

FAILURE ANALYSIS OF PAPER MACHINE SHAFT

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Abstract

This work presents results of the analysis of the broken shaft (OD 310 mm) of a paper machine. The projected and measured operation tension of the shaft was under elasticity strength of the material. The fracture surface of the shaft was investigated at macroscopic level by light microscopy. Also an investigation at microscopic level by scanning electron microscopy was made. Other information was obtained by measuring the chemical composition of the shaft. Microstructure of the shaft was studied in all three axes. All this information was compared with strength calculations and calculations of the lifetime of the shaft. Fractography mechanism based on measurement and the most likely cause of fracture are discussed.

Keywords: *Paper machine shaft, lifetime calculation, strength calculation, scanning microscopy*

INTRODUCTION

One step in the production of paper is pressing and drying of the semifinished product. This procedure is performed at the paper dewatering press. The active parts of a paper dewatering press are two counter-rotating rollers (Fig.1). During the production campaign a paper dewatering press works in continuous mode.

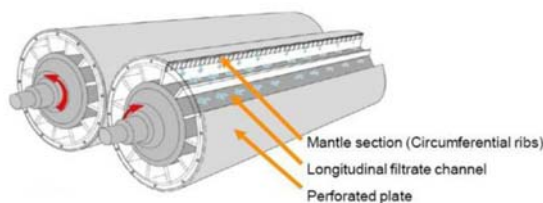


Fig.1. Scheme of drying rollers of a paper machine [1].

Since the year 1996, work with the paper dewatering press machine has been carried on. The first set of rollers were changed in the year 2004. Reason for changing old rollers was wear of the active surface of the rollers. New rollers were in service from 2004 to 2010. On August 15, 2010, the shaft of a new roller failed. No changes in the operating parameters of the machine were made by the operator. After rupture there has been a several times rotation of the roller caused by inertia forces.

STRENGTH CALCULATIONS

The first roller is fixed securely and second is forced against it. Pressing force is caused by two hydraulic pistons. These pistons are connected in parallel. The hydraulic pistons' parameters are a pressure of 2.6×10^7 Pa and diameter 75 mm. With these parameters there will be pressing force 114.8 kN. The torsion moment was set at value 12 ± 2 kNm. The moment is limited by safety valves. Average rotations over the last ten years is 6.3 r/min. A paper machine works 341 days/year and the lifetime was 5.6 years. It means more than 17×10^6 cycles. According to the accompanying documentation, the roller shaft should be loaded with alternating cylinders rotating bending with low nominal stress. Computational scheme with marked forces is shown in Fig.2.

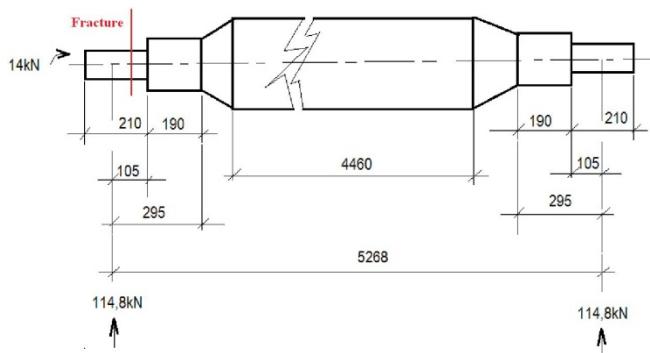


Fig.2. Force model of roller [1].

On the basis of the calculation shown in the report [1] a shaft of paper machine was properly designed. Dimensions of the shaft and projected stress rate may not allow fracture or fatigue fracture.

MATERIAL CHARACTERISTICS

As shown in Table 1, material of the shaft is low-alloy construction steel, which can be categorized as steel grade 13141 by Czech national norms. That is in agreement with material used for strength calculations.

Tab.1. Measured chemical composition (InnovXsystems DELTA CLASSIC - ED-XRF)

Elements	Measured	
	wt. %	±
Cr	0.11	0.01
Mn	1.23	0.03
Fe	98.41	0.23
Ni	0.13	0.04
Cu	0.16	0.015
Mo	0.03	0.002
C	undetected	

Hardness measurement was used for verification of mechanical properties. Hardness was measured at the surface of the shaft and four centimeters under the surface (which may be equal to measurement of the shaft core). Surface hardness was 155 ± 10

HV10 and core hardness 124 ± 2 HV10. Measurement of micro hardness near the fracture surface was prevented by deformed area near the fracture. This deformation was caused by rotation after failure of the shaft.

