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THE INFLUENCE OF THE POSITION AND NUMBER OF STEEL AND PLASTIC SHEAVES ON THE SERVICE LIFE AND LIFETIME OF WIRE ROPES: A COMPARATIVE BENDING FATIGUE STUDY

Summary

In the field of modern rope technology, particularly in reeving systems, there is still a notable trend towards lightweight construction that encourages the use of plastic sheaves.

Despite the attractive weight and cost savings associated with plastic sheaves, the use of at least one steel sheave is usually necessary and foreseen. This necessity stems from the fact that wire breaks on the rope surface are more likely to occur with steel sheaves, allowing a better detection of the rope's end of service life.

This document is a comprehensive study that compares the impact of the positioning and number of plastic and steel sheaves on rope life and service life in reeving systems, with a specific focus on real-world applications. It investigates the influence of sheave material on the visibility of the rope discard and the overall lifetime of ropes. Utilizing a bending fatigue testing machine, the study compares different sheave configurations, including full-steel, full-plastic, and mixed setups. The findings aim to provide insights into how sheave materials affect rope durability and safety, offering valuable guidance for industry applications.

1 The unexpected rope failure on a cable crane

In 2019, an unexpected incident occurred on the construction site, where a cable crane was working: The rope of the cable crane, which had been installed three years ago, broke during operation. This led to the hook block falling from a height of over 100 meters.

The cable crane, which was primarily equipped with plastic sheaves to save weight and to extend the service life of the rope, have had a total of seven plastic sheaves within the reeving system. Each with a diameter of 1.4 meters and a D/d ratio of 38, were used and spaced widely apart. Another feature was one steel sheave in the system.

The analysis of the reeving system showed that the only steel sheave in the system, experienced only a minimal amount rope bends. Other sections of the rope, however, were subjected to more significant bends over the plastic sheaves.

The failure analysis of the used rope an 8xK26WS – EPIWRC revealed that parts of the rope were rusted, and there were considerable mechanical wear and fatigue fractures inside. The internal plastic layer of the rope was also worn down. A lack of regular relubrication and the use of a poorly penetrating lubricant contributed to this damage pattern. It is noteworthy that most of the damage was found inside the rope, specifically on the rope core and on the bottom of the outer strands. Furthermore, the

discard of the rope was not visible, incorporating the aspect that there were no premature indications of an impending rope failure.

Excluding the influence of the lubricant, the observed damage pattern is typical for ropes subjected to the influence of large D/d ratios [1] and the use of plastic sheaves [2]. This case raised the question of whether the rope failure could have been avoided if the steel sheave in the system had been positioned in a different part of the reeving system and whether such a repositioning would have an influence on the visibility of the rope's discard criteria.

However, the optimal placement of this steel sheave within the sheave arrangement, as well as the question of whether one single steel sheave is sufficient, remain largely unresolved. Additionally, it is often challenging to determine, if a given rope section moves through the entire reeving system, adding complexity to the investigation.

Therefore, the primary goal of this study is to gain insight into the effects of different sheave materials and their positioning on rope life and service life through a comprehensive investigation of bending fatigue. The results of these investigations aim to determine whether a single steel sheave is sufficient in a system that is otherwise composed of plastic sheaves, and if so, what the optimal position for this steel sheave would be. This study shall significantly contribute to understanding the impact of sheave materials and their arrangement on the performance, endurance, and safety of ropes in reeving systems.

2 Experimental Setup & Methodology

In the study, an advanced machine concept was employed to test ropes under bending fatigue, markedly different from conventional testing methods. As it can be seen in **Figure 1**, at the core of this machine is a system comprising five sheaves, which can consist of varied materials. Unlike traditional testing machines that run the rope over a single sheave, this approach creates more realistic test conditions, especially regarding the influence of positioning different sheave materials in the reeving system.

