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Failure Analysis of Wire Rope Used in Hoist System

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Abstract

During heavy lift operations in the hoist system, the steel wire rope in a 10-ton hoist crane system experienced catastrophic failure after 120 days of service, exhibiting severe structural damage. To determine the cause of failure, the samples from the damaged rope were investigated through visual inspection and stereomicroscopic and Scanning Electron Microscopy (SEM) analysis. Further, the nature of the damages was determined based on worksheet data collected to correlate operational conditions with potential failure mechanisms. The initial inspection results revealed that the localised failure zones in the upper-layer wires of the cable strands were not caused by fatigue. Stereomicroscopic and SEM analysis confirmed that localised plastic deformation and wear of individual wires led to the development of stress concentration, ultimately resulting in fatigue failure. All these occurrences were attributed to the operation of the crane hoist system and the conditions during installation.

Major Findings: *During heavy lift operations in the hoist system, the steel wire rope in a 10-ton hoist crane system experienced catastrophic failure after 120 days of service, exhibiting severe structural damage.*

Keywords: *Fatigue, Metallographic Analysis, Plastic Deformation, Steel Wire Rope*

1.0 Introduction

Steel wire ropes, with their high axial strength and bending flexibility, are essential structural components in various industries for efficiently transporting heavy loads using overhead cranes and hoist systems[1,2]. Wire ropes are extensively utilised in harbours, ships, and various industrial applications, where their integrity is critical to operational and equipment safety[3]. The quality and wear of wire ropes directly impact the reliability of mining hoists, cranes, elevators, and aerial transport systems[4]. Therefore, continuous condition monitoring is essential to ensure timely replacement or extended service life within safe operational limits. A hoisting rope must endure cyclic axial tension and bending stresses imposed by the drum and guide wheel, leading to fretting wear between steel wires[5]. This wear accelerates fretting damage, crack initiation, propagation, and eventual fracture failure[6,7]. Given the critical role of wire ropes in crane systems, failure analysis is essential for identifying potential issues, assessing performance, and preventing recurrence[8,9]. Therefore, special attention must be given to wire ropes in service, particularly in studying wear mechanisms and monitoring performance to extend service life[10,11].

Several researchers have analysed wire rope performance and failure mechanisms. Zhang *et al.*[12] explored bending fatigue behaviours and failure mechanisms using both non-destructive quantitative detection and artificial inspection methods. Giglio and Manes[13] investigated the lifespan of wire ropes under axial and bending loads, comparing various analytical models to assess stress distribution in internal and external wires. Chaplin[14] conducted an in-depth analysis of wire rope failure mechanisms across three applications: a mine hoist rope on a drum winder, a mooring rope for an offshore structure, and a spin-resistant offshore crane rope. Périer *et al.*[15] investigated the fretting-fatigue behaviour of drawn steel wires exposed to sodium

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chloride solutions. Experimental tests were conducted to replicate contact conditions in spiral strands subjected to free-bending deformations and corrosion. In a subsequent study[16], the same author examined the impact of aqueous environments on the fretting behaviours of steel wires used in civil engineering cables. Wang *et al.*[17] studied hoisting rope failures, focusing on various factors influencing fretting-fatigue behaviours. He examined the effect of displacement amplitude on fretting-fatigue in steel wires under low-cycle fatigue at two cyclic strain levels.

Additionally, Wang *et al.*[18] developed a simulation model to analyse rope tension, assessing the impact of different kinematic parameters on tension magnitude and amplitude during lifting operations. Further research explored the effect of strain amplitude on fretting fatigue behaviours using a specialised test rig capable of applying a constant normal contact load. Moreover, Wang *et al.*[19] investigated the influence of terminal mass on fretting and fatigue parameters in hoisting ropes during lifting cycles in coal mines. He also analysed the stress distribution of contacting wires during the early stages of fretting-fatigue using the FEM[20].

Elata *et al.*,[21] investigated the mechanical behaviour of a wire rope featuring an independent wire rope core. In a subsequent study, Shen *et al.*,[22] performed fretting wear tests using a custom-designed fretting wear rig to examine the wear characteristics of steel wires under friction-enhancing grease conditions. The findings revealed that fretting regimes were influenced by displacement amplitudes and normal loads. Tittel *et al.*,[23] investigated the impact of the die drawing angle on the wire drawing and bunching process.

