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Stub Axle Failure Analysis

BACKGROUND

A fractured stub axle was received for metallurgical failure analysis. The stub axle is fairly new and has a somewhat smooth fracture, beginning in the radius where the flange transitions to the bell. The fracture extended from this surface / corner inward and terminates at the corner of the inside drill cut.

METALLURGICAL PROCEDURES

1. Sectioning: The fracture surface was removed from the body of the stub axle and the remaining axle section sectioned was split into two pieces; see Figure 1.

2. Macro-Etching: The full length of one section was ground, polished and macro-etched in a10% nitric acid solution for the purpose of examining grain distribution and flow; see Figure 1.

3. Mounting / Metallographic Sample Preparation: The section containing the fracture surface was mounted longitudinally and prepared for optical microstructure examination using standard ASTM procedures. The hardness next to the fracture surface was measured using a calibrated Tukon microhardness tester. The section was examined using the optical microscope in the as-polished condition followed by etching the metal with a 2% nital etch to delineate the microstructure. The fracture surface microstructure was photographed; see Figures 2 and 3.

Test Results:

1. Macro-Etching: The grain flow is unacceptably very fine and exhibits micro alloy segregation (banded grain structure); see Figure 1. As a result of an extremely fine banded grain structure, the mechanical properties of this section have been seriously compromised.

2. Fracture Surface: This is a high cycle low stress fatigue fracture which initiated at the outside corner radius and progressed inward to the corner of the drill hole. Macro ductility or a ductile lip is not exhibited in this fracture; a strong indication the grain size is very fine.

3. Microhardness Testing: The hardness measured across the fracture surface is 39.8 HRC @ O.D.; 38.3 HRC @ I.D. with the remaining metal varying in hardness from 33.3 HRC to 36.2 HRC. The measured hardness is consistent with the observed microstructure. The case hardness is expected to be ~55 HRC.

4. Microstructure Analysis: The microstructure is mixed tempered martensite and ferrite; see Figures 1 & 2. Transformation to martensite has not been complete; material exhibits micro alloy segregation or banding due to not being normalized prior to hardening. The grain size is extremely fine, much finer than ASTM 10. The metal has not been heated sufficiently at the required austenitizing temperature with the correct settings for surface induction hardening. A partially hardened microstructure is evident throughout. no case hardening is evident; see example in Figure 1.

DISCUSSION

In order to solve the problem with premature fatigue breakage, the metallurgical properties must be specified at the time the material is ordered from the supplier or mill. Primarily, the ASTM grain size must be in the range of ASTM 3 - 7. Grain size any finer than ASTM 7 seriously limits the elasticity of the metal when in the tempered martensite condition. Secondly, the mill bar stock must be in the normalized and tempered condition. What this requires is that the mill heat the metal to about 1700°F., followed by slow cooling. This heat treatment causes the microstructure to re-crystallize and homogenize prior to shipping. The net benefits are: easier machining; a consistent grain size and resulting mechanical properties following hardening heat treatment; and an a tempered martensite which is more elastic and fatigue crack resistant. Think about this: “A fine grain size, when mechanically impacted tends to crack, while a larger grain size tends to plastically deform and resist cracking”. It is far easier and cheaper for a mill to send metal out the door without normalize heat treatment. However, without normalizing the grain size and allowing the mechanical reduced, elongated and sometimes fractured grain to re-crystallize and homogenize; additional internal microstructure strain can reduce product life dramatically and cause premature product failure. The normalizing heat treatment is a microstructure homogenization and reconditioning treatment which literally gives the metal new life.

The measured hardness of this axle far too low, due to insufficient heating during induction hardening. The macro-etched section revealed the part was heated too long at too low of an austenitizing temperature. As a result, the microstructure is a mixture of ferrite and martensite and not one hundred percent tempered martensite as desired. A process procedure needs to be developed for the induction hardening process; specifying the parameters for correct heating and hardening.

Lastly, there is a very outside diameter sharp radius where the stub axle transitions to the bell. This sharp radius needs to be enlarged to reduce localized fatigue over-stress. The fracture originated at this outside diameter radius and propagated inward due to excessive over-stress.