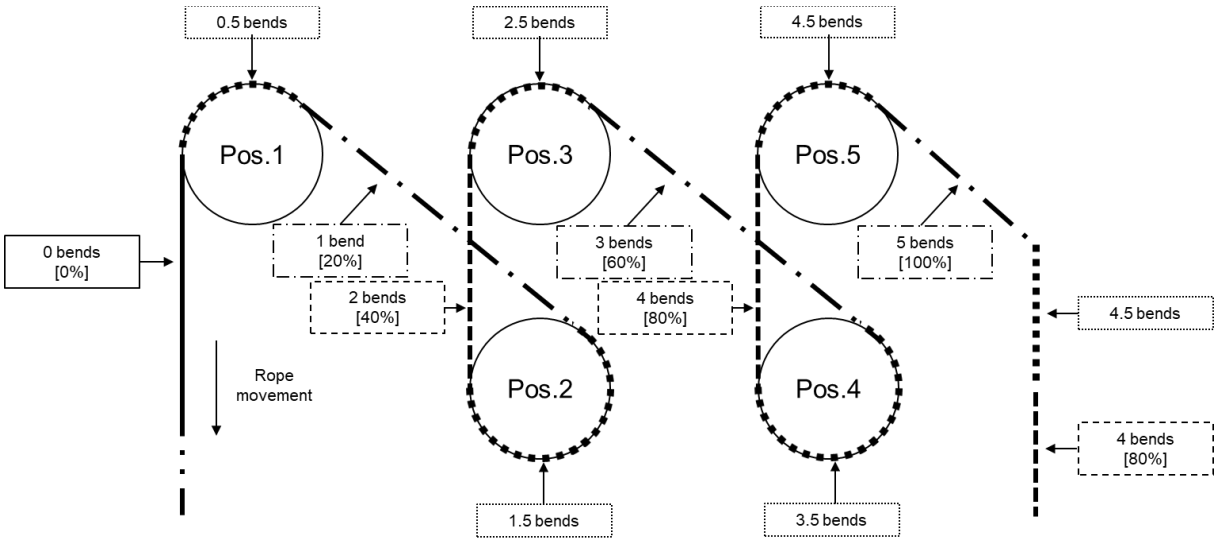


Figure 1: Bending test sheave arrangement

This specialized bending fatigue machine allows for the testing of ropes in controlled conditions, with a focus on the most heavily stressed section of the rope. In this area, the rope is subjected to 10 bending cycles per machine cycles (100%), while adjacent areas experience decreasing bending cycles (80%, 60%, 40%, 20%), showed in **Figure 2**.

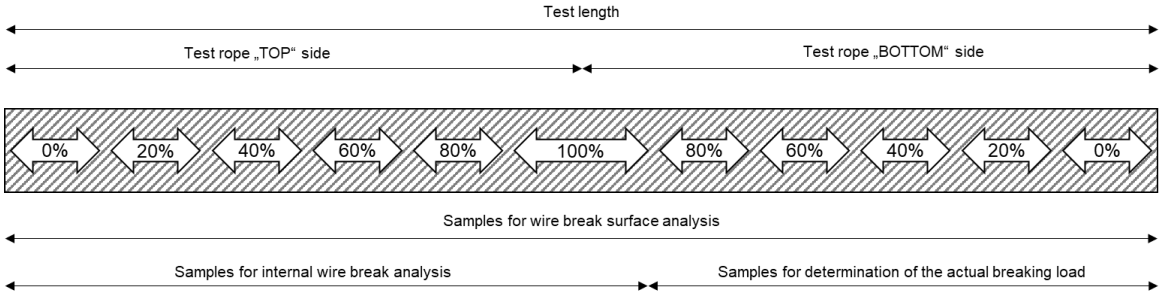


Figure 2: Bending test evaluation scheme

Furthermore, the design allows for continuous measurement of various rope properties and a detailed analysis of both, external and internal rope damage as well as the actual breaking forces of the ropes at various stages of their lifecycle. A detailed description of the concept can be found in [3].