The application of Magnetic Flux Leakage (MFL) methods for the Non-Destructive Evaluation (NDE) of metal components has been well-established for decades[24]. MFL techniques are widely employed for non-intrusive detection and characterisation of wire rope defects[25]. Christen *et al.*,[24] utilised three-dimensional localisation techniques to detect defects in stay cables. While commercial electromagnetic testing instruments can identify small defects, they provide only approximate defect locations. To enhance defect detection, Cao *et al.*,[26] introduced a novel electromagnetic method for inspecting local wire rope defects. Most electromagnetic testing instruments produce a one-dimensional axial MFL signal, which fails to capture the circumferential distribution of defects. To address this, an inspection prototype incorporating a Hall sensor array was developed to acquire two-dimensional magnetic leakage signals. Wei and Jianxin[27] designed a transducer using fluxgate sensors for wire rope defect detection, while Chen and Xu[28] proposed a real-time, online monitoring system for multi-rope hoist wire tension, enabling precise calculation of hoisting loads and tension variations. Vallan[29] analysed uncertainty factors affecting defect position measurements in electromagnetic testing systems, integrating a laser-based detector with a digital acquisition system for enhanced accuracy. Vallan and Molinari[30] developed a measurement system utilising a video camera and an offline image-processing algorithm. This system captures image sequences of running ropes, extracts contours, and measures strand distances and overall displacement during testing. Radovanovic *et al.*,[31] employed magnetic inspection techniques to ensure comprehensive wire rope monitoring in compliance with international standards. Additionally, Stroffek and Lesso[32] proposed an acoustic method to measure Young's modulus of steel wire ropes, contributing to the evaluation of mechanical properties and structural integrity.

A review of the existing literature indicates that researchers have extensively investigated the fretting behaviour and wear scars of steel wires through experimental, analytical, and simulation approaches. However, to the best of the authors' knowledge, no research has specifically investigated the impact of localised plastic deformation and individual wire wear on the development of stress concentration.

Therefore, the objective of this study is to conduct a failure analysis of a steel wire rope that experienced catastrophic failure under standard operating conditions, without prior detectable anomalies (deviations) in the overhead crane system's performance. The failure occurred after 75 days of service while lifting a weight of 8-ton industrial paper roll, despite an expected operational lifespan that was twice as long. In contrast, a previously used wire rope with identical specifications remained functional for the 100 days before undergoing preventive maintenance.

2.0 Materials and Methods

2.1 Profile of the Steel Rope

The investigated steel wire rope consists of 19 individual strands, with each strand comprising 7 wires of uniform diameter.

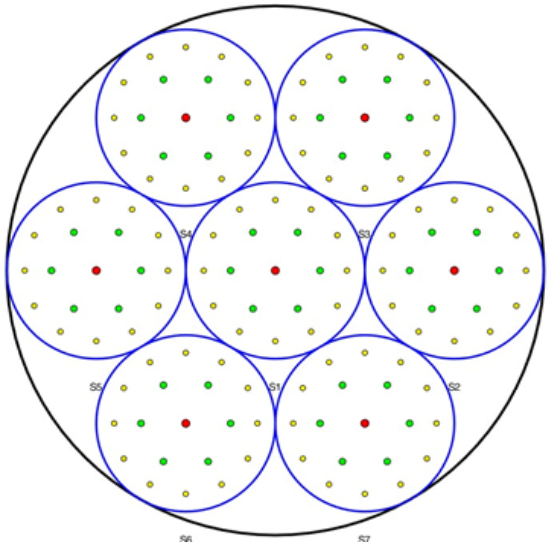


Figure 1. Wire rope of 19×7 type.

This wire rope is an integral component of an overhead crane system designed for material handling applications, specifically for transporting industrial paper rolls. The crane system has a maximum load capacity of 20 tons, with a typical operational lifting range of 5–7 tons. Failure of the wire rope core was observed under normal working conditions, necessitating a comprehensive failure analysis to determine the contributing factors.

The chemical composition of the steel wire rope was characterised following the American Society for Testing and Materials (ASTM) E-415[33] and ASTM E-1019[34] standards to ensure compliance with material specifications as shown in Table 1. The mechanical properties were evaluated, with the Ultimate Tensile Strength (UTS) of each strand measured at 572kg according to ASTM E-8 standards[35]. These evaluations provide insight into the rope's load-bearing capability and potential failure mechanisms under cyclic loading conditions.

Figure 2 presents the wire rope and pulley system installed in the crane assembly. A notable observation from the analysis is the significant accumulation of paper dust on various crane components, particularly on the wire rope. This particulate contamination poses a potential risk to the performance of the wire rope, as paper dust has a high absorption capacity for lubricants. The absorption and retention of lubricant by the dust particles can reduce the wire rope's effective lubrication, accelerate wear, increase frictional resistance, and potentially contribute to premature mechanical degradation. Understanding the impact of these environmental factors is crucial for developing maintenance strategies that enhance the longevity and reliability of the crane system.

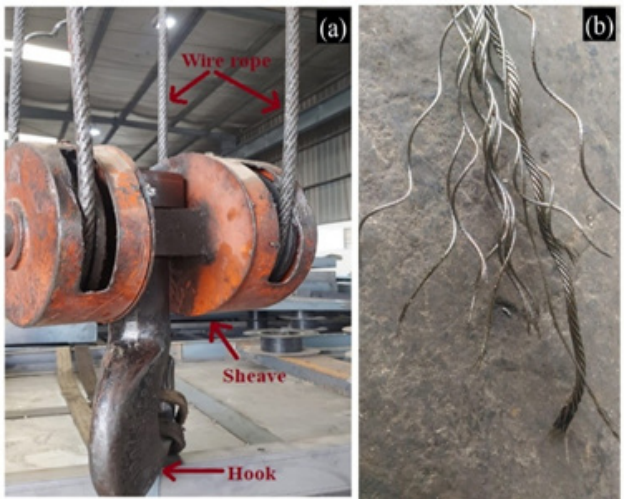


Figure 2. Wire rope and pulley mechanism with failed steel wire rope.

