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THE OPTIMAL USE OF BENDING FATIGUE TESTING MACHINES FOR ROPES: A COMPARATIVE STUDY

Summary

This study investigates the use of different bending-fatigue testing machines for wire ropes and evaluates their comparability under harmonized test conditions. Therefore, three exemplary machine types were examined using identical rope construction, load, and geometric parameters to isolate the influence of the test setup itself.

Although the test conditions were harmonized, variations in fatigue life were observed, indicating that additional factors affect the rope performance. Possible influencing mechanisms were identified and discussed based on experimental observations and theoretical considerations.

The study highlights the importance of controlling mechanical and operational parameters to ensure the reliability of test results obtained from different bending-fatigue machines. The findings shall contribute to a better understanding of machine-dependent effects in rope fatigue testing and support future efforts toward improved standardization and reproducibility of experimental method.

Keywords: bending fatigue, wire ropes, OIPEEC recommendations, fatigue testing machines, service life, test standardization, reproducibility, single-sheave, multiple-sheave.

1 Introduction

1.1 Motivation and Background

During the 1961 Torino conference, Professors **Ugo Rossetti** and **Gideon Meeuse** brought together researchers, rope manufacturers, and users to address a fundamental issue: **different institutions had different definitions of a bending cycle, making data comparison nearly impossible [1].**

Initial meetings in Brussels (1962) and the first General Assembly in Zürich (1963) established a collaborative international framework with the objective of harmonizing test methods and terminology [1]. The motivation was consistent: to **ensure that** fatigue testing procedures were standardised so that results from different laboratories are valid and can be compared directly with each other.

This led to the establishment of the **O**rganisation **I**nternationale **p**our l'**É**tude de l'**E**ndurance des **C**âbles (**OIPEEC**) in the early 1960s.

As highlighted by **Gabor Oplatka** in the 2024 OIPEEC Conference keynote, the original motivation remains highly relevant: **reproducible test results**, independent of geographical location or test machine design, are indispensable for reliable endurance evaluation of wire ropes. However, despite more than six decades of technical progress, today´s situation differs markedly from OIPEEC`s founding vision.

A wide variety of bending fatigue testing machines and methodologies is now used worldwide. These differ in mechanical principles**,** reeving configurations**,** applied loads**,** bending lengths**,** evaluation criteria and many more [2]. This raises the question whether, bending fatigue results obtained from different machine types can be compared, even when testing with identical parameters and rope constructions.

This increasing methodological diversity has reintroduced the very problem OIPEEC set out to eliminate: **the lack of a universal, reproducible basis for assessing rope fatigue performance.** Addressing this issue is the core motivation for the present study.

1.2 Objectives of the study

The aim of this work is to quantify the influence of different bending fatigue machine principles on rope lifetime and service life, and to identify the key machine-related causes of irreproducibility between laboratories. Specifically, the study aims to:

- **evaluate** how machine design affects fatigue life results,
- **identify** machine-based sources of scatter and deviations,
- and **contribute** toward future harmonized testing standards by supplying quantitative machine-comparison data.

To achieve these objectives, three exemplary bending fatigue testing machines are investigated:

- **Single-Sheave** fatigue tester – conventional, widely used in industry [3].
- **Multiple-Sheave** principle[1] – designed to simulate realistic reeving systems [4].
- **Three-Zone** test stand[2] – enabling multiple bending regimes in one test loop.

Ultimately, this research aims to contribute to the development of harmonized testing standards for bending fatigue evaluation, supporting improved comparability and reproducibility of results across different machine types and laboratories**.**

1.3 OIPEEC Recommendations, and Current Standards

In 1988, OIPEEC published recommendations to standardize bending fatigue testing procedures across laboratories [5]. These guidelines introduced consistent terminology and minimum requirements for:

- **bending test types** (SBS[3], BSR[4]),
- bending **length** and bending **cycle definitions**,
- minimum **documentation requirements**,
- **standardized test parameters** (e.g., D/d = 25, σ = 100 N/mm²),
- **wire-break evaluation** rules over 6xd and 30xd reference lengths.
- and maximum **temperature recommendation** of 50°C.

These recommendations provided a crucial foundation for reproducible testing and significantly improved data comparability at the time. However, several requirements have emerged today:

- **Modern high-performance ropes** (e.g., compacted strands, plastic-coated cores, hybrid systems) were not considered.

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[1] by Verreet, Teissier
[2] by TU Dresden
[3] straight – bent – straight; simple bending
[4] bent – straight – reverse bent; reverse bending

- **Realistic multiple-sheave systems** and non-uniform bending exposure are not represented [6][7].
- **Machine-specific loading patterns** are not quantified.
- **Service-relevant effects** (e.g. lubrication degradation, heat buildup, or environmental effects) are insufficiently addressed.

However, the 1988 OIPEEC recommendations remain a valuable baseline. But recent developments in international standards highlighting bending fatigue testing results as a basis for proof of competence, show the necessity of standardized test procedures. Exemplary recent ISO developments are:

- **ISO 16625:2025 [8]** emphasizes cycle-based fatigue design requirements.
- **ISO 4309:2017 [9]** defines more detailed discard and inspection rules.

These advancements underline the urgent need to update bending fatigue testing standards toward greater realism, comparability, and machine independence — a central motivation of the present study.

2 Fundamentals of Bending Fatigue Testing

2.1 Physical Mechanism of Bending Fatigue

Bending fatigue of wire ropes is a progressive damage process caused by repeated curvature changes under tensile load. Each passage over a sheave produces alternating bending stresses in the outer and inner wires, superimposed on the axial tensile stress**.** The resulting cyclic strain variations lead to alternating elongation and compression within the rope cross-section. These fluctuations cause relative motion between wires and strands, among others leading to contact wear, and local stress concentrations. At these locations, microcracks initiate and propagate under continued cyclic loading until wire fractures occur — both on the outer surface and within the inner layers of the rope. The accumulation of such fractures progressively reduces the rope's residual strength, stiffness, and structural integrity.