The specific test parameters, test sheaves used, and the rope construction that was investigated are shown in the table below:

Rope		**Sheaves**			**Parameters**	
Construction	8 x K26WS EPIWRC		Steel	Plastic	Safety Factor SF	8.33
Rope diameter d	16 mm	Material composition	42CrMo4	PA66	Rope velocity v	1,15 m/s
Lay direction	RHOL	Hardness	53[1]	160/125[2]		
Surface	Galvanized	D/d ratio	20	20		
Nom. wire strength R_0	1960 N/mm^2	r/d ratio	0.53	0.53		
Rope Category Number (RCN)	09	Opening angle	60°	60°		
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					

Table 1: Test materials & parameters

[1] HRC
[2] $H_{358/30}$ according ISO 2039-1

The aim was to design the test environment as realistically as possible to enable comparability with the cable crane and existing internal data. Therefore, the test parameters were carefully selected and adjusted. The 8xK26WS - EPIWRC rope construction is identical to that used in the cable crane described in the first chapter, with the rope diameter specifically adapted to ensure optimum compatibility with the test machine peripherals.

The materials and geometry of the test sheaves were carefully adapted to match those used in real-world applications. This adaptation is important to ensure the significance of the test results. However, the D/d-ratio has been reduced from 38 to a value of 20, to reduce test time and to mirror typical crane applications, where D/d-ratios of around 20 are more common.

As a result, the focus of the study could be placed on the main investigation reason: the influence of the position and number of steel and plastic sheaves on the service life and lifetime of wire ropes. This focus is crucial to gain specific insights into the interactions between the rope and sheaves, thus providing a deeper understanding of the material properties and failure criteria.

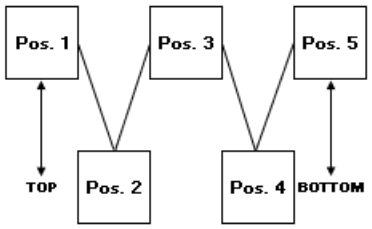
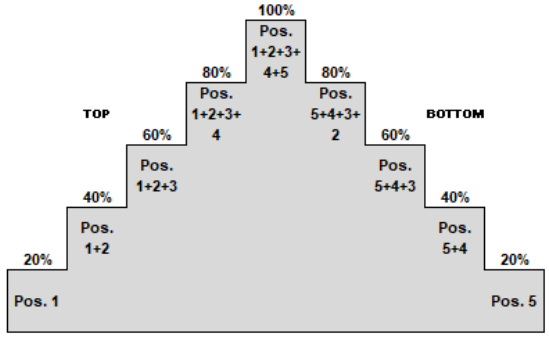
To comprehensively achieve this objective, a total of six specific tests were conducted. These were based on the materials and parameters detailed in **Table 1**, as well as the arrangements of the test sheaves depicted in **Figure 3** through **Figure 8**.

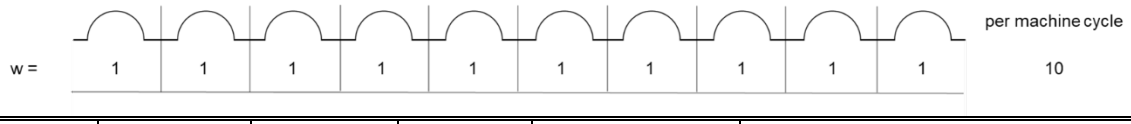
In the first approach, both, one test with a complete sheave arrangement of only steel sheaves (**Figure 4**) and only plastic sheaves (**Figure 5**), was conducted. These, served as reference values for the rope lifetime, the discard of the rope, its internal damage and residual breaking force of the different lifetime stages of the rope for further investigation.

Secondly, the plastic sheave in the middle (Pos. 3) was replaced by a steel sheave to maintain a symmetrical structure (**Figure 6**) and the test was repeated once.

In another experimental setup (**Figure 7**), the first plastic sheave (Pos. 1) was replaced with a steel sheave, resulting in an asymmetrical arrangement.