Table 1. Chemical composition of the steel wire rope

Chemical Component	C	Mn	P	S	Cu	Ni	Si	Cr	Al	Ca	Pb	Sn	Other
Weight (%)	0.64	0.55	0.07	0.01	0.06	0.01	0.16	0.04	0.01	0.02	0.05	0.01	0.04

3.0 Experimental Techniques

3.1 Visual Inspection

To conduct a comprehensive failure analysis, the wire rope was systematically categorised into two different sections, designated as "B" and "C" in Figure 3.

Furthermore, Figure 4 (a) provides a macroscopic overview of the wire rope's condition, highlighting areas of wear and deformation (denoted by red circles). Furthermore, the external strands of the wire rope exhibit fractured wires, indicative of a brittle fracture mechanism.

Figure 4 (b) illustrates the presence of multiple defects distributed along the longitudinal axis of the wire rope, including within its core. Additionally, fractures are evident at locations distal to the primary failure site, as indicated by directional arrows. Notably, these wear patterns represent a correlation with regions exhibiting significant wear scars and plastic deformation.

3.2 Fractographic Analysis

Figure 5 (a) exhibits wear wires displaying both pre-fracture plastic deformation and brittle fracture morphology. Additionally, the wear-induced degradation is evident on the external strands of the wire rope. These wear-deformed regions, where strain localisation occurs, serve as preferential nucleation sites for premature wire failure and ultimately compromise the structural integrity of the rope.

The plastic deformation induces localised strain hardening, accelerating towards the fracture initiation and promoting the crack nucleation. Furthermore, these worn surfaces act as stress concentrators during bending

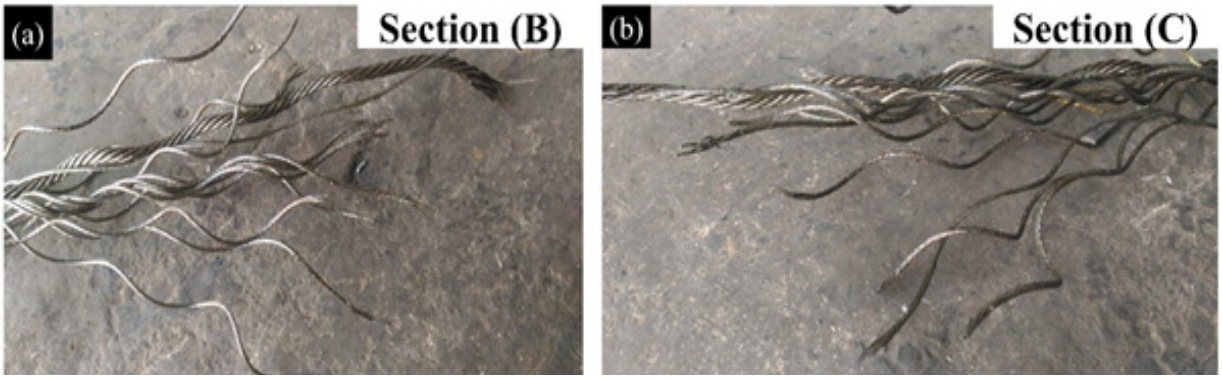


Figure 3. The failed steel wire rope.

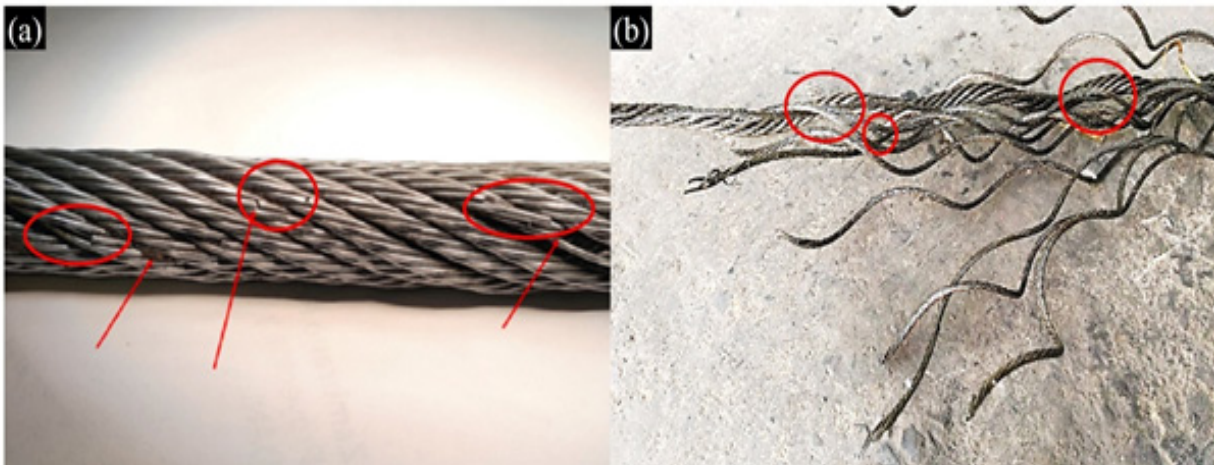


Figure 4. Failure defects **(a)** In the wire ropes and **(b)** in the strand sections.