Microstructures in all cross-sections are shown in Figs.3–8. Microstructure is ferritic-bainitic. No differences in microstructure were observed. There were no particles, which could lead to decreasing of mechanical properties.

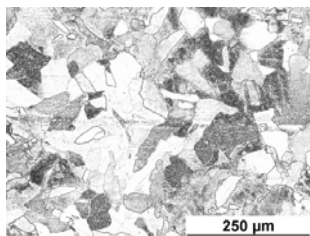


Fig.3. Microstructure of longitudinal 0° section

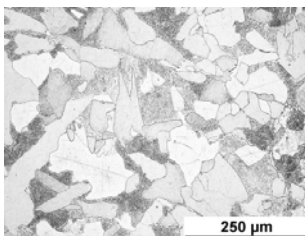


Fig.4. Microstructure of cross-section

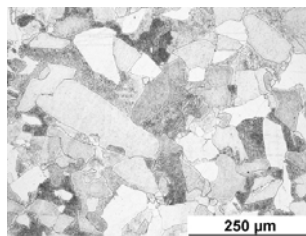


Fig.5. Microstructure of longitudinal 90° section

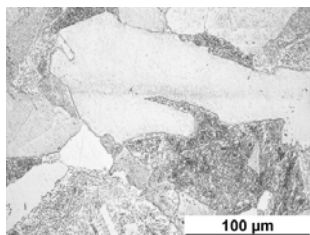


Fig.6. Microstructure of longitudinal 0° section

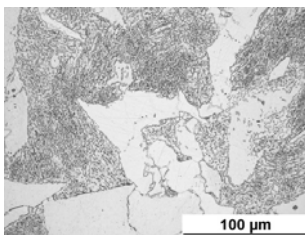


Fig.7. Microstructure of cross-section

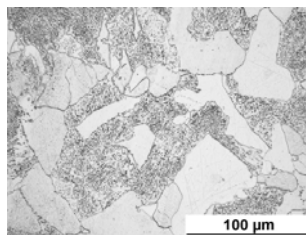


Fig.8. Microstructure of longitudinal 90° section

FRACTOGRAPHY

The look of the fracture surface is typical for alternating bending at rotation [2]. Unfortunately, the fracture surface is heavily damaged (Fig.9). The damage was caused by rotation of roller after failure. These facts lead to inability to determine the initiators of cracking. The final fracture area has a dimension of 7.3% of complete cross-section area. The location of the crack was situated under the bearing, which is in agreement with the position of maximum tension. Another problem is corrosion at surface.



Fig.9. Fracture surface



Fig.10. Detail of fracture surface

The goal for SEM was to try to find some marks of fatigue. There were two main problems. Firstly, it was deformation of fracture surface and then corrosion attack of the surface. At the surface were found some marks of fatigue, such as step fold fatigue crack growing (Figs.11-12). The final failure by cleavage fracture is shown in Figs.13-14.