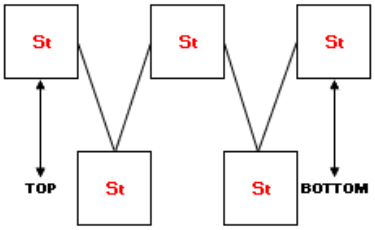
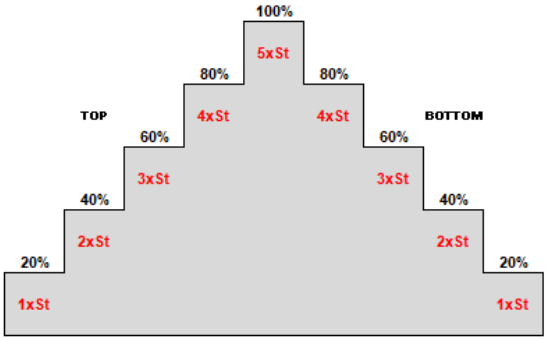
The last arrangement (**Figure 8**) differs from the previous one in that the second sheave (Pos. 2) in the setup has also been replaced with a steel sheave.

Sheave arrangement	Areas of bending
	



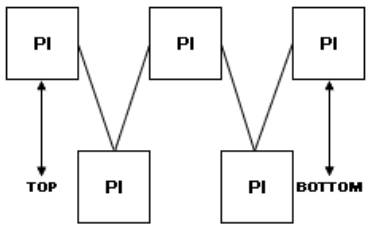
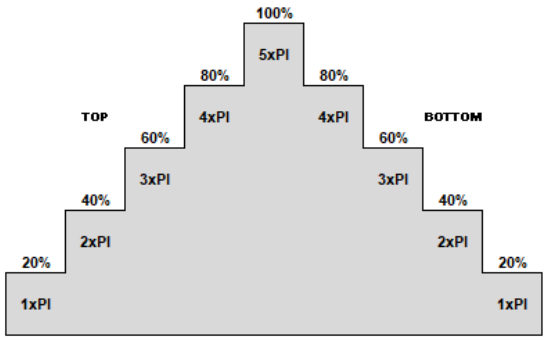
Number of steel sheaves	% of steel sheaves	Number of plastic sheaves	% of plastic sheaves	Location	Sheave order (per machine cycle)
-	-	-	-	-	-

Figure 3: General test methodology

Sheave arrangement (Test 1)	Areas of bending
	

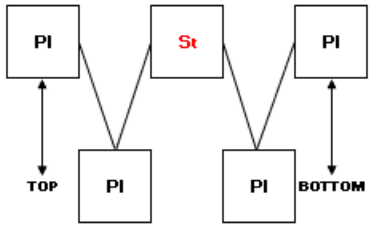
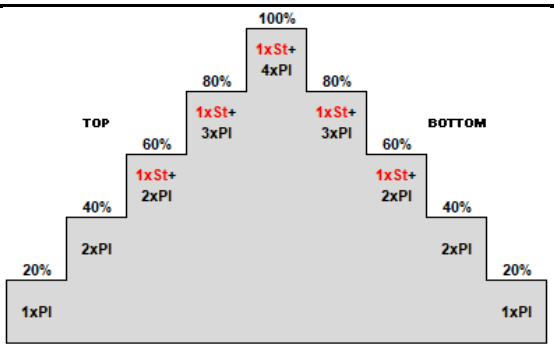
Number of steel sheaves	% of steel sheaves	Number of plastic sheaves	% of plastic sheaves	Location TOP - BOTTOM		Sheave order (per machine cycle)	
2	100%	0	0%	20%	-	St	St
4	100%	0	0%	40%	-	St-St	St-St
6	100%	0	0%	60%	-	St-St-St	St-St-St
8	100%	0	0%	80%	-	St-St-St-St	St-St-St-St
10	100%	0	0%	100%-100%		St-St-St-St-St-St-St-St-St-St	
8	100%	0	0%	-	80%	St-St-St-St	St-St-St-St
6	100%	0	0%	-	60%	St-St-St	St-St-St
4	100%	0	0%	-	40%	St-St	St-St
2	100%	0	0%	-	20%	St	St