2.2 Fatigue Life of Wire Ropes

Most wire-rope failures in service are not the result of a single overload event, but of cumulative damage from thousands or even millions of bending cycles. Laboratory bending-fatigue tests aim to reproduce these loading conditions under controlled, repeatable circumstances, allowing the systematic assessment of rope performance and the influence of design, material, and operational parameters.

The fatigue life of a wire rope denotes the number of bending cycles it can withstand under defined conditions before final fracture. The service life is the number of bending cycles it can withstand before reaching its state of discard, typically indicated by a specified number of wire breaks or a critical loss of diameter [9]. In contrast to static strength, which depends mainly on the tensile properties of the wires, fatigue resistance reflects the rope's ability to sustain repeated bending under tension without progressive structural degradation.

2.2.1 Characteristic Fatigue Behaviour

The fatigue behaviour of wire ropes can be represented by an S–N (Wöhler) curve, in which the number of cycles to failure decreases with increasing bending severity, typically quantified by the D/d ratio [3]. The lifetime N can be estimated empirically using several established approaches, including:

Stuttgart method by *Feyrer* [3]:

$$\lg N = b_0 + \left(b_1 + b_3 \lg\frac{D}{d}\right) \cdot \left(\lg\frac{S}{d^2} - 0{,}4 \lg\frac{R_0}{1770}\right) + b_2 \lg\frac{D}{d} + f_i \qquad (1)$$

b_i regression constants
R_0 wire tensile grade
f_i factors for further influences

and the **Leipzig method**, as further developed by Anders [10] and Schmidt [11]:

$$N^{\mathrm{PA\%}} = \frac{H^{\mathrm{PA\%}}}{y^{CL}} \qquad (2)$$

$N^{\mathrm{PA\%}}$ no. of bending cycles with failure probability PA
$H^{\mathrm{PA\%}}$ service life constant for failure probability PA
y overall stress
CL Woehler line exponent

The parameters of these estimation methods are influenced by several factors, which are described in the following section.

2.2.2 Influence of Test Parameters on Fatigue Life

The measured fatigue life of a wire rope in laboratory tests is highly dependent on the selected test parameters. Even small variations can lead to substantial differences in the number of cycles to failure or discard, making strict control and documentation essential for reproducibility. Key parameters include:

- **D/d Ratio and Rope Tension:** among the most influential factors, defining the bending and axial stress levels as well as contact pressure.
- **Bending Frequency / Test Speed:** higher frequencies increase heat generation and may accelerate degradation mechanisms.
- **Sheave and Groove Design:** hardness, surface finish, and material (steel vs. polymer) significantly influence wear and fatigue.
- **Lubrication:** influences friction and fretting behaviour between wires.

These parameters do not act independently. For example, the effect of a larger D/d ratio can be offset by high mean tension, and the positive of polymer sheaves can diminish in combined reeving systems [6][7]. **This underlying complexity of interacting parameters is likely also present across different bending-fatigue machine types**. Variations in machine design**,** principles of load introduction, and rope guidance may therefore introduce additional systematic differences, even when testing identical parameter and rope constructions.

2.2.3 Failure Criteria

Commonly applied end-of-life, service life criteria are defined i.e., in ISO 4309:2017 [9]. According to this standard, a rope is considered to have reached the end of its service life when characteristic signs of deterioration become evident. These include an excessive number of visible wire breaks within a reference length, a measurable decrease in rope diameter beyond the permissible tolerance, or severe external and internal deformations that impair the rope's safe and functional performance, and consequently a significant reduction in residual breaking strength compared to the nominal value.

2.3 Practical Significance

An important current development in rope design is reflected in ISO 16625:2025 [8], which replaces traditional running-time-based system[5] with cycle-based classification. Thus, the number of bending cycles a wire rope can endure before reaching its state of discard has become a fundamental design parameter in rope-drive engineering.

In service, fatigue life determines inspection intervals, maintenance schedules, and the selection of rope constructions for given applications. Since fatigue behaviour is highly sensitive to operating conditions and reeving geometry, laboratory tests provide a controlled baseline, but field performance may differ significantly. This underlines the need for reproducible test methods and machine designs that realistically simulate in-service conditions.

3 Comparison of Testing Machines and Principles

Bending fatigue testing machines for wire ropes vary widely in their mechanical design, reeving configuration, and operational control. While all aim to simulate cyclic bending under tensile load, the distribution of bending cycles, the uniformity of loading, and the measurement methodology differ significantly between machine types.

This paper compares three test machine designs, highlighting the key design principles of representative bending-fatigue machines and their potential impact on test conditions and data comparability.

3.1 Single-Sheave Test Machines

Single-sheave machines are the most common type of bending fatigue tester. They consist of a test sheave over which the rope is repeatedly bent while under controlled tension. Typically, the rope forms a closed loop, with one or more idler sheaves completing the circuit [3] (**Figure 2**).

Test Principle

The rope passes over a single test sheave with a defined D/d ratio under constant mean tension. One bending cycle is completed each time the rope passes over the test sheave, see **Figure 1**. Bending frequency is governed by the rotational speed of the test sheave, and fatigue life is recorded either until a predefined number of wire breaks occurs or the rope fails completely.

