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".

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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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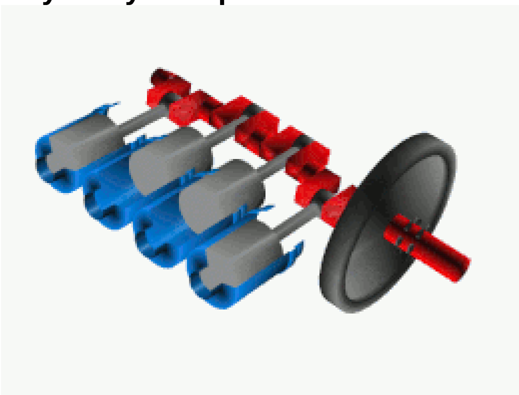
Materials Safety analysis report on the crankshaft fatigue failure



Crankshaft (red), pistons (gray), cylinders (blue) and flywheel (black)

Problem Overview:

The report investigated the reasons for the fracture of a crankshaft used in an air compressor. The focus was on understanding the cause of the fracture, especially considering the presence of beach marks with a semi-elliptical shape surrounding the fatigue crack initiation region. These marks were indicative of the expansion of the fatigue crack. The report provide insights into the fatigue behavior of 42CrMo steel under its cyclic operational conditions.

A. Description of investigation methods applied

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

From the report, the means of investigation for the failure analysis included:

1. Experimental analysis of the crankshaft: which consists of chemical composition detection, which reveals that the chemical composition of the main shaft was in accordance with the requirements of 42CrMo steel; and the crankshaft's mechanical properties.

2. Analysis of macroscopic and microstructural features: the microstructure of the crankshaft was analyzed around the lubrication hole and the transition fillet of the journal.

3. Theoretical calculations: derivation of safety factors for different sections of the crankshaft, such as the lubrication hole and the transition fillet of the journal.

- **What computational methods were used?**

The author lists a couple of computation methods as follows:

1. Scanning Electron Microscope (SEM) to confirm the fracture type and the initiation of crack source region, its propagation, and the cause of possible fracture.

2. MATLAB simulation: obtain the curve of theoretical stress concentration factor and the curve of the relative stress strength factor on lubrication hole

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

Main result: The main results obtained are chemical composition detection, mechanical properties test, macroscopic analysis, microstructure of the fracture surface, analytical theoretical calculations of different properties of the broken crankshaft.

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 was identified as the crack on the edge of the lubrication hole. The fracture surface was divided into three regions: fatigue crack initiation region, fatigue expansion region, and static fracture region. The catastrophic fracture, which indicates a high fatigue crack growth rate, seems to be a result of high bending. This high bending loading was attributed to the misalignment of the main journals and the small fillet of the lubrication hole.

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

The chronological order of the transmission towers' failure is as follows:

1. Initiation of micro cracks: micro cracks formed due to high bending stress concentration appeared on the fillet of the lubrication hole. However, the crankshaft continued to operate in a near-normal condition.
2. Fatigue crack extension: As the working time extended, the crankshaft began to exhibit noticeable fluctuations. The fatigue crack extended gradually, moving towards the static fracture region.
3. High bending stress concentration: This high bending loading was attributed to the misalignment of the main journals and the small fillet of the lubrication hole. This accelerates the fracture status of the crankshaft.
4. Complete fracture: eventually, the crankshaft fractured completely. At the moment of fracture, friction and collision occurred between the two fracture surfaces, leading to some degree of damage on the surfaces.

C. Ruling out alternate failure mechanisms

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

No, plastic deformation cannot be ruled out. The report mentions high bending stress concentration at the fillet of the lubrication hole as a significant factor leading to the initiation of micro cracks. The stress concentrations can lead to plastic deformation

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

Creep can be ruled out due to the absence of prolonged high-stress levels. It's unlikely that the crankshaft experienced stresses conducive to creep.

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

Brittle fracture can be ruled out. The microscopic observation of the fracture surface using Scanning Electron Microscopy (SEM) does not reveal a brittle fracture surface.

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

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

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

Environmentally assisted failure can be ruled out. Environmentally assisted failures often exhibit specific features, such as corrosion pits, which were not observed on the crankshaft.

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 conditions: ensure that the chemical composition of the crankshaft material is in accordance with the requirements of the specific steel type (e.g., 42CrMo steel). Proper heat treatment and nitridation can enhance the mechanical properties of the material, making it more resistant to fatigue.

2. Regular inspections: implement regular inspections using SEM to detect early signs of fatigue or other damage. Early detection can prevent catastrophic failures.

3. Design modifications: address potential areas of high stress concentration, such as the fillet of the lubrication hole. Redesigning these areas to reduce stress concentration can significantly reduce the risk of fatigue crack initiation.

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