Figure 4: Test methodology Test 1

Sheave arrangement (Test 2)	Areas of bending
	

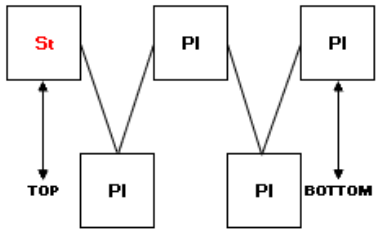
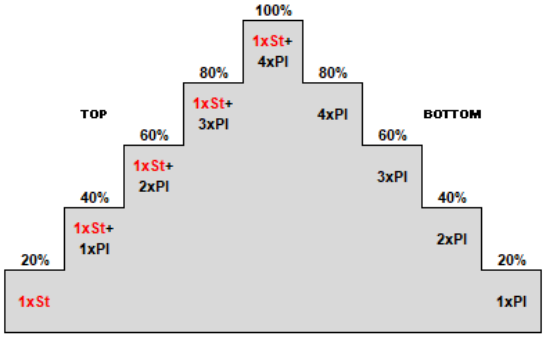
Number of steel sheaves	% of steel sheaves	Number of plastic sheaves	% of plastic sheaves	Location TOP - BOTTOM		Sheave order (per machine cycle)	
0	0%	2	100%	20%	-	Pl	Pl
0	0%	4	100%	40%	-	Pl-Pl	Pl-Pl
0	0%	6	100%	60%	-	Pl-Pl-Pl	Pl-Pl-Pl
0	0%	8	100%	80%	-	Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl
0	0%	10	100%	100%-100%		Pl-Pl-Pl-Pl-Pl-Pl-Pl-Pl-Pl-Pl	
0	0%	8	100%	-	80%	Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl
0	0%	6	100%	-	60%	Pl-Pl-Pl	Pl-Pl-Pl
0	0%	4	100%	-	40%	Pl-Pl	Pl-Pl
0	0%	2	100%	-	20%	Pl	Pl

Figure 5: Test methodology Test 2

Sheave arrangement (Test 3)	Areas of bending
	

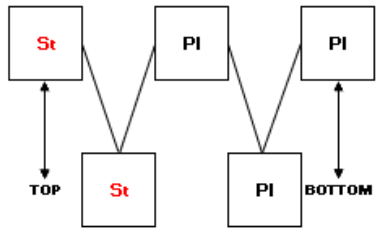
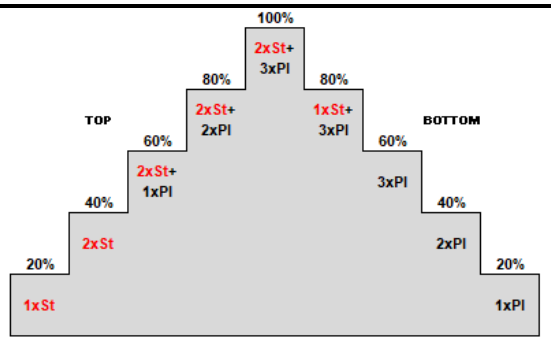
Number of steel sheaves	% of steel sheaves	Number of plastic sheaves	% of plastic sheaves	Location TOP - BOTTOM		Sheave order (per machine cycle)	
0	0%	2	100%	20%	-	Pl	Pl
0	0%	4	100%	40%	-	Pl-Pl	Pl-Pl
2	33,33%	4	66,67%	60%	-	Pl-Pl-St	St-Pl-Pl
2	25%	6	75%	80%	-	Pl-Pl-St-Pl	Pl-St-Pl-Pl
2	20%	8	80%	100%-100%		Pl-Pl-St-Pl-Pl-Pl-Pl-St-Pl-Pl	
2	25%	6	75%	-	80%	Pl-Pl-St-Pl	Pl-St-Pl-Pl
2	33,33%	4	66,67%	-	60%	Pl-Pl-St	St-Pl-Pl
0	0%	4	100%	-	40%	Pl-Pl	Pl-Pl
0	0%	2	100%	-	20%	Pl	Pl