Evaluation Scheme

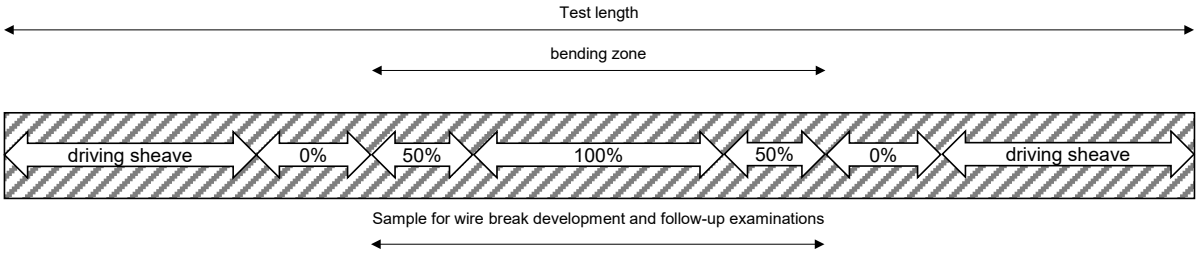


Figure 1: Single Bending Fatigue – Evaluation Scheme

[5] with M-classes

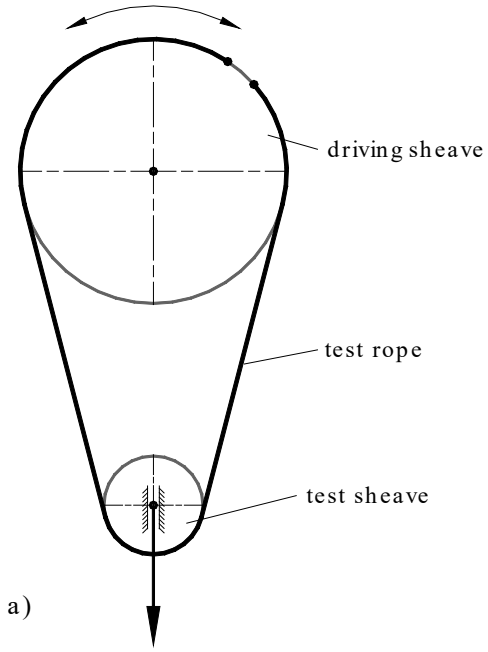


Figure 2: Single Bending Fatigue – Sheave Arrangement

Advantages:

- Simple design, easy operation, and low maintenance.
- High reproducibility when properly calibrated.
- Well-suited for comparative studies on rope constructions under constant D/d and load.

Limitations:

- Simulates only one bending point per cycle, not representative of multiple-sheave systems (**Figure 1**).
- Localized wear at the bending point may exaggerate certain failure mode.
- Limited test speed and inability to study sheave-material sequences.

3.2 Multiple-Sheave Principle (Verreet/Teissier)

The multiple-sheave principle was designed to overcome the limitations of single-sheave machines by reproducing more realistic multiple-sheave reeving systems**,** as found in cranes, winches, and offshore applications [3][6][7]. Its core element is a five-sheave arrangement, configurable with different sheave materials (e.g., steel, cast iron, polymer).

Test Principle

Unlike conventional single-sheave machines, see **Figure 3**, the rope is bent at multiple locations per loop, resulting in different bending intensities along its length. The setup ensures that one section of the rope experiences 100 % bending cycles per machine revolution, while other sections undergo reduced exposure (e.g., 80 %, 60 %, 40 %, 20 %, 0%). This configuration simulates the non-uniform fatigue exposure typical of real reeving systems (**Figure 4**).

Evaluation Scheme

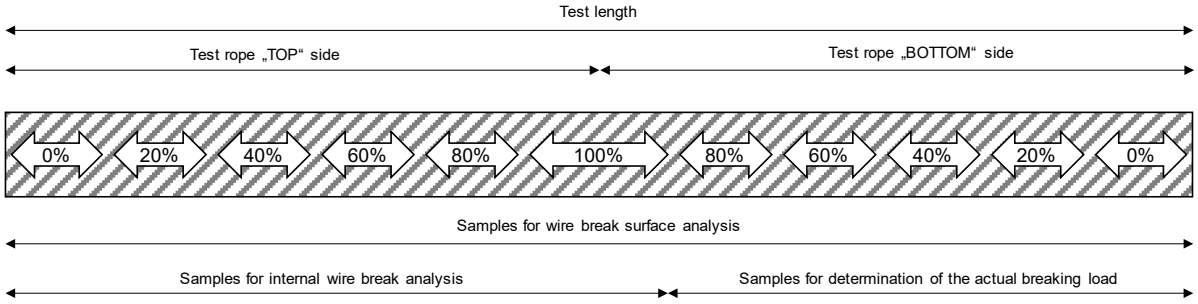


Figure 3: Bending Fatigue Test – Evaluation Scheme

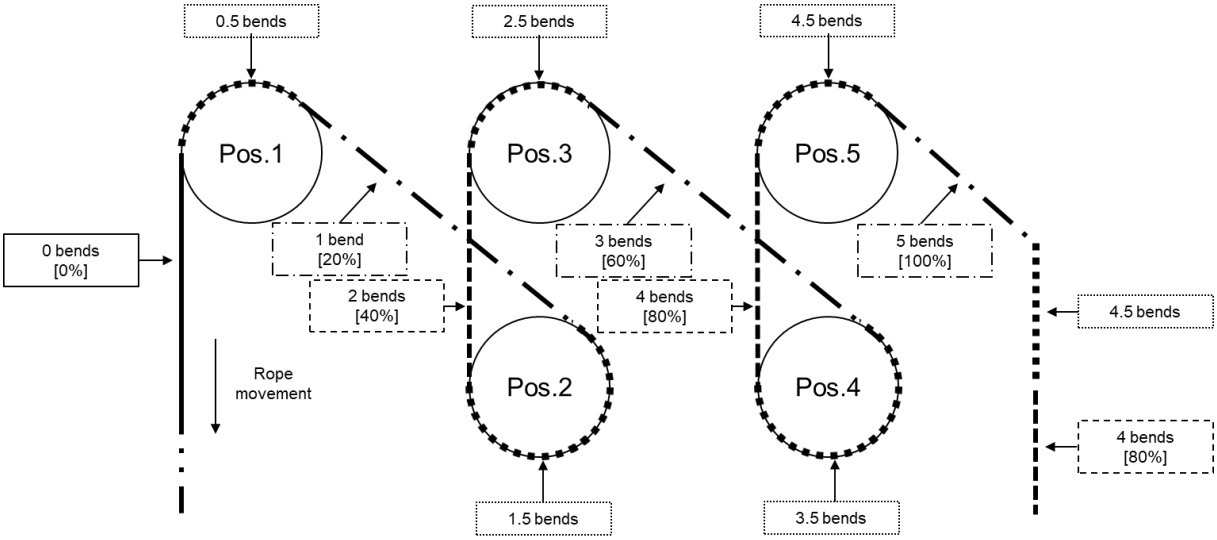


Figure 4: Multizone Bending Fatigue – Sheave Arrangement

Advantages:

- Provides a realistic simulation of in-service multiple-sheave rope systems.
- The **staged bending exposure** enables targeted analysis of fatigue-damage progression: rope sections can be inspected for external wear and wire-break distribution, internal wire failures, and reduction in residual breaking force.
- Enables systematic investigation of the influence of sheave materials and their position within the reeving system.
- Multiple fatigue regimes significantly increase data efficiency and allow comparative evaluation of the evolution of rope deterioration without the need for separate tests.
- Counter-bending tests possible with an adjusted five-sheave configuration.

