FRACTOGRAPHIC ANALYSIS OF SHEAR FRACTURE OF A FORGED STEEL AXLE SPINDLE

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INTRODUCTION

Several identical AISI-SAE 1008 (0.08%C) cold-forged axle spindles for truck semi-trailers fractured under loads less than the anticipated service loads after a very short time in service. The fracture surfaces were examined with the goal of identifying the cause of the failures. Figure 1 shows the macro-etched cross section as it appears after the right (inner) end is upset by forging. The smaller diameter here is 79.4 mm and the largest diameter of the upset end is 133 mm. The diameter on the right is reduced to accommodate a hollow shaft of about 133 mm outside diameter that is arc welded to the spindle. The spindle at its largest diameter is subjected to stresses from bending and from double shear, in both cases at levels well below the yield stress.

OPTICAL EXAMINATION

Figure 2 shows the complete 133-mm diameter fracture surface. The fracture occurred in the most severely deformed region of the upset end of the spindle. As this portion of the spindle corresponds to the left part of Figure 1, it will be termed the left portion and its matching face the right portion. The 6 holes are drilled parallel to the spindle axis in the larger diameter region to about its mid thickness, and tapped. This fracture surface is almost exclusively comprised of an overlapping double shear mode such as would be expected from the stress applied [1], except that the scale of the resultant shear feathers is much larger than might be expected; i.e., visible to the naked eye.

A closer view of the initiation region at an approximately 9 o'clock position (looking at the face as of a clock, with 12 o'clock at the top) is shown in Figure 3. The fine-scale regions have an appearance here similar to cleavage fracture of steel, but closer examination, as in Figure 4, which is at the center of Figure 2, shows finer shear feathers. These two photographs show that the orientation of the feathers or ligaments opened up in shear varies greatly from point to point, suggesting that as the crack advances over an irregular front the shear stress orientation varies from the expected 12:00 - 6:00 orientation.

A view near the 12:00 position of the matching right portion of this fracture is shown in Figure 5. The bottoms of two of the holes lie approximately in the plane of the fracture. A detailed survey of the orientation of the shear feathers on the matching fracture surfaces revealed several regions where the feather edges pointed in opposite directions, as would be expected, but by no means all of the fracture surfaces could be so described.

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SCANNING ELECTRON MICROSCOPY

A detailed scanning electron microscope (SEM) examination was made of several areas on the fracture. As all areas indicated similar features, two are illustrated here. Figures 6 and 7 show the appearance in the initiation region that can be seen at 7:00 in Figure 2. Figures 8 and 9 are of a region well removed from the 9:00 initiation point on the left fracture. Note that the shear stress direction here was in the 3:00 - 9:00 direction, in constrast to the external loads which would cause shear in the 6:00 - 12:00 direction.

MECHANICAL TESTS

Tensile tests of bars machined from another spindle, parallel to the spindle axis, showed extremely low ductility in the region of maximum plastic deformation from forging.

Hardness tests on samples cut from the spindle showed hardness ranging from a low of 76 Rockwell B (139 Brinell hardness number) in the base metal near the circumferential weld, to 100 Rockwell B (240 Bhn) in severely cold worked metal.

CONCLUSIONS

These fractures resulted from moderate shear stresses in the presence of the combined effects of severe cold working of the part by the forging; annealing and a consequent reduction in strength in the vicinity of the weld; and both were probably aggravated by the presence of non-metallic inclusions near the outer surface that acted as stress raisers in the brittle plane of plastically deformed material.