Figure 6: Test methodology Test 3

Sheave arrangement (Test 4)	Areas of bending
	

Number of steel sheaves	% of steel sheaves	Number of plastic sheaves	% of plastic sheaves	Location TOP - BOTTOM		Sheave order (per machine cycle)	
2	100%	0	0%	20%	-	St	St
2	50%	2	50%	40%	-	St-Pl	Pl-St
2	33,33%	4	66,67%	60%	-	St-Pl-Pl	Pl-Pl-St
2	25%	6	75%	80%	-	St-Pl-Pl-Pl	Pl-Pl-Pl-St
2	20%	8	80%	100%-100%		St-Pl-Pl-Pl-Pl-Pl-Pl-Pl-Pl-St	
0	0%	8	100%	-	80%	Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl
0	0%	6	100%	-	60%	Pl-Pl-Pl	Pl-Pl-Pl
0	0%	4	100%	-	40%	Pl-Pl	Pl-Pl
0	0%	2	100%	-	20%	Pl	Pl

Figure 7: Test methodology Test 4

Sheave arrangement (Test 5)	Areas of bending
	

Number of steel sheaves	% of steel sheaves	Number of plastic sheaves	% of plastic sheaves	Location TOP - BOTTOM		Sheave order (per machine cycle)	
2	100%	0	0%	20%	-	St	St
4	100%	0	0%	40%	-	St-St	St-St
4	66,67%	2	33,33%	60%	-	St-St-Pl	Pl-St-St
4	50%	4	50%	80%	-	St-St-Pl-Pl	Pl-Pl-St-St
4	40%	6	60%	100%-100%		St-St Pl-Pl-Pl-Pl-Pl-Pl-St-St	
2	25%	6	75%	-	80%	Pl-Pl-Pl-St	St-Pl-Pl-Pl
0	0%	6	100%	-	60%	Pl-Pl-Pl	Pl-Pl-Pl
0	0%	4	100%	-	40%	Pl-Pl	Pl-Pl
0	0%	2	100%	-	20%	Pl	Pl

Figure 8: Test methodology Test 5

3 Test results

This thorough approach mentioned in the previous section aimed to ensure a precise and reliable evaluation of the investigation. The primary focus was to determine the influence of the positioning and number of plastic sheaves and steel sheaves on the rope life to discard and failure as well as on the internal damage of the rope.

To this end, the operational fatigue testing of the rope for the selected sheave combination was conducted until either a failure of an outer strand was detected or a significant increase in elongation occurred within a predefined period of time, indicating potential failure of the rope core.

On completion of the tests, a careful assessment of the rope's discard state was carried out, and the remaining breaking load of some sections was determined. This assessment was based on the examination of the specific sections, shown in **Figure 2** and was in accordance with the guidelines of the ISO 4309 [4].

The bending fatigue results obtained from the different test arrangements are shown in the following table:

Sheave order (per machine cycle)		Lifetime N [cycles]	Discard N_{A30d}[3] [cycles]	Discard N_{A30d}	Test Label[4]	Test No.
St-St-St-St-St	St-St-St-St-St	242590	127164	52%	1^T	1
			102320	42%	1^B	
Pl-Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl-Pl	632290	619644	98%	2^T, 2^B	2
Pl-Pl-St-Pl-Pl	Pl-Pl-St-Pl-Pl	433750	433750	100%	3-1^T, 3-1^B	3-1
		414930	402482	97%	3-2^T, 3-2^B	3-2
St-Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl-St	511000	112420	22%	4^T	4
St-St-Pl-Pl-Pl	Pl-Pl-Pl-St-St	411500	102875	25%	5^T	5

Table 2: Bending fatigue test results

3.1 