Limitations:

- More complex setup and maintenance requirements.
- Load distribution may vary if alignment and calibration are not meticulously controlled.

3.3 Three-Zone Test Stand (TU Dresden)

The Three-Zone Test Stand is designed to evaluate wire rope performance of a large test sample length comprising three independent bending zones with one continuous test loop.

Test Principle

A rope sample driven by a traction sheave alternates forwards and backwards over three non-overlapping bending zones (**Figure 5** and **Figure 6**). An adjustable bending length ensures sufficient unbend rope length between the zones, depending on the selected sheave diameters. Usually, identical sheave diameters are applied for each zone, but different D/d-ratios can also be implemented. The approach allows direct comparison of rope behaviour under varying conditions without the need of separate test runs.

Evaluation Scheme

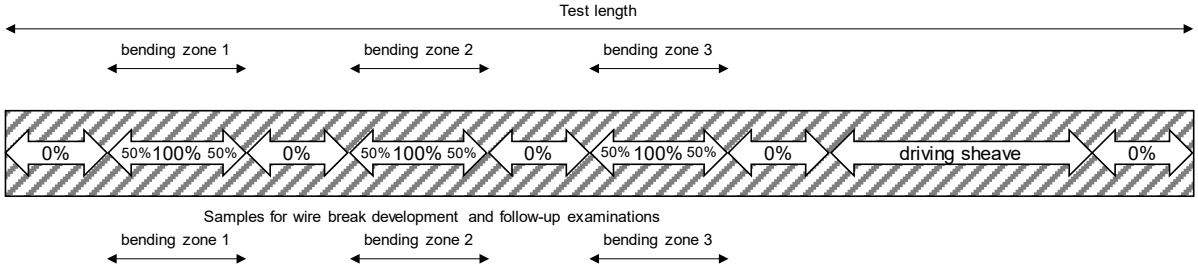


Figure 5: Three Zone Bending Fatigue – Evaluation Scheme

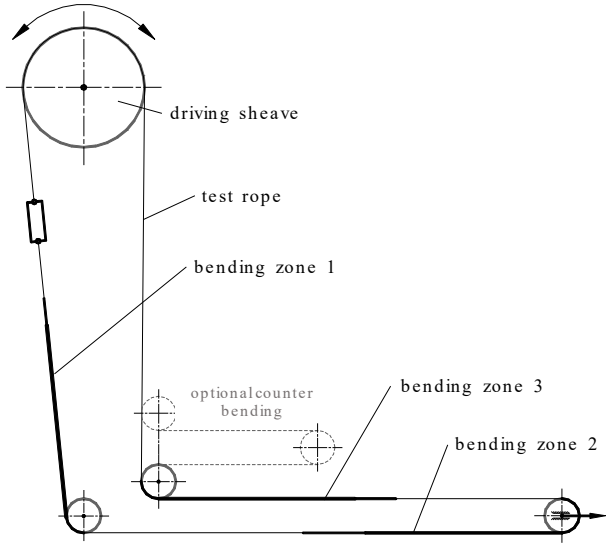


Figure 6: Three Zone Bending Fatigue – Sheave Arrangement

Advantages:

- High reproducibility when properly calibrated.
- Tests a long rope length under identical or varied conditions in one loop.
- Detects irregularities or in-rope quality variations.
- High data efficiency: three fatigue values can be obtained in one test. Typically, one bending zone fails first; the other two can be examined near full lifetime (≈ 100%).
- Suitable for comparative studies of rope constructions under different D/d ratios and loads.
- Counter-bending tests possible with an adjusted five-sheave configuration.

Limitations:

- More complex setup and maintenance than single-sheave systems.
- Limited test speed and restricted variation of sheave-material sequences.

3.4 Technical Parameter Comparison

The following table (**Table 1**) summarizes the key technical parameters and operational characteristics of the three bending-fatigue testing machines discussed above.

Parameter / Feature	Single-Sheave	Multiple-Sheave	Three-Zone
Bending distribution	Uniform: 100 % in one location	Staged: 100 ,80 ,60 ,40 ,20 %	3 distinct levels per revolution
D/d-ratios	Fixed, single value	Fixed, single value	Fixed, single value
Sheave materials	Typically, one	Mixed combinations possible	Mixed combinations possible
Speed	Regulated by Temperature max. 45°C	Max. 1.15m/s	Regulated by Temperature max. 45°C
Simulation of real reeving systems	Low	High	Medium–High
Test-duration-efficiency	Low (one regime / test)	High (multiple regimes / test)	High (three regimes / test)
Complexity of setup	Low	High	Medium
Typical applications	Basic comparative studies, QC testing	Sheave material studies, service-life simulations Measurement of the evolution of deterioration	Multi-condition fatigue studies, D/d influence testing

Table 1: Technical Parameter Comparison of Test Machines

4 Research Methodology & Experimental Design

Following the comparative description of different bending-fatigue test machine types, this section outlines the experimental methodology. The experimental design was structured to isolate the influence of machine configuration while maintaining identical rope, load, and environmental conditions.

4.1 Test Design

Tests were performed under consistent operating conditions to enable comparison between the three machine types. The applied stress level, D/d ratio, and environmental settings were kept constant for all configurations. In addition to the applied load conditions, the test speed was varied to evaluate its potential influence on fatigue life and thermal behaviour.

For the Multiple-Sheave machine, tests were conducted at both the maximum permissible operating speed and at half of that value to assess the sensitivity of fatigue performance to increased test velocity.

In contrast, for the Single-Sheave and Three-Zone machines, the rotational speed was adjusted such that the rope surface temperature did not exceed 45 °C at any point during testing. This limitation was introduced to avoid thermally induced degradation effects and to ensure comparability of purely mechanical fatigue mechanisms. The complete methodology is shown in **Figure 7**.

