Materials safety: article exercise

You are working as a materials expert in your organization and your responsibility is to guarantee safe and efficient use of materials in your facility. One day, a failure in similar facility is brought to your attention, and you need to investigate the possible implications this failure has for your facility. Your job is to interpret and analyze the given failure report and to write a report, which will allow others in your organization to understand the key developments and causes leading to the failure and the necessary actions for prevention of such failures.

Read the given article and analyze the failure. Describe, how the deformation and failure mechanisms presented during the course are reflected in the case and establish the chain of actions leading to the failure. The report should work as an introductory material to your team; it should not be very long but it should enable other team members to understand the key features of the failure without reading the failure report itself.

In addition to establishing the primary cause of the failure, show why alternate failure mechanisms can be ruled out. Some failure mechanisms have not been discussed in the course yet. Conduct the analysis using your present knowledge on the subject.

If the author of the failure analysis has, in your view, neglected to address some aspects of the failure, you may indicate this in your report and suggest tests or actions that should have been done to clarify the issue.

Prepare your response by editing this word document and export it as PDF. The file name identifies you and the article. Do not change the file name (other than the extension to pdf). E-mail the pdf to "materials.safety@iikka.fi".

You may use the question list below to guide you in your analysis:

A. Description of investigation methods applied

- What means of investigation were used in the failure analysis?
- What computational methods were used?
- What material or results were obtained?

B. The primary cause of the failure and description of the failure mechanism

- What is the primary cause of the failure (also provide reasoning)?
- What's the chain of action that led to the failure?

C. Ruling out alternate failure mechanisms

- Can plastic deformation be ruled out? If yes, explain how.
- Can creep be ruled out? If yes, explain how.
- Can brittle fracture be ruled out? If yes, explain how.
- Can fatigue be ruled out? If yes, explain how.
- Can environmentally assisted failure be ruled out? If yes, explain how.

D. Recommendations to prevent similar failures in the future

- How should the design, material, use, etc. be develop to avoid similar failures in the future? Provide several alternatives and indicate most promising.

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Materials Safety analysis report on brittle fracture failure of axle shaft of forklift

Problem Overview:

The report investigated the reasons for the failure of axle shafts used in forklifts. These shafts are the integral components of the rear axle, and they are pivotal in transmitting torque and maintaining wheel positions. Notably, one axle shaft, crafted from 42CrMo4 grade steel, malfunctioned after just 296 hours of service (12.3 days). The abrupt failure, marked by a sudden jerk, raised concerns about potential overloading, material integrity and manufacturing processes.

A. Description of investigation methods applied

- **What means of investigation were used in the failure analysis?**

The author tries to determine possible if the observed inclusions are the result of brittle/ductile fracture material on the axle shaft, both in the core and on the thin case of 3-mm. From the report, the means of investigation for the failure analysis included:

1. Chemical Analysis: The chemistry of the failed axle shaft was analyzed to match with known steel grades, which is 42CrMo4 grade.
2. Micro-Hardness Testing: The micro-hardness of different locations on the failed samples was determined using a pneumatically controlled automatic micro-hardness tester.
3. Microstructural Analysis: The failed sample was etched and examined to understand its microstructure, including the presence of any inclusions or inconsistencies.

- **What computational methods were used?**

The author lists a couple of computation methods as follows:

1. Field Emission Gun Scanning Electron Microscopy (FEG-SEM): This method was used to identify the exact phases present in the samples.
2. Inclusion Rating: The failed component was rated for inclusions in ASTM E45 standards.
3. Fractography: The nature of the fracture surface was studied to determine whether it was brittle or ductile. It was shown that the core suffered from ductile fracture while the case suffered from brittle, cleavage fracture.

- **What material or results were obtained?**

Main result: The outer surface of the fracture showed a cleavage nature, suggesting a brittle fracture, while the inner core revealed a dimple nature, indicating a ductile fracture. Both coarse and fine pearlite structures were seen in the core due to an improper heat treatment process.
Additionally, the un-etched microstructure of the shaft revealed the presence of thin and thick sulphide (Type A) inclusions with severity ratings of 2.5 and 0.5, respectively.

B. The primary cause of the failure and description of the failure mechanism

- **What is the primary cause of the failure (also provide reasoning)?**

The primary cause of the failure is likely to be brittle fracture due to improper heat treatment. There are four main reasons for this type of failure:

- **What's the chain of action that led to the failure?**

The chronological order of the superheater tubes' failure is as follows:

1. Observations: The axle shaft failed in shear mode at almost 45° to the longitudinal direction under torque. The fracture surface had two distinct regions: a smooth annular region at the periphery where the fracture initiated and a rough core.
2. The hardening layer was found to be non-uniform across the section, and in some areas, it exceeded the specified depth (>2–3 mm).
3. The un-etched microstructure showed numerous sulphide inclusions, indicating that the steel was not clean.
4. The surface of the rod sample exhibited an inhomogeneous/banded microstructure in a martensitic matrix, while the core displayed a ferrite pearlite structure
5. The un-etched microstructure of the shaft revealed the presence of thin and thick sulphide (Type A) inclusions with severity ratings of 2.5 and 0.5
6. The difference in fracture behavior was caused by the variation in the microstructure of the case and core resulting from the improper hardening treatment.

C. Ruling out alternate failure mechanisms

- Can plastic deformation be ruled out? If yes, explain how.

No, it cannot be ruled out due to the dimple nature of fracture in the inner core (B). Dimpled fracture surfaces are characteristic of ductile fracture and are indicative of plastic deformation prior to failure. Dimples are microscopic voids or cavities that form in the material due to the nucleation, growth, and coalescence of voids under tensile stress.

- Can creep be ruled out? If yes, explain how.

Creep can be ruled out since the report does not mention the axle shaft operating at elevated temperatures or under constant loads for extended periods. Additionally, the axle shaft failed after just 296 hours of service, which is also a short time that is uncommon for creep.

- Can brittle fracture be ruled out? If yes, explain how.

No, it cannot be ruled out since it is the main reason stated in the report.

- Can fatigue be ruled out? If yes, explain how.

Fatigue can be ruled out. The non-uniform distribution of hardness across the shaft, with a very high hardness on the surface-hardened layer, suggests that the material was more susceptible to brittle fracture. Fatigue would typically initiate at regions of stress concentration, and there's no mention of such typical fatigue initiation sites.

- Can environmentally assisted failure be ruled out? If yes, explain how.

Environmentally assisted failure can be ruled out since the report does not mention the axle shaft being exposed to any corrosive chemicals or high humidity or any harsh conditions.

D. Recommendations to prevent similar failures in the future

- How should the design, material, use, etc. be developed to avoid similar failures in the future? Provide several alternatives and indicate the most promising.

To avoid similar failures in the future, several design, material, and usage recommendations can be inferred from the paper:

1. Material selection: Choose cleaner steel grades with fewer non-metallic inclusions, especially manganese sulphide inclusions, which can act as stress concentration sites. Consider using steel grades with better resistance to brittle fracture.

2. Heat treatment process: Implement a more controlled heat treatment process to avoid the formation of both coarse and fine pearlite structures in the core, which resulted from the improper heat treatment process.

3. Quality control: Regularly inspect axle shafts in service for signs of wear, deformation, or potential failure. Non-destructive testing methods like ultrasonic testing or magnetic particle inspection can be used.

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