REFERENCES

1. American Society for Metals, "Fractography and Atlas of Fractographs", Metals Handbook, 8th Edition, 9, 1974, 79.

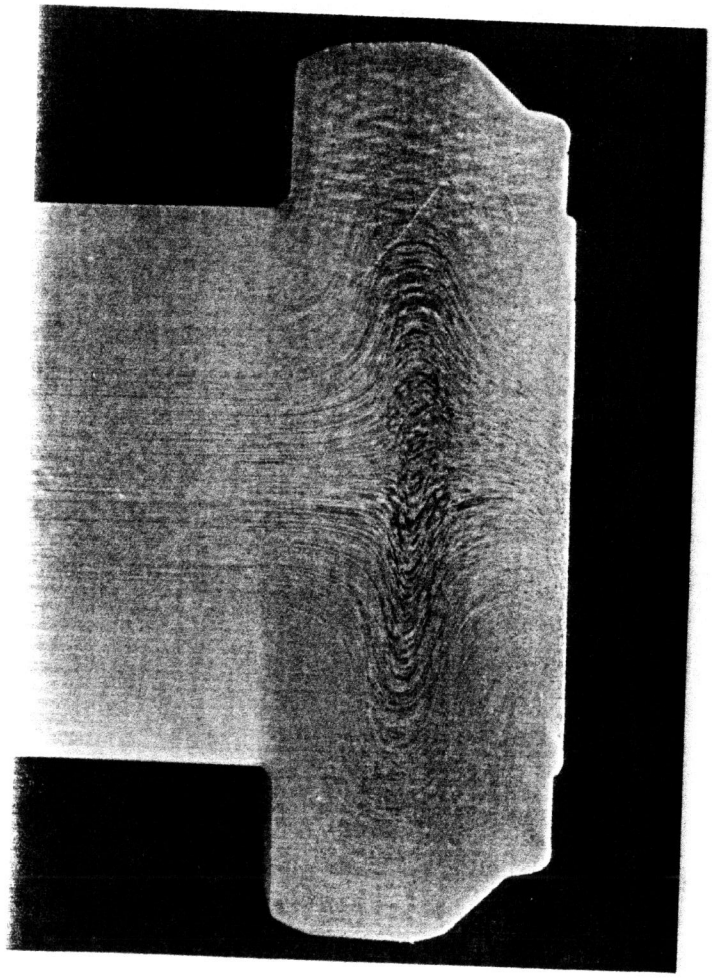

Figure 1 Macro-Etched Cross Section of the Spindle

Figure 2 Fracture Surface of the Left Portion of Spindle. The Arrow Indicates an Initiation Site near the Neutral Axis in Bending

