FAILURE ANALYSIS OF A WIRE ROPE BELONGING TO THE TRACTION SYSTEM OF A CABLE CAR

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ABSTRACT

Failure analysis of a wire rope belonging to the traction system of a cable car was conduced. The specific failed wire rope, a 6x19 Seale type with nylon fiber soul, had been in service for three years by the time of the accident. The whole system had been in service for 30 years without similar reports of such a failure. Project loads for the specific traction system attended the reference standards and the loads were much lower than the specified resistance at the moment of the failure. The microstructure of the wires had no metallurgical problems and its hardness was in accordance with the specified resistance limit. Nevertheless, it was observed that the fiber soul was completely degraded at the fracture region, which resulted in insufficient oil lubrication and absence of corrosion protection. Corrosion has developed at the interior of the wire rope, resulting in corrosion-fatigue failure. Several cracks were found throughout the interior part of the cable. The failure occurred at the wire rope section inside of the pulley system which is the region that imposes the severest cyclic load conditions to the rope, therefore prone to fatigue failures. The failure originated inside the cable, turning it impossible to detect it during the daily visual inspections and diameter measurements. The reasons that have led to the degradation of the soul remain unknown. As a consequence of the occurrence of this failure, a complete review of the maintenance and inspection procedures was realized in order to increase the system security.

1 INTRODUCTION

A wire rope belonging to the traction system of a cable car has fractured in service. The incident left neither injured people nor significant material damages. Nevertheless, the reasons behind this unexpected failure were studied in order to correct any possible flaws in the system. The system has been in operation for more than 30 years with regular exchanges of the steel cable whenever its diameter achieves a pre-established value. There were no reports of similar accidents during that time and the fractured cable had been in service for three years by the time of its failure. The wire rope rupture has happened 40 meters away from the car in a region that circulates along the whole pulley system, which is the region where the rope is submitted to the severest cyclic load conditions. Great concern arose from the accident since there was no reasonable cause, thus requiring a detailed failure analysis.

The wire rope used at the traction system was a 6x19 Seale type with fiber soul schematic presented in Figure 1a[1]. The rope diameter was 24mm, while each cable leg was composed by 9 external wires of 1.1mm of diameter, 9 internal wires of 1.1mm and one central wire of 2.1mm. The minimal effective resistance specified was 327.8kN while the specified resistance limit of the wire is 1.77GPa. A picture of the fractured cable is presented in Figure 1b. The criterion for substitution of the wire rope was based in its external wear, therefore regular measurement of the external diameter of the rope is recomended[2].

2 EXPERIMENTAL PROCEDURES

The failure analysis started with detailed photographs of the cable and all the involved equipments. The load at the moment of the failure was estimated as 38kN according to operational records. An analysis of the traction system that contained this wire rope was conducted, concluding that it was in accordance with the pertinent standard references[2,3,4].

(a) (b)

Figure 1 – (a) Schematic drawing[1] of the (b) fractured traction cable structure.

A new wire rope produced by the same manufacturer was provided for the necessary comparisons. Chemical composition of both cables is presented in Table I, where it can be noticed that there is no significant variations between the failed cable and the new one.

Table I – Chemical analysis of the wires from the new cable and from the fractured cable.

CHEMICAL ANALYSIS (%WEIGHT)									
Sample	C	Mn	Cr	Ni	Mo	P	S	Si	Cu
Wire from a New Cable	0,65	0,69	0,02	0,01	0,00	0,005	0,018	0,25	0,01
Wire from the Fractured Cable	0,70	0,66	0,05	0,04	0,00	0,010	0,018	0,21	0,07

Vickers microhardness of the wires was determined in order to compare it to the specified resistance limit of the wire.

Optical microscopy was performed on the three kinds of wires from the fractured rope. Sample preparation consisted of cutting, grinding, polishing and etching both at the longitudinal and at the transversal section.

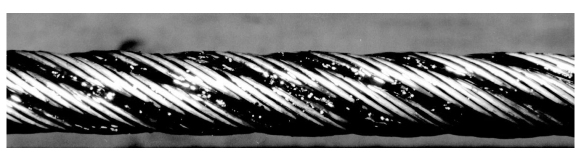
The fracture surfaces from each wire were inspected in detail under the scanning electron microscope. In order to do so a Jeol 5800 LV equipped with a Noran EDS probe was used.

