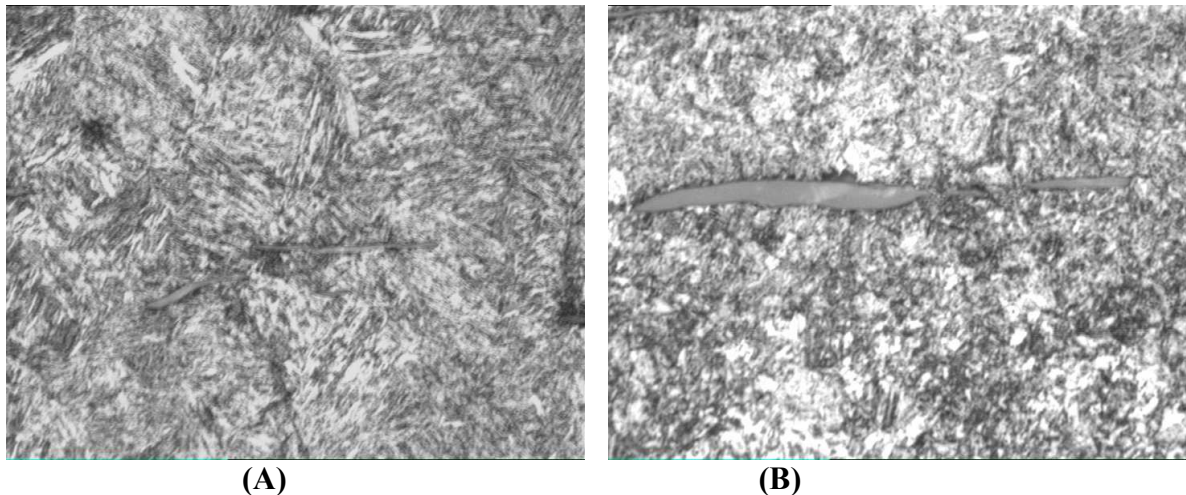


Figure 7: Optical micrographs of the cardan yoke in the induction quenched region (A) and in the center (B), revealing sulfide inclusions.

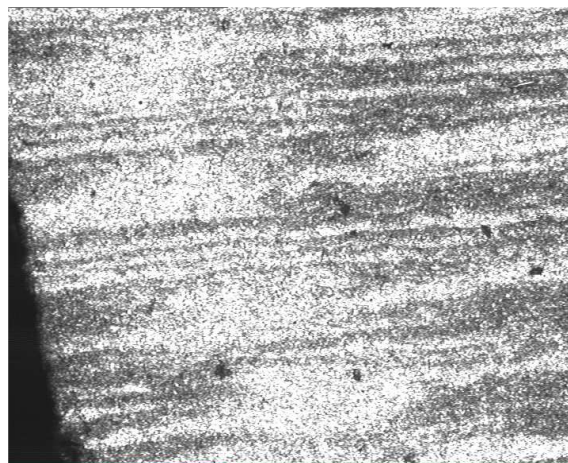


Figure 8: Optical micrograph revealing a banded structure.

Figure 9 shows a general and lateral view of the fracture surface of the second cardan yoke. The fracture took place in the final of the splines, close to the bearing seat during the bending operation. The fracture started in the undercut, between the spline final and the bearing seat, spreading to

almost all the external component diameter (spreading right across the section of the component). The darkened fracture surface suggests that the fracture occurred before the tempering heat treatment. The microstructure in the bearing seat was due to the induction hardening treatment and consisted of tempered martensite as shown in Figure 10. However, cross sectional microstructure analysis of the fractured area revealed a banded structure with bainite plus martensite in the inner part of the component. This had hardness higher than the maximum specified for this application (50 to 61 HRC), which could be attributed to the higher carbon content in the segregated banded structure, shown in Figure 11.