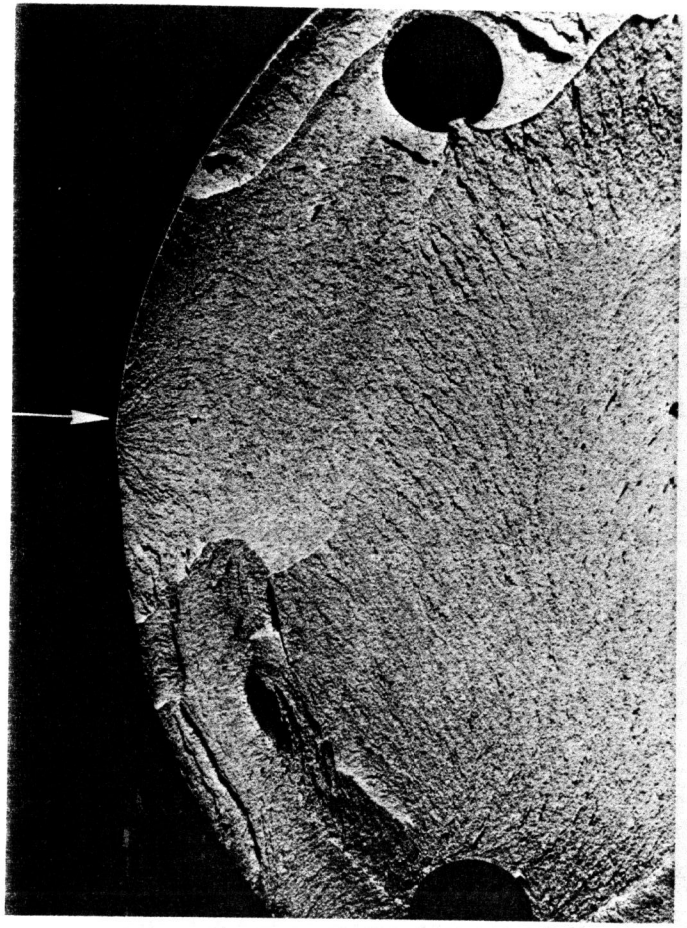

Figure 3 The 9:00 Initiation Region of Figure 2

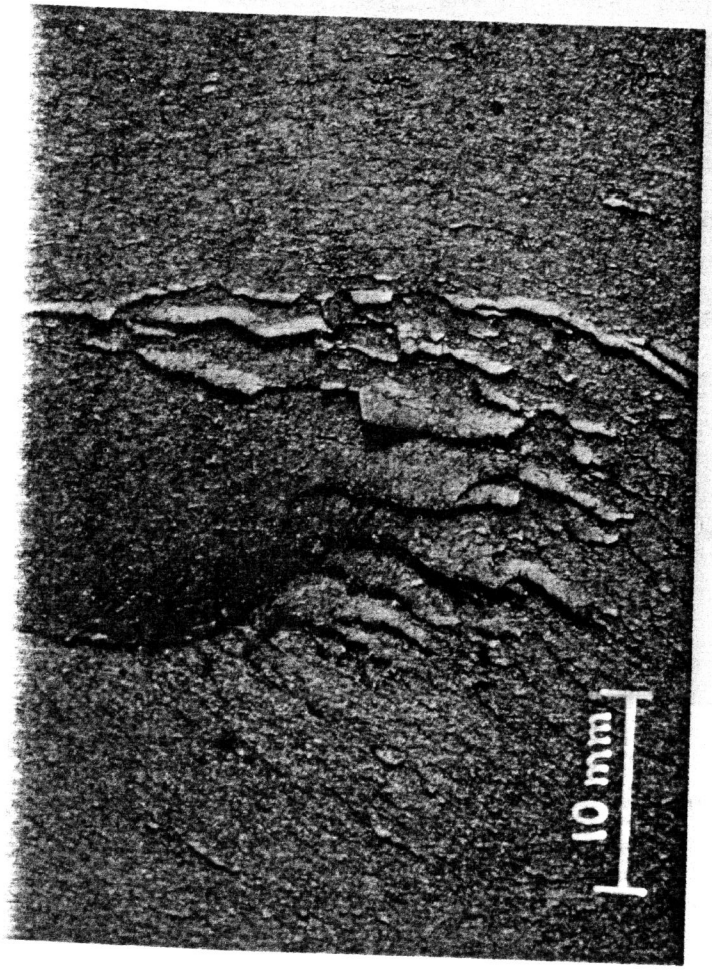

Figure 4 Detail at the Center of Figure 2

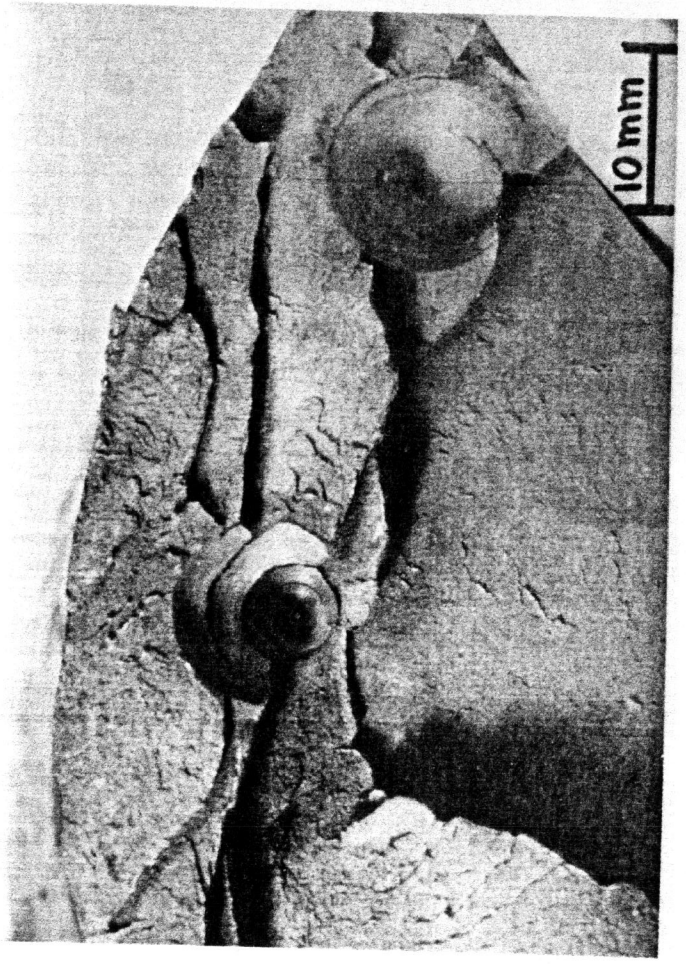

Figure 5 Detail at 12:00 on the Right Fracture Surface

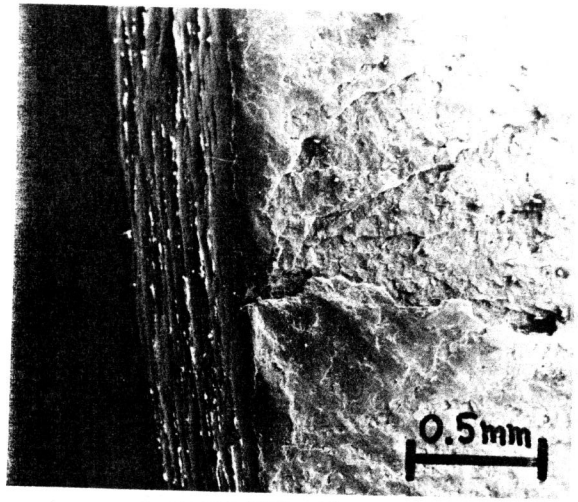

Figure 6 The Initiation Region at 7:00 on the Left Fracture Surface, by SEM. The 12:00 Direction is to the Upper Right