3 RESULTS AND DISCUSSION

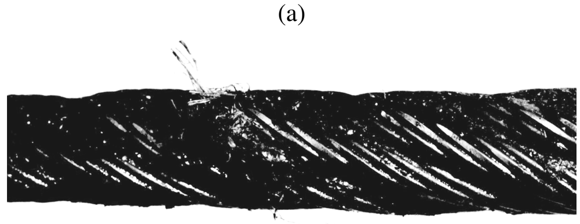
During failure analysis, the first noticed fact was the excellent conditions of maintenance of all the wire rope system. It is important to remark that maintenance procedures included weekly oiling, daily measurement of the external diameter of the cable and visual inspection in search for failed wires. Wire rope substitution was conduced whenever the external diameter presented a 6% reduction in the external diameter.

The microstructure observed was typical of a drawn ferritic-perlitic steel wire with no signs of any kind of metallurgical problems, which is confirmed by the microhardness tests that evaluated the resistance limit in 1,62GPa, close enough to the specified resistance limit for a cable that had been three years in service.

Figure 2 presents a comparison between a new rope and a sample obtained from fractured cable. Visual inspection near the fracture revealed that the wires presented natural wear as a result from the time in service. It should also be pointed out that there are nylon fiber squeezed between the rope legs, suggesting that something might have occurred with the fiber soul. In fact, the observation of the fiber soul near the fracture showed that it had completely lost its fibrous nature (presented in Figure 3a), having been transformed in a fragile polymer block as showed at Figure 3b.



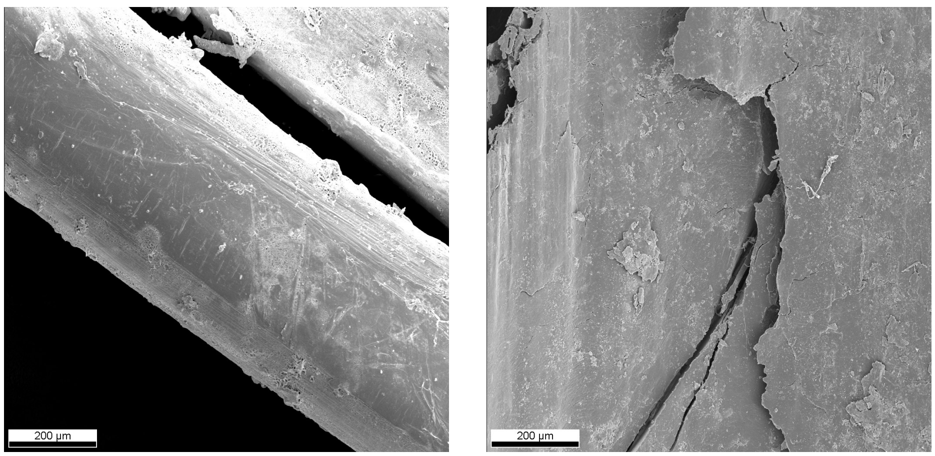
(a)



(b)

Figure 2 – (a) New cable perfectly oiled. (b) Region from the fractured cable near the fracture presenting part of the nylon fiber soul squeezed between the cable legs.

Degradation of the fiber soul resulted in insufficient oiling of the interior of the steel cable which generated a corrosion process as can be seen at Figure 4. This corrosion coupled with cyclic loads induced by the pulley system seems to have resulted in a fatigue-corrosion mechanism. Several wires have presented cracks which completely degraded the wire integrity as can be seen in Figure 5. The fracture surface presented clear signs of fatigue, as the striations shown in Figure 6 clearly evoke. Final fracture occurred by the overload of the reminiscent resistant section as can be seen in Figure 7 where microcavities testify the maintenance of the ductile behavior of material.



(a) (b)

Figure 3 –SEM micrographs of the nylon soul from (a) a new cable and (b) from the region where the failure occurred showing how the fiber has been transformed into a monolithic fragile block.

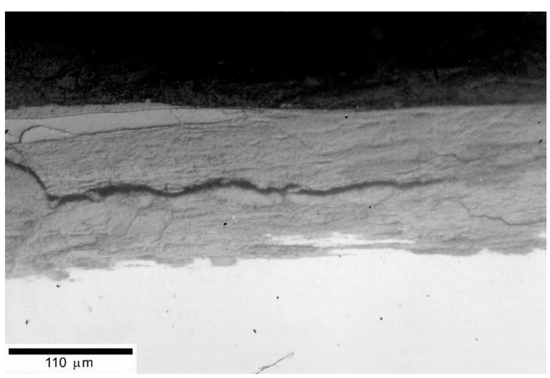


Figure 4 – Optical micrograph of a polished longitudinal section where an oxide layer can be clearly identified.