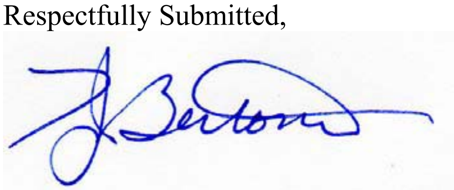
RECOMMENDATIONS

1. Purchase order to mill must specify the following:
   Material must be in the normalized and tempered condition
   The grain size must be ASTM 3-7.
2. The radius, at the transition of the axle shaft to the bell, needs to be enlarged.
3. The correct temperature must be applied during induction hardening in order to correctly austenitize the surface before quenching. This axle was not induction hardened correctly. A process procedure needs to be developed specifying the parameters for correct hardening.

CONCLUSION

There are multiple reasons causing the reduced service life of this stub axle. The metallurgical deficiencies noted in this report need to be corrected in order to prevent re-occurrence of this fatigue failure. Most important is the development of a process procedure for correct surface hardening of the stub axle and increasing the radius at the transition to the bell. In this case, the heat treater’s liability is minimal.

Respectfully Submitted,



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Metallurgy Professor

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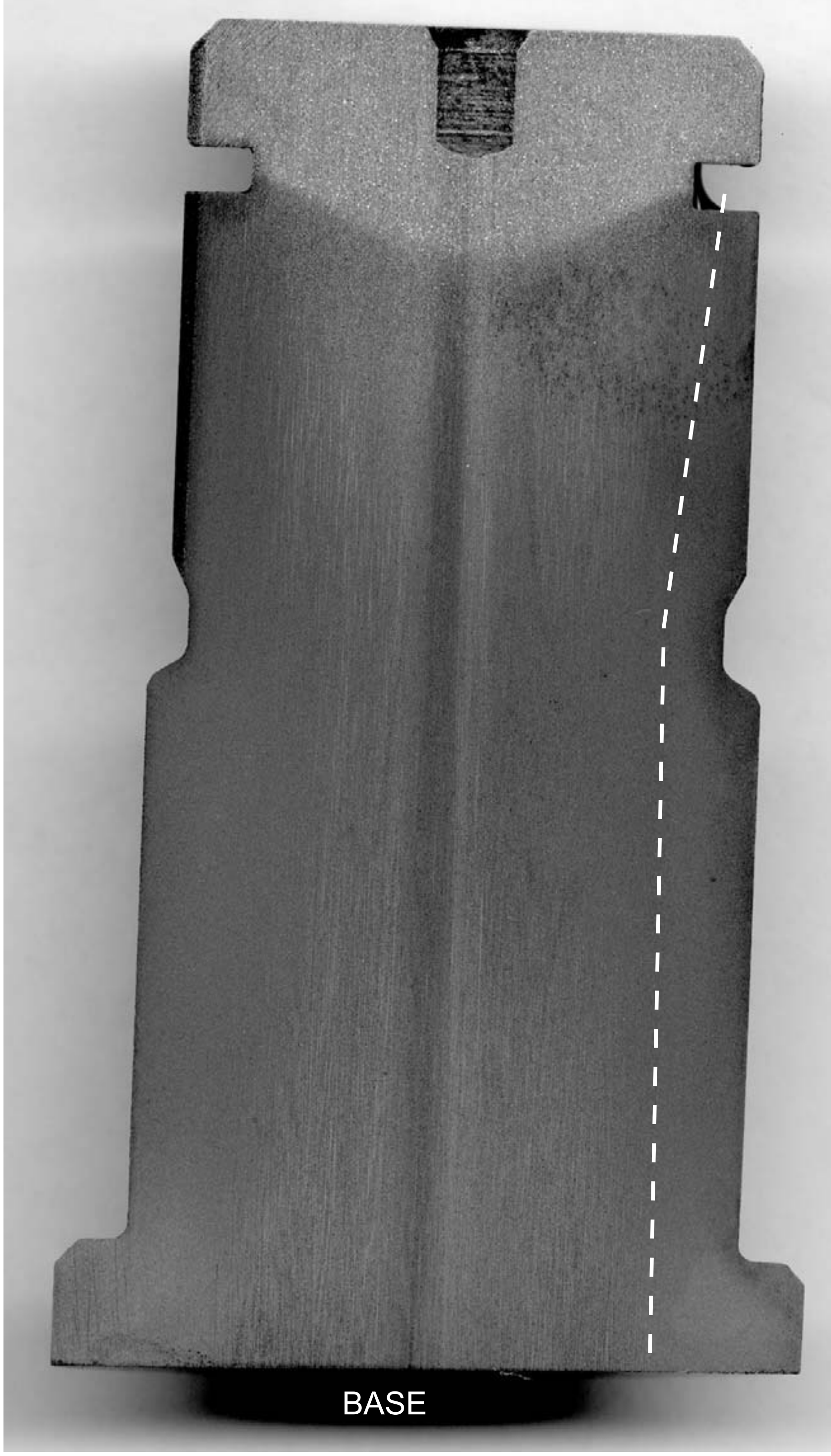
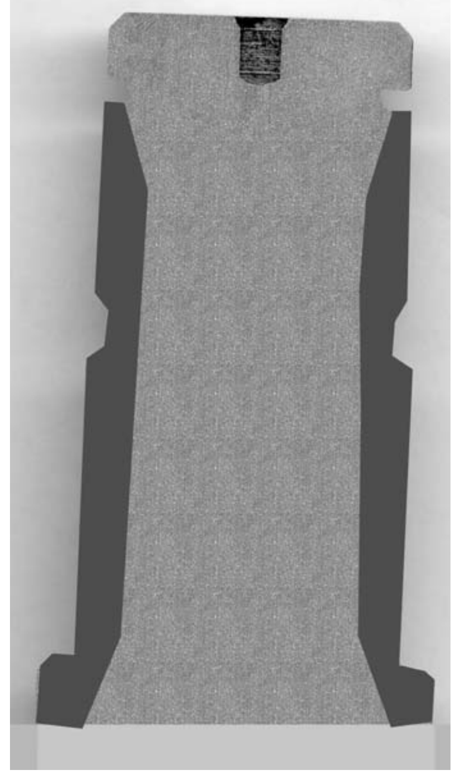
INSUFFICIENT AUSTENITIZING TEMPERATURE