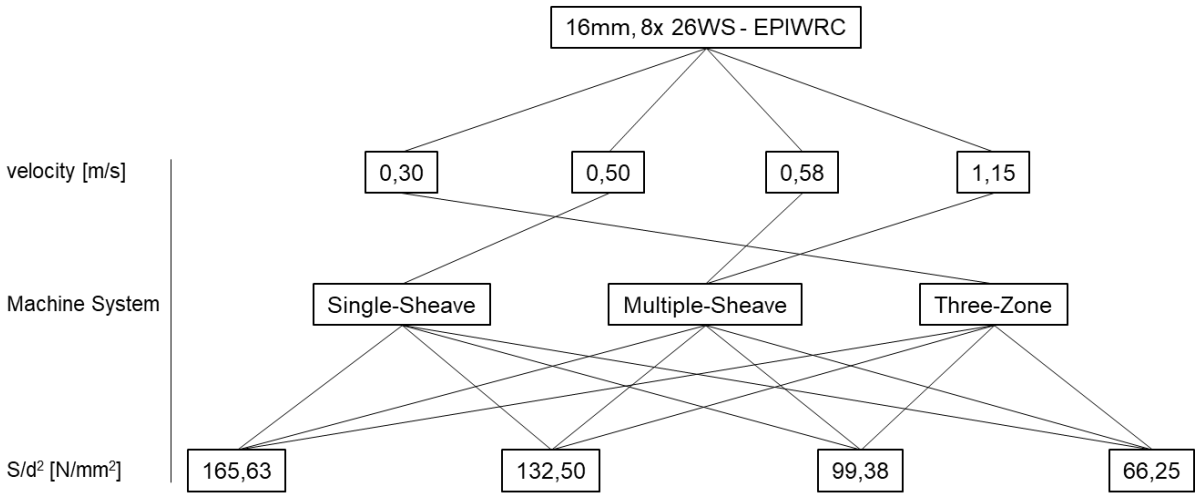


Figure 7: Bending Fatigue Test Methodology

Details of the rope and test sheaves used in the investigation are provided in the table below (**Table 2**).

	Rope
Construction	8 x 26WS EPIWRC
Rope diameter d	16 mm
Lay direction	RHOL
Surface	Galvanized
Nom. wire strength R_0	1960 N/mm²
Rope Category Number (RCN)	09
Discard criteria ISO 4309	
Number of visible wire breaks on reference length of 6d	9
Number of visible wire breaks on reference length of 30d	18

	Sheave
Material composition	42CrMo4
Hardness	53 HRC
D/d ratio	20
r/d ratio	0.53
Opening angle	60°

Table 2: Rope, Sheave Construction & Properties

4.2 Evaluation Criteria

Fatigue life evaluation followed in general the procedures defined in ISO 4309:2017 [9]. A test was terminated when either (i) a visible strand fracture occurred or (ii) a sudden increase in elongation indicated internal damage or core failure. The rope sections were examined visually to document the wire-break distribution and failure characteristics in accordance with these guidelines. The following parameters were evaluated:

- the number of bending cycles at the occurrence of the first wire break **(FWB)**,
- the number of bending cycles to discard within a reference length of 6×d (**NA_{6d}**),
- the number of bending cycles to discard within 30×d **(NA_{30d})**,
- the total number of bending cycles to failure **(N)**,
- and the average rope surface temperature during testing.

5 Results

5.1 Summary

The results obtained from the bending-fatigue tests are summarized in the following table (**Table 3**). They include the stress level, test velocity, measured temperature, and the corresponding number of bending cycles for the defined evaluation criteria. At the time of submission, the two missing tests on the Single-sheave configuration were still ongoing.

ID	Machine	S/d² [N/mm²] (SF[6])	velocity [m/s]	Temp.[7] [°C]	FWB[8] [-]	NA_{6d} [-]	NA_{30d} [-]	N [-]
1	Multiple-Sheave	165,63 (5)	1,15	71,07	12980	27237	28185	69180
2	Multiple-Sheave		1,15	73,12	14278	28918	24726	64900
3	Multiple-Sheave		0,58	61,83	15066	26439	25930	75330
4	Three-Zone		0,30	43,00	23333	-	39167	101818
5	Single-Sheave		0 - 0,30	42	38000	75000	72500	134393
6	Multiple-Sheave	132,50 (6,25)	1,15	64,03	9518	26164	23069	95180
7	Multiple-Sheave		1,15	66,94	10591	34726	30550	105910
8	Multiple-Sheave		1,15	68,96	10258	32685	31986	102850
9	Multiple-Sheave		0,58	50,4	9568	30224	27413	95680
10	Three-Zone		0,30	35,00	26666	-	36667	131216
11	Single-Sheave		0 - 0,30	33	30000	68000	58000	142036
12	Multiple-Sheave	99,38 (8,35)	1,15	56,01	15630	33081	29164	134200
13	Multiple-Sheave		1,15	56,68	20292	39317	34930	131460
14	Multiple-Sheave		1,15	55,40	16652	36156	35230	154790
15	Multiple-Sheave		0,58	40,37	13350	35020	33775	145210
16	Three-Zone		0,30	32,00	26666	-	41833	215522
17	Single-Sheave		0 - 0,30	-	-	-	-	-
18	Multiple-Sheave	66,25 (12,5)	1,15	45,70	6915	19969	9640	230510
19	Three-Zone		0,30	30,00	10000	-	26667	433302
20	Single-Sheave		0 - 0,30	-	-	-	-	-

Table 3: Bending Fatigue Test Results

[6] **S**afety **F**actor
[7] Average Temperature for most bent regimes.
[8] **F**irst **W**ire **B**reak; values from Multiple-Sheave were extrapolated, not read directly.

The following **Figure 8** present the results from **Table 3** in graphical form, arranged according to the evaluation of the first wire break appeared.