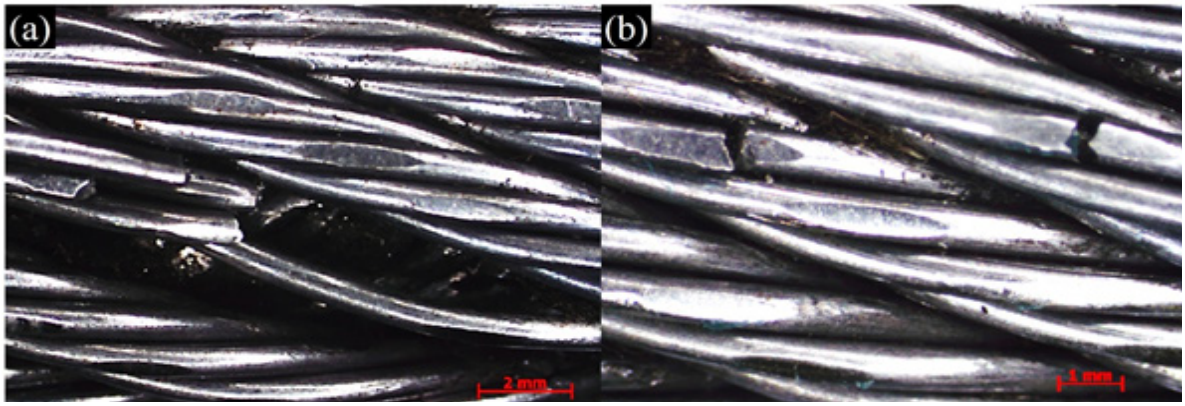


Figure 5. **(a)** Multiple wires exhibit surface wear, and **(b)** Presence of brittle fracture on the outer layer of the wire.

cycles within the overhead crane system, enhancing wear, deformation, and progressive fracture propagation along the wire rope.

Figure 5 (b) illustrates wire fractures within wear-deformed zones, resulting from the synergistic effects of strain localisation and tensile stress states[36]. Such conditions are prevalent during wire rope winding over crane system pulleys, where metal-to-metal contact between the pulley and rope accelerates tribological wear[37].

3.3 Fracture Mode Characterisation

Fracture morphology and microstructural analysis provide critical insights into the failure mechanism and its

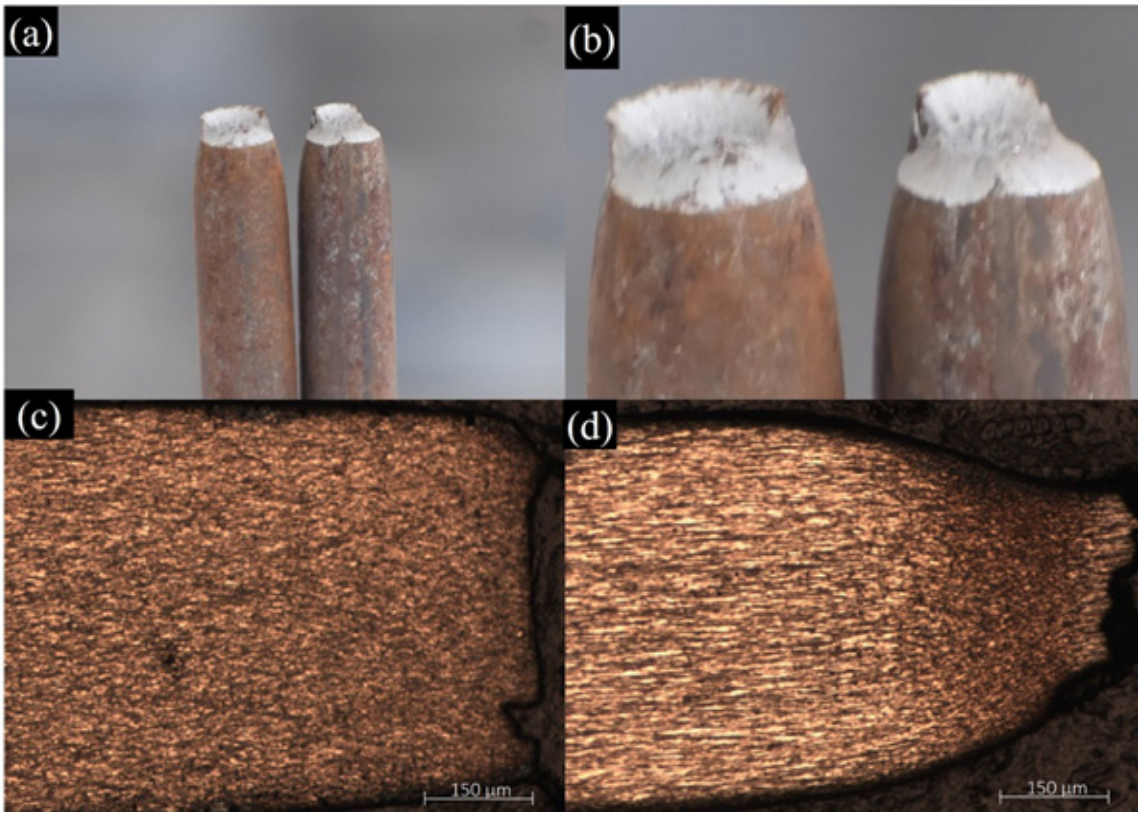


Figure 6. Illustrative examples of failure modes along.