STUB AXLE CORRECTLY INDUCTION HARDENED



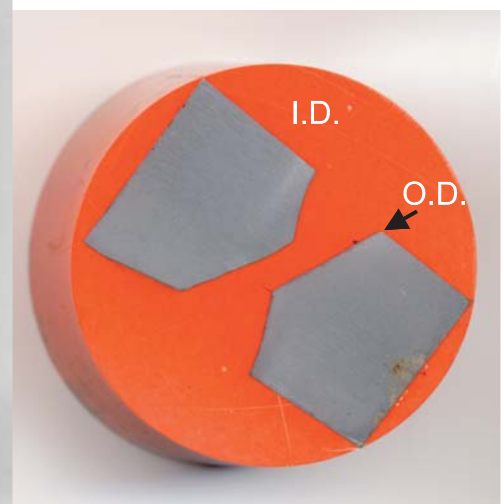


FIGURE 1. The grain flow lines in the large section indicate an extremely fine grain structure which is micro-banded and was not normalized prior to being induction hardened. There is NO evidence of a CASE as expected when the surface is induction hardened: see dotted lines. The exemplar stub axle is hardened correctly; note the well defined induction hardened case.

The orange mount contains the etched cross-section of the fracture surface examined in Figures 2 and 3. These pieces were cut from the base of the stub axle which intersects the bell. The arrow points to the sharp corner and lack of a sufficient radius.

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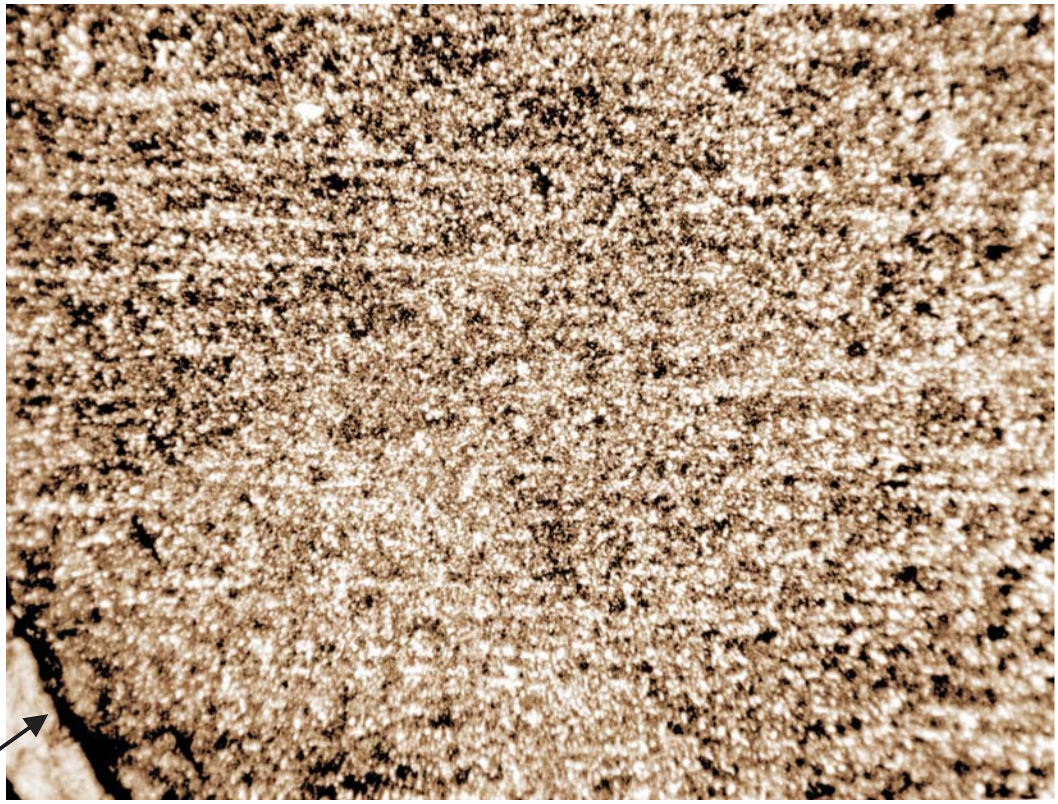