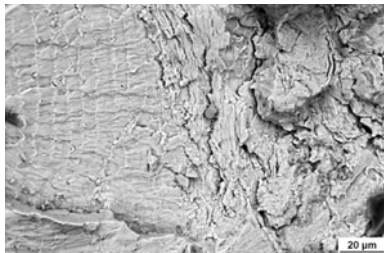


Fig.11. Step fold fatigue crack growth

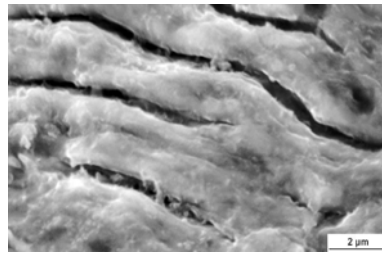


Fig.12. Detail of striation

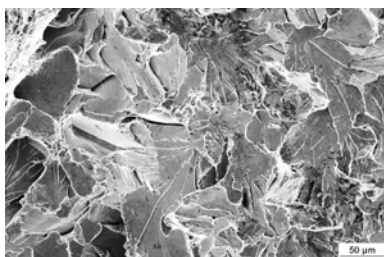


Fig.13. Cleavage fracture

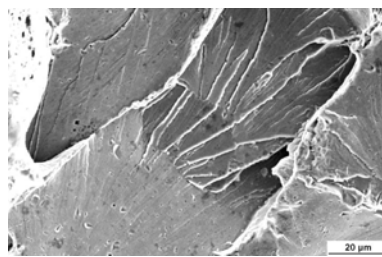


Fig.14. Detail of cleavage fracture

Results of measuring the length of steps are shown in Figs.15-16. Step distance was about 8 μm. This dimension had no connectivity with microstructure.

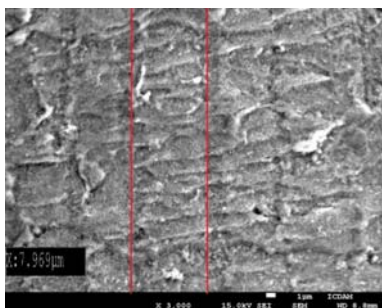


Fig.15. Measurement of step distance

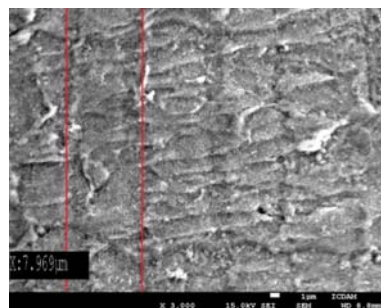


Fig.16. Measurement of step distance

CONCLUSION

The first set of rollers of paper dewatering press served without defects for approximately 8 years. The reason for replacement was lower thickness of shell. The second set of rollers failed after six years of service (equal to 17×10^6 cycles). The fracture was situated under the bearing.

The shaft is loaded by alternating bending at rotation (with added torque moment). Forces operating on rollers were the pressing force (114.8 kN) and torsion moment

(12±2kNm). During the production campaign, a paper dewatering press works in continuous mode. For strength calculations and lifetime calculations a maximal value of torsion moment 14 kNm was used. Results of calculations have shown that the shaft was designed properly and there wasn't reason for failure. Material verification was done by measurement of chemical composition and measurement of hardness. The chemical composition is equivalent with composition of material in technical documentation. Hardness measurement did not show significant difference between shaft core and surface hardness. Measurement of micro-hardness at and around the surface was prevented by significant deformation of the outer surface and some part of the fracture surface. Structural evaluation showed that microstructure of the shaft was ferritic-bainitic with recrystallized grains. Microstructure is in agreement with the value of hardness. Evaluation of fracture the surface confirmed typical signs of fatigue. From the macroscopic view of the fracture surface it is likely that there was more than one initiation of fatigue. Unfortunately the shaft surface was heavily damaged by rotation after failure, so it is not possible to identify initiation. The fracture area is 7.3% of cross-section of shaft. Fatigue mechanism was confirmed.

Some failure analyses of paper machines are listed in literature. In [3] is shown analysis of failure of a cast drying roller. The drying roller was in contact with evaporated water from paper and fracture was caused by corrosion cracking. [4] shows analysis of a fracture of roller shell caused by corrosion fatigue. Both [3] and [4] present results of the failure of a roller shell caused by corrosion. The shaft of roller is out of the wet corrosive area. Literature [5] analyzed the fracture of pressing rods of a paper machine. This failure was caused by the wrong choice of radius and high stress which lead to fatigue crack of rod. Under the bearing was no radius or other design element. Other fatigue failure of the roller is shown in [6]. Fatigue crack was caused by unbalance of the roller and high rotation. In our case the average rotation of the roller was about 6.3 r/min, which is too low for this possibility. It means that this type of failure is not usual and probably was caused by some other reason. A complex calculation model for paper machine is shown in [7]. Many parameters with different relevance were included in the model. One parameter was the torsion moment, which had quite a high influence as to the complex designing of a paper machine.

The control system of the manufacturing line measures the torsion moment. During 4 hours before failure the torsion moment jumped over maximal allowed value of 14 kNm to 17 kNm. It means that safety valves did not work properly. The problem with safety valves allowed a higher torsion moment which lead to fatigue of the paper dewatering press machine shaft.

Acknowledgements

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