etiological factors. Extensive fractographic studies were conducted, beginning with the help of stereomicroscopic examination. Figure 6 (a, b) exhibits brittle fracture surfaces with negligible reduction in cross-sectional area, indicative of low-energy crack propagation. Figure 6 (c, d) reveals ductile fracture surfaces with pronounced plastic deformation, including necking near the fracture zone characteristic of tensile overload failure. This ductile response suggests cyclic loading as a contributing factor.

A predominance of brittle fractures was observed in the analysed wires, lacking neck formation in Figure 6 (a) and (b), consistent with fatigue-induced failure mechanisms. Conversely, the ductile fracture morphology in Figure 6 (b) and (d) correlates with stress concentration-induced fracture, likely arising from cyclic loading conditions.

3.4 Mechanical Response and Strain Hardening Behaviour

Strain hardening, induced by plastic deformation, alters the mechanical properties of the material and influences its failure mechanism. To assess the localised strain hardening in the wire rope, microhardness testing was conducted across distinct regions of interest. These measurements aimed to quantify variations in hardness along the wire, spanning from the adjacent unaffected zone to the fracture zone[37].

As illustrated in Figure 7, the hardness distribution reveals minor but discernible differences. Specifically, the fracture zone in zone "B" exhibits a slight increase in hardness compared to other regions, correlating with more pronounced damage accumulation. Similarly, in zone "C", the fracture zone demonstrates marginally higher hardness than its adjacent unaffected region. Each data point represents the mean hardness value derived from 20 indentations per zone, with standard deviation ranging between 1.03 and 1.17, indicating consistent measurement reproducibility.

Table 2 shows the additional Hardness Values (HV10) taken from different zones of a failed wire rope for comparison. These hypothetical values help give a broader picture of material consistency and possible anomalies contributing to failure.

Table 2. Hardness values of failed wire rope (HV10)

Location of Sample	Hardness (HV10)
Away from the damage zone	273 ± 2
Near the fracture location	274 ± 2
Surface layer (outer strands)	270 ± 2
Mid-length (between ends)	263 ± 3
The opposite end of the fracture	275 ± 2
Adjacent to the wire rope clamp	262 ± 2
Damaged zone (localised)	276 ± 4

The hardness values are consistent, indicating uniform heat treatment and material quality. Slightly higher hardness in the damaged zone (273 ± 4 HV10), where the work hardening is due to overloading or deformation. No significant soft zones were found, which rules out tempering or thermal degradation as a failure cause.

The load-displacement and stress-strain curves of the wire rope (Figure 8) reveal distinct deformation characteristics under tensile loading. The load-displacement response exhibits a nonlinear progression, reaching a peak load of approximately 35kN, followed by gradual softening indicative of progressive wire

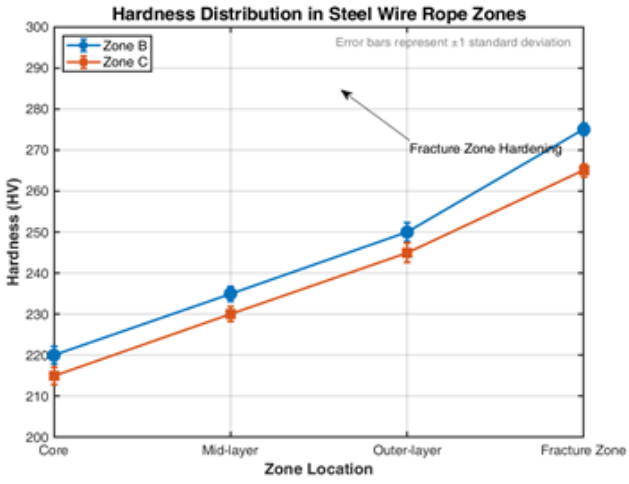


Figure 7. Hardness characteristics of steel wire rope in distinct zones.