FIGURE 2. Arrow points to the fracture surface. The microstructure contains ferrite when it should be fully martensitic. Micro-banding is evident and the grain size is extremely fine <ASTM 10.

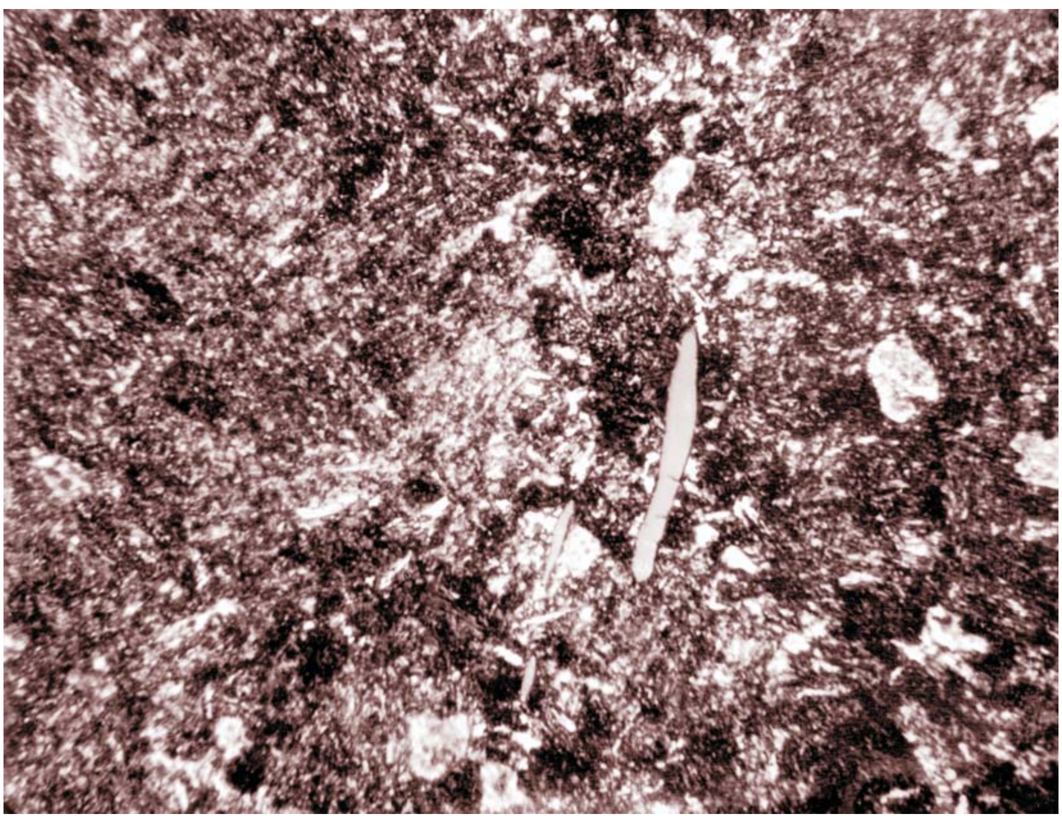

FIGURE 3. Arrow points to the fracture surface. The microstructure is blotchy due to ferrite and incomplete martensitic transformation during induction hardening.