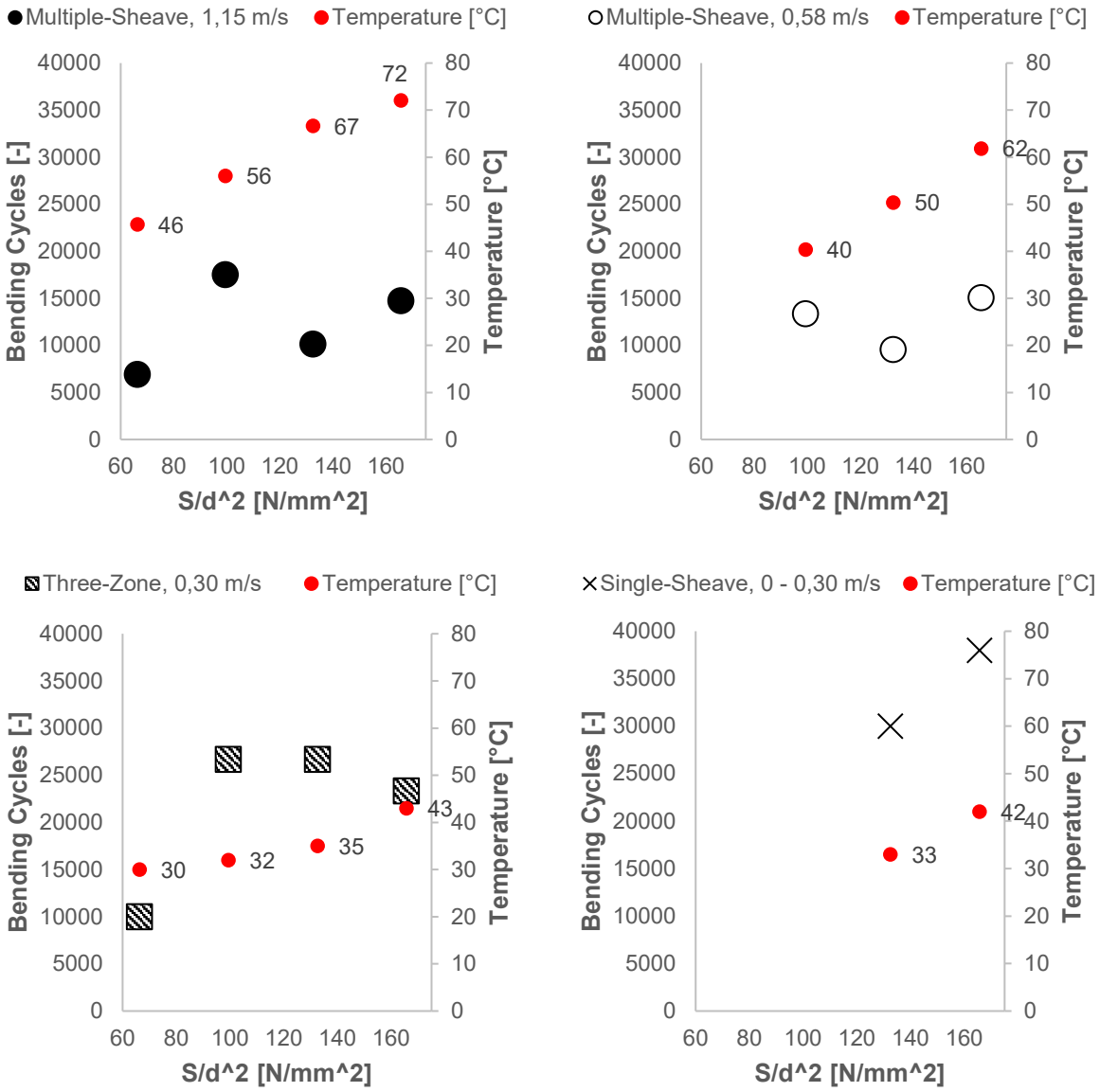


Figure 8: Bending Fatigue Results: First Wire Break

The results concerning the first wire break show a comparable but unusual behaviour across all test machines. The earliest occurrence of the first wire break at the lowest load is unexpected but consistently present in all test principles.

For the multiple-sheave testing system, the analysis revealed no significant velocity-, acceleration- [3] or temperature-related correlation with the initiation of the first wire break. Both experimental series exhibited similar patterns.

At higher loads, a slight trend becomes visible: the multiple-sheave system tends to indicate the first wire break earlier, while the three-zone system shows the opposite behavior.

The following **Figure 9** present the results from **Table 3** in graphical form, arranged according to the evaluation of the bending cycles until discard.