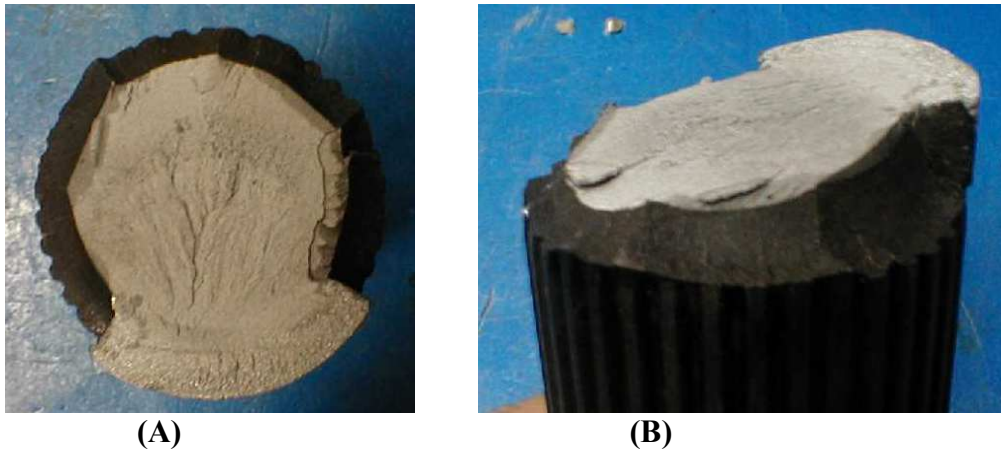


Figure 9: (A) General view of the cardan yoke fracture surface, showing a dark ring-shaped nail, indicating a pre-existing crack. (B) Lateral view of the cardan yoke fracture surface.



Figure 10: Typical micrograph of the cardan yoke tempered by induction.

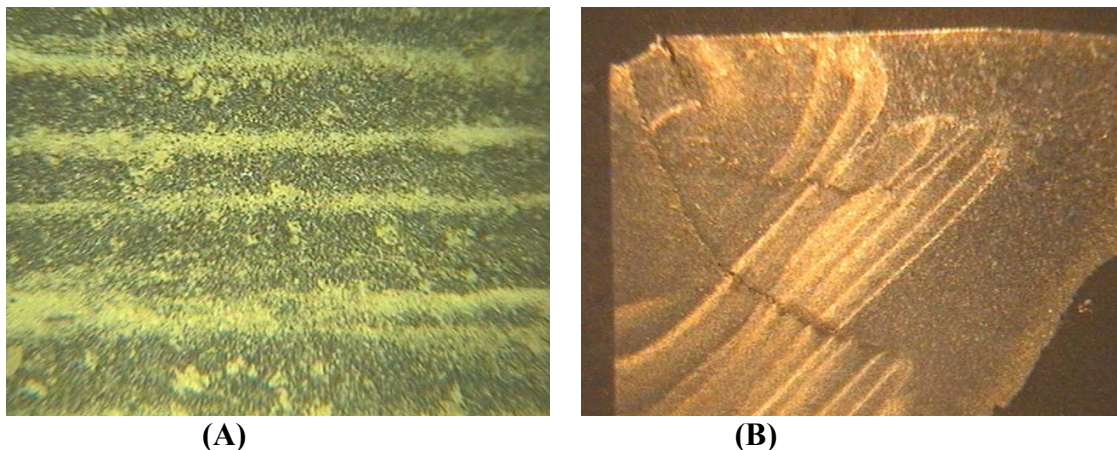


Figure 11: (A) Typical micrograph of the cardan yoke, revealing a banded structure. (B) Macrograph of the fracture region, which shows superimposed martensite layers (banding).

**Conclusions**

Failure analysis of two cardan yokes that fractured during the straightening operation revealed that due to bending stresses, the rupture initiated at the edges of the component from circumferential cracks. The fracture mode was predominantly intergranular, indicating that the component was in a brittle state. In the failed region, the hardness was higher than the specified value. This was due to segregation, which resulted in a microstructure consisting of superimposed martensite layers (banding). This segregation can be also linked to sulfide inclusions observed in the components, which may have led to rupture of the component caused by the high forging temperature. The crack nucleation process was strongly related to the presence of sulfide particles in the primary austenite grain boundaries, and the fracture mode could be determined from the size distribution of the particles, which is controlled by the cooling rate from the austenitic phase.

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