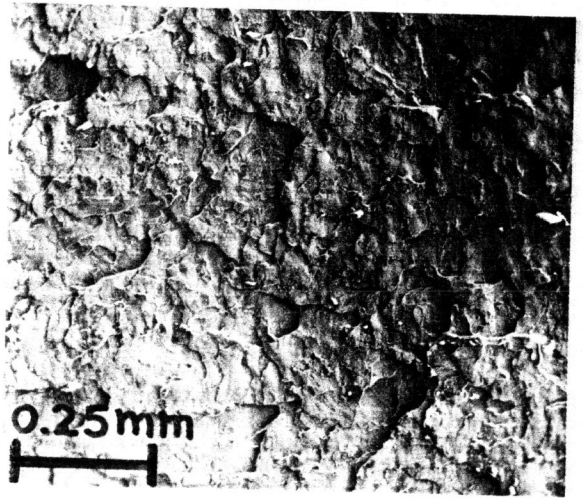

Figure 7 The Same Area as Figure 6, 5 mm Inward from the Edge. The 12:00 Direction is to the Upper Right

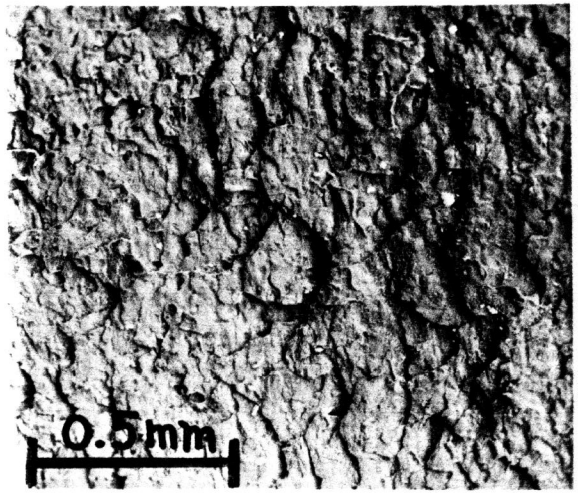

Figure 8 Fracture Surface at 15 mm Inward from the 9:00 Initiation Point in the Left Fracture Surface. 12:00 is Straight Up

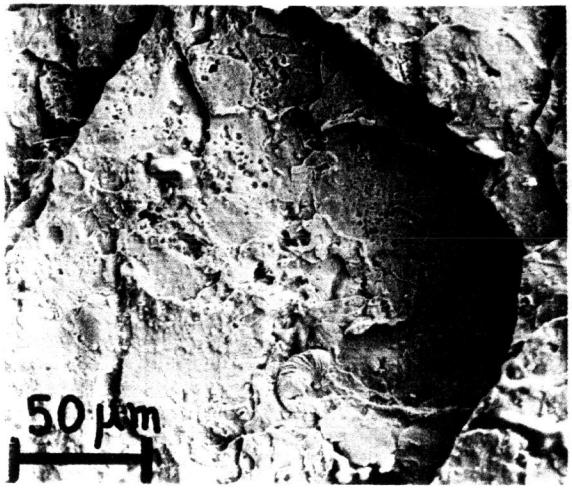

Figure 9 At the Exact Center of Figure 8