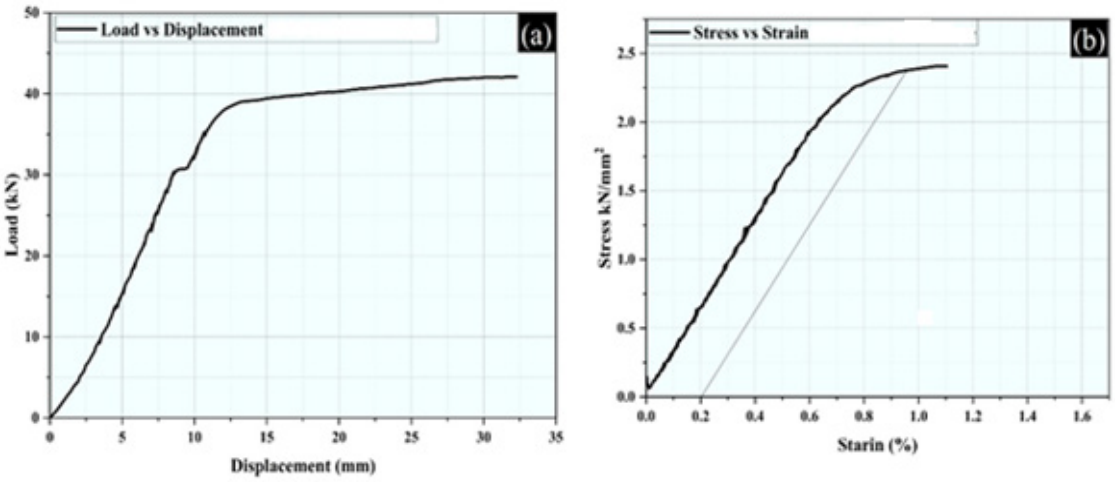


Figure 8. **(a)** Load-displacement and **(b)** stress-strain curves of wire rope.

rope failure. Correspondingly, the stress-strain curve demonstrates strain hardening, with stress peaking at ~2.5 kN/mm² at 1.6% strain, reflecting the material's capacity to redistribute localised plastic deformation before fracture.

In contrast, the wire rope (Figure 8) displays a comparatively stiffer initial response, with load-displacement trends suggesting an earlier onset of yielding and reduced ductility. The stress-strain relationship further highlights this difference, as the curve plateaus at lower stress levels, implying limited strain hardening capacity. These variations are attributed to differences in wire rope architecture; the configuration's layered wire arrangement enhances load distribution and delays localised failure, while the wire rope's simpler geometry concentrates stresses more rapidly.

3.5 SEM Analysis

Fractographic analysis via SEM is shown in Figure 9 (a, b), which revealed brittle fracture characteristics in both the core and wires, indicative of fatigue-induced failure and strain hardening effects. Fatigue fractures exhibited three distinct stages: crack initiation, and final overload rupture.

Fractures predominantly originated in worn-deformed regions, with tribological wear evident in both the core and outer wires, as marked by arrows (Figure 9 a, b).

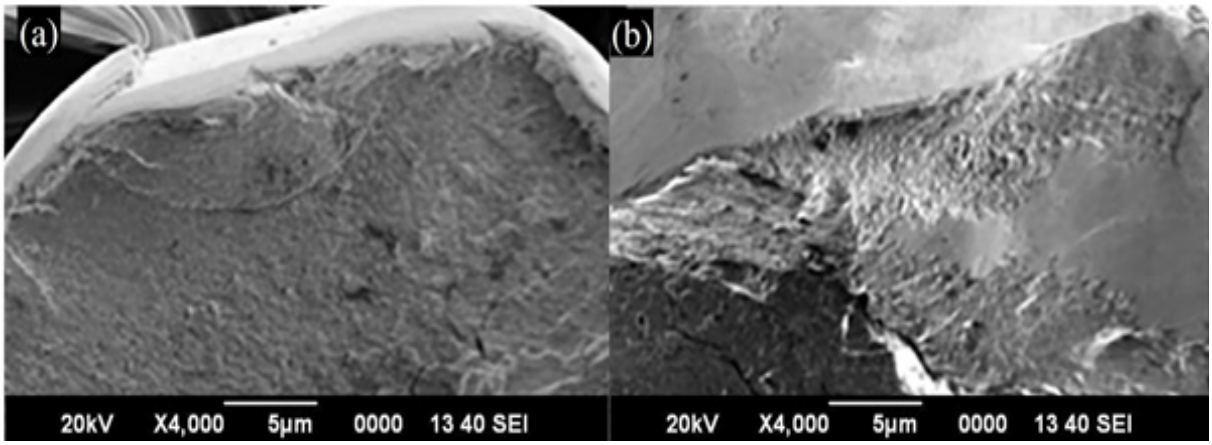


Figure 9. **(a)** and **(b)** Scanning electron microscopy of wire rope.

4.0 Discussion

The failure mechanism of the wire rope can be attributed to multiple interrelated factors, with contact stress playing a pivotal role in accelerating fatigue degradation through localised wear-induced deformation. Wear progression is further influenced by maintenance practices, inspection frequency, and selection criteria, including mean and cyclic stress ranges as well as operational length, all of which are collectively responsible for fatigue behaviour. Empirical studies suggest that failure initiation occurred due to wear-induced deformation of the outer wires, driven by factors such as service life exhaustion, overload conditions beyond permissible stress limits, and core degradation exacerbated by lubricant breakdown. Visual inspections and stereoscopic analysis confirmed severe lubricant deterioration, compounded by contamination from paper dust, which absorbed the lubricant and formed a high-viscosity residue, significantly impairing lubrication efficacy. Metallographic and fractographic assessments revealed that wear-induced stress concentrations facilitated fatigue crack nucleation, with evidence of necking in fractured wires indicating a progressive failure sequence, initial rupture of worn wires, followed by overload failure of the remaining wires due to load redistribution.

5.0 Conclusion

Based on the failure analysis, the following sequence of events is proposed to explain the progressive degradation of the wire rope:

- The failure mechanism initiated with deformation and wear on the outer wires, leading to crack nucleation. These cracks propagated under cyclic loading as the rope passed over the pulley, ultimately resulting in the rupture of multiple outer wires. This mechanism was verified by SEM analysis.
- Following the failure of the outer wires, the remaining wires experienced increased stress concentrations, eventually exceeding the elastic limit of the material. This led to strain hardening, particularly in the core wires, culminating in brittle fracture. Visual inspection confirmed lubricant degradation, further exacerbating stress accumulation in the central region.
- The remaining wires failed catastrophically due to cyclic loading beyond their yield strength, resulting in a loss of tensile integrity.

6.0 Declaration

The authors have confirmed that this manuscript is original, has not been published elsewhere, and is not under consideration by another journal. All authors have approved the final version and agree to its submission.

7.0 References

1. Pei B, Chong A, Xia H, Kang X. Design and key construction technology of steel-concrete-steel sandwich composite pylon for a large span cable-stayed bridge. Sci Rep. 2023; 13(1):1-17. https://doi.org/10.1038/s41598-023-33316-7 PMid:37095167 PMCid:PMC10125975.
2. Tajani F, Fang S, Mazurek P. A comprehensive review of steel wire rope degradation mechanisms and recent damage detection methods. Sustain. 2023; 5441(15):6:5441. https://doi.org/10.3390/su15065441
3. Banfield S, Casey N. Evaluation of fibre rope properties for offshore mooring. Ocean Eng. 1998; 25(10):861-879. https://doi.org/10.1016/S0029-8018(97)10017-8
4. Jiang Y, Wen Z, Chen Y, Xiang C, Chao S. Friction and wear failure mechanism analysis of QT600-3 ductile iron elevator traction sheave. Eng Fail Anal. 2025; 173:109414. https://doi.org/10.1016/j.engfailanal.2025.109414
5. Wang G *et al*. Tribological properties and residual strength of wire rope with different strands during the interlayer-transition stage. Wear. 2021; 480-481:203930. https://doi.org/10.1016/j.wear.2021.203930
6. Sunde SL, Berto F, Haugen B. Predicting fretting fatigue in engineering design. Int J Fatigue. 2018; 117:314-326. https://doi.org/10.1016/j.ijfatigue.2018.08.028
7. Hojjati-Talemi R, Wahab MA, Giner E, Sabsabi M. Numerical estimation of fretting fatigue lifetime using damage and fracture mechanics. Tribol Lett. 2013; 52(1):11-25. https://doi.org/10.1007/s11249-013-0189-8
8. Hojjati-Talemi R, Abdel Wahab M, De Pauw J, De Baets P. Prediction of fretting fatigue crack initiation and propagation lifetime for cylindrical contact configuration. Tribol Int. 2014; 76:73-91. https://doi.org/10.1016/j.triboint.2014.02.017