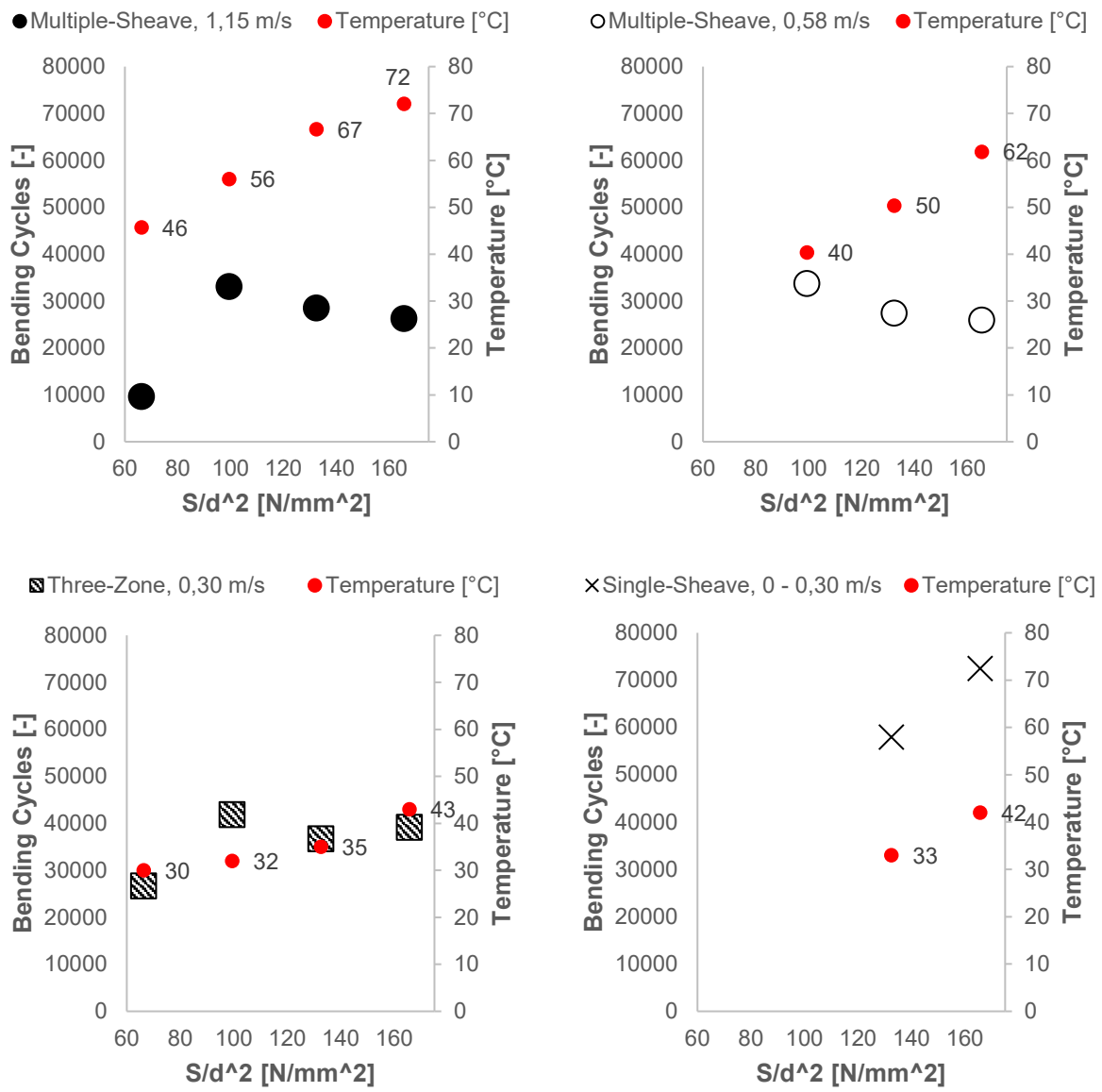


Figure 9: Bending Fatigue Results: Rope Discard at 30d

Corresponding to the unexpected occurrence of the first wire break, the discard cycles also show an anomaly, with the lowest load producing the earliest discard. The multiple-sheave system showed only minor differences between the two test velocities, while the three-zone machine generally reached slightly higher discard cycles.

When comparing both systems, the trend reversed relative to the first wire-break behavior: in the multiple-sheave system the discard cycles decreased with increasing load, whereas the three-zone machine showed a higher discard cycle count at the highest load.

The same slight trend is also evident for the discard cycles: the multiple-sheave system shows earlier discard with increasing load, while the three-zone machine exhibits the opposite behavior.

The following **Figure 10** present the results from **Table 3** in graphical form, arranged according to the evaluation of the overall lifetime, meaning no. of bending cycles until rope failure.

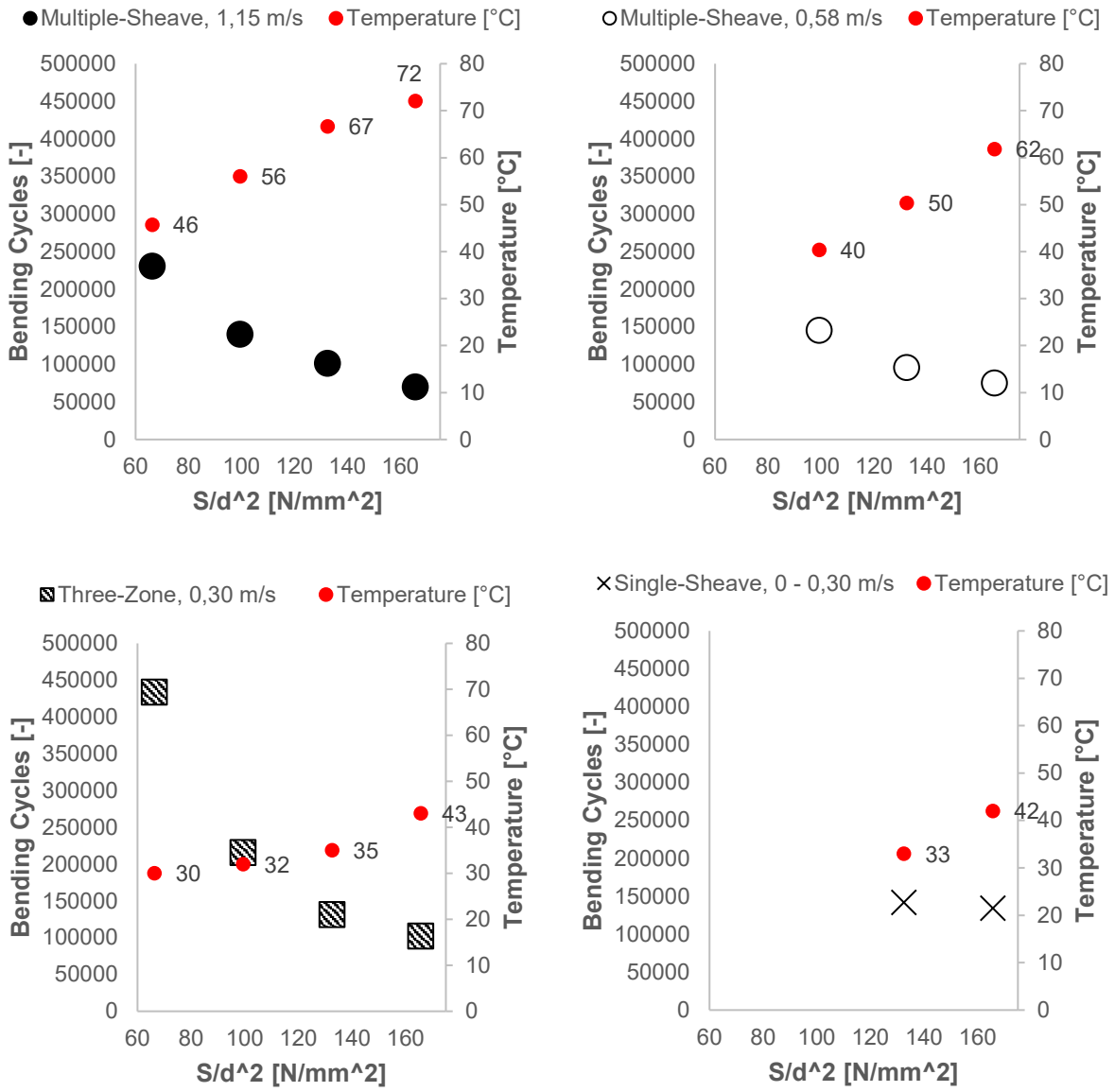


Figure 10: Bending Fatigue Results: Overall Lifetime

The number of bending cycles until rope failure shows the expected load-dependent behaviour. In the multiple-sheave system, the two test velocities produced only minimal differences at their respective load levels.