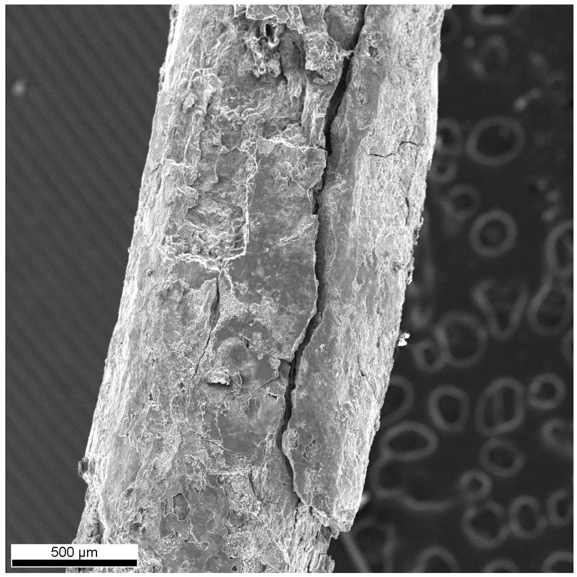


Figure 5 – SEM micrograph of a wire where a fatigue crack was found.

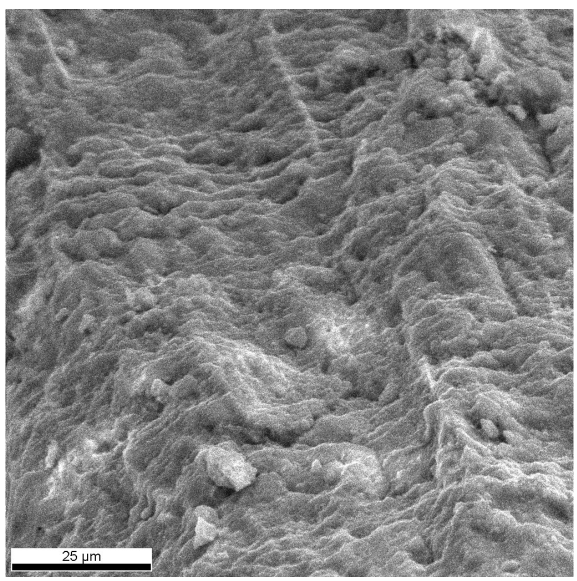


Figure 6 – SEM micrograph at a $\phi = 1{,}9$mm wire presenting distinctive striations formed as a result of the corrosion fatigue process.

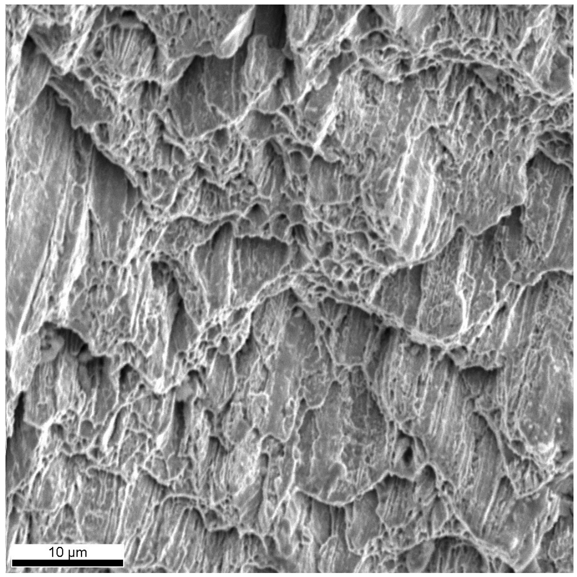


Figure 7 – SEM micrograph of the final fracture of the $\phi = 1,1$mm wire from the cable presenting dimples.

4 CONCLUSION

A failure analysis of a wire rope was conduced in order to determine the mechanism undergone. The failure resulted from the degradation of the fiber soul, which lacked its function of retaining the lubrication oil regularly dipped. Therfore, the interior of the rope remained without oil protection and a corrosion process started. At the pulley region this led to a corrosion-fatigue mechanism which completely degraded the rope resistance resulting in the final overload failure. The reasons behind the fiber soul degradation remain unknown.

The occurrence of this failure has led to a series of countermeasures by the wire rope user. Lubrication oil has been changed, a cable life control based upon the number of load cycles was implemented and, what is most important, magnetoscopy of the role cable system was conduced since daily external diameter measures could not detect defects in the interior of the cable.

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