9. Pereira K, Bhatti N, Abdel Wahab M. Prediction of fretting fatigue crack initiation location and direction using cohesive zone model. Tribol Int. 2018; 127:245-254. https://doi.org/10.1016/j.triboint.2018.05.038
10. Madge JJ, Leen SB, Shipway PH. A combined wear and crack nucleation-propagation methodology for fretting fatigue prediction. Int J Fatigue. 2008; 30(9):1509-1528. https://doi.org/10.1016/j.ijfatigue.2008.01.002
11. Hojjati-Talemi R, Wahab MA. Fretting fatigue crack initiation lifetime predictor tool: Using damage mechanics approach. Tribol Int. 2013; 60:176-186. https://doi.org/10.1016/j.triboint.2012.10.028
12. Zhang D *et al*.. Bending fatigue behaviour of bearing ropes working around pulleys of different materials. Eng Fail Anal. 2013; 33:37-47. https://doi.org/10.1016/j.engfailanal.2013.04.018
13. Giglio M, Manes A. Life prediction of a wire rope subjected to axial and bending loads. Eng Fail Anal. 2005; 12(4):549-568. https://doi.org/10.1016/j.engfailanal.2004.09.002
14. Chaplin CR. Failure mechanisms in wire ropes. Eng Fail Anal. 1995; 2(1):45-57. https://doi.org/10.1016/1350-6307(95)00004-A
15. Périer V, Dieng L, Gaillet L, Tessier C, Fouvry S. Fretting-fatigue behaviour of bridge engineering cables in a solution of sodium chloride. Wear. 2009; 267(1-4):308-314. https://doi.org/10.1016/j.wear.2008.12.107
16. Périer V, Dieng L, Gaillet L, Fouvry S. Influence of an aqueous environment on the fretting behaviour of steel wires used in civil engineering cables. Wear. 2011; 271(9-10):1585-1593. https://doi.org/10.1016/j.wear.2011.01.095
17. Wang D, Zhang D, Ge S. Effect of displacement amplitude on fretting fatigue behavior of hoisting rope wires in low cycle fatigue. Tribol Int. 2012; 52:178-189. https://doi.org/10.1016/j.triboint.2012.04.008
18. Wang D, Zhang D, Zhang Z, Ge S. Effect of various kinematic parameters of mine hoist on fretting parameters of hoisting rope and a new fretting fatigue test apparatus of steel wires. Eng Fail Anal. 2012; 22:92-112. https://doi.org/10.1016/j.engfailanal.2012.01.008
19. Wang D, Zhang D, Ge S. Effect of terminal mass on fretting and fatigue parameters of a hoisting rope during a lifting cycle in coal mine. Eng Fail Anal. 2014; 36:407-422. https://doi.org/10.1016/j.engfailanal.2013.11.006
20. Wang D, Zhang D, Ge S. Finite element analysis of fretting fatigue behavior of steel wires and crack initiation characteristics. Eng Fail Anal. 2013; 28:47-62. https://doi.org/10.1016/j.engfailanal.2012.09.007
21. Elata D, Eshkenazy R, Weiss MP. The mechanical behavior of a wire rope with an independent wire rope core. Int J Solids Struct. 2004; 41(5-6):1157-1172. https://doi.org/10.1016/j.ijsolstr.2003.11.021
22. Shen Y, Zhang D, Duan J, Wang D. Fretting wear behaviors of steel wires under friction-increasing grease conditions. Tribol Int. 2011; 44(11):1511-1517. https://doi.org/10.1016/j.triboint.2010.10.021
23. Tittel V, Zelenay L, Met KM, and undefined 2012. Effect of drawing angle size of a die on wire drawing and bunching process. Acad Tittle. Available from: https://www.academia.edu/download/116000669/176.pdf
24. Christen R, Bergamini A, Motavalli M. Three-dimensional localization of defects in stay cables using magnetic flux leakage methods. J Nondestruct Eval. 2003; 22(3):93-101. https://doi.org/10.1023/B:JONE.0000010736.74285.b6
25. Zhang D, Zhao M, Zhou Z, Pan S. Characterization of wire rope defects with gray level co-occurrence matrix of magnetic flux leakage images. J Nondestruct Eval. 2013; 32(1):37-43. https://doi.org/10.1007/s10921-012-0156-6
26. Cao YN, Zhang DL, Wang C, Gu Y, Xu DG. A novel electromagnetic method for local defects inspection of wire rope. IEEE Reg. 10 Annu Int Conf Proc. /TENCON. https://doi.org/10.1109/TENCON.2006.343716 PMCid:PMC13953508.
27. Wei G, Jianxin C. A transducer made up of fluxgate sensors for testing wire rope defects. IEEE Trans Instrum Meas. 2002; 51(1):120-124. https://doi.org/10.1109/19.989914
28. Chen H, Xu G. Multi-rope hoist wire rope tension on-line monitoring and analysis of reasons about tension imbalance. 2011 Int Conf Consum Electron Commun Networks, CECNet 2011 – Proc. 2011; 485-487. https://doi.org/10.1109/CECNET.2011.5768661
29. Vallan A, A system for the measurement of wire-rope defect positions. Conf Rec IEEE Instrum Meas Technol Conf. 2004; 2:1410-1415. https://doi.org/10.1109/IMTC.2004.1351330
30. Vallan A, Molinari F. A vision-based technique for lay length measurement of metallic wire ropes. IEEE Trans Instrum Meas. 2009; 58(5):1756-1762, https://doi.org/10.1109/TIM.2009.2012953
31. Radovanović ID, Rajović NM, Rajović VM, Jovičić NM. Signal acquisition and processing in the magnetic defectoscopy of steel wire ropes. 2011 19th Telecommun

Forum, TELFOR 2011 – Proc Pap. 2011; 864-867. https://doi.org/10.1109/TELFOR.2011.6143681
32. Stroffek E, Lesso L. Acoustic method for measurement of Young's modulus of steel wire ropes. Metalurgija. 2001; 40(4).
33. Test method for analysis of carbon and low-alloy steel by spark atomic emission spectrometry. 2021. https://doi.org/10.1520/E0415-21
34. Test methods for determination of carbon, sulfur, nitrogen, and oxygen in steel, iron, nickel, and cobalt alloys by various combustion and fusion techniques. 2018. https://doi.org/10.1520/E1019-18
35. Test methods for tension testing of metallic materials. 2022. https://doi.org/10.1520/E0008_E0008M-22
36. Zhang J *et al*. Tribo-fatigue behaviors of steel wire rope under bending fatigue with the variable tension. Wear. 2019; 428-429:154-161. https://doi.org/10.1016/j.wear.2019.03.004
37. Peterka P, Krešák J, Kropuch S, Fedorko G, Molnar V, Vojtko M. Failure analysis of hoisting steel wire rope. Eng Fail Anal. 2014; 45:96-105. https://doi.org/10.1016/j.engfailanal.2014.06.005