The three-zone test stand, however, resulted in significant higher fatigue-life values. The gap, in rope lifetime, between both systems widens with decreasing the test forces: at lower loads, the absolute difference in cycles increases substantially. At higher loads, by contrast, the results of the three-zone and multiple-sheave machines converge, showing only minor deviations in bending cycles.

5.2 Evaluation Possible Impact Factors

Although all tests were conducted under harmonized conditions, differences in fatigue life between the investigated test machines were observed. The recorded number of bending cycles at the first wire break and until discard do not follow the typically expected trend across the load levels. Especially the smallest load level is untypically leading to the fastest wire break development. In particular, the lowest load produced the earliest wire break initiation—an atypical behaviour. As this phenomenon occurred in more than one test machine, it is likely linked to the rope sample itself, potentially caused by a specific load distribution between outer strands and the rope core. The overall lifetime until rope failure does not show this effect.

These deviations indicate that additional influencing parameters—beyond the nominal test setup—affect the rope's bending-fatigue performance.

The following section discusses three principal categories influences: thermal effects (5.3.1) and machine-specific dynamic behaviour (5.3.2, 5.3.3).

5.2.1 Influence of Temperature

The investigation showed that rope surface temperatures exceeded the limits foreseen in the OIPEEC Recommendations [5]. As emphasized by Feyrer [3], constant environmental and frictional conditions are essential for reproducible results in long-term bending tests. Temperature control therefore serves primarily to stabilize the tribological system rather than representing an explicit factor in lifetime calculation.

Rope surface temperatures above approximately 50 °C do not directly cause fatigue damage but may alter lubrication conditions and frictional behavior between wires, leading to accelerated wear and reduced reproducibility of bending-fatigue results under laboratory conditions. Hence, maintaining the rope temperature below this level should be regarded as **a methodological precaution rather than a physical limit**.

In the present study, the use of a high-performance lubricant effectively eliminated thermally induced degradation effects. Any residual influence of temperature can be considered negligible, since elevated surface temperatures were confined to the rope section running over all sheaves in the Multiple-Sheave machine, while temperatures in the remaining sections at discard were significantly lower.

5.2.2 Influence of the Test Machines

Even when the nominal parameters are identical, the three bending-fatigue test machines examined differ in their mechanical and dynamic characteristics. These differences primarily arise from variations in drive concept, structural stiffness, load transmission, bending length and the length of free rope between the sheaves.

More flexible drive systems may generate minor tension fluctuations during acceleration and deceleration, whereas more rigid systems can impose sharper load transitions at the start of each bending cycle. Such effects may **lead to tension–tension interactions**, resulting in superimposed axial load variations along the rope. A preliminary estimation of the acceleration-induced influences following the approach in [3] was carried out; however, no correlation with the measured fatigue life could be identified. At present, these dynamic interactions have not been systematically investigated, and no precise quantitative statement can yet be made regarding their effect on fatigue life.

5.2.3 Influence of Multiple-Sheave Configurations

Multiple-sheave configurations may influence the rope's bending-fatigue behaviour by creating interactions between consecutive bending zones. The arrangement of several sheaves in series, as introduced in [4] as an application-oriented test concept, may modify how bending and axial loads are transmitted along the rope.

This is particularly relevant because comparable multiple-sheave arrangements are common in real applications, where ropes operate in complex reeving systems with multiple bending points. Under such in-service conditions, similar interaction effects may occur, potentially affecting the rope's local stress state and resulting fatigue life.

This mechanism provides an explanation for the deviations observed between the test machines in the previous sections. It is conceivable that the influence increases with the number of sheaves arranged in series and may even depend on the rope length between bending zones, like effects known from reverse-bending configurations. However, this potential length dependence was not investigated in the present study and requires further systematic analysis.

6 Conclusions & Outlook

The results presented in this study provide a first comparative assessment of the bending-fatigue behaviour of special wire ropes tested on fundamentally different machine configurations. While the occurrence of first wire breaks showed comparable trends across the systems, the evolution toward discard and complete rope failure revealed substantial divergences. The three-zone test machine consistently produced higher fatigue-life values, exceeding those of the multiple-sheave configuration by approximately 30% to 90% for overall rope failure and by 30% to 170% for discard criteria.

These discrepancies may indicate that additional dynamic effects influence fatigue performance when several bending zones are arranged in series. Multiple-sheave configurations may induce interaction effects between consecutive bending zones, leading to local stress superposition even under identical nominal loading. Comparable effects can also arise in real applications, where ropes operate in complex reeving systems with multiple sheaves and limited free rope length between bending points.

Similar behaviour is known from reverse-bending configurations, where a minimum recovery interval is specified to allow the rope to relax before encountering the next curvature. This indicates that rope segments may require temporal recovery to dissipate stresses from a preceding bend—an effect that could also play a role in multiple-sheave arrangements and may contribute to the deviations observed between the test machines.

The present study did not investigate the potential length dependence or the magnitude of such recovery effects. Future work should therefore focus on systematically evaluating the influence of sheave spacing, number of consecutive bending points, and dynamic load interactions on fatigue performance.

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9 Author introduction



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He received his Bachelor of Engineering degree in Mechanical Engineering from the University of Applied Science Kaiserslautern in 2015, followed by a Master of Engineering degree in the same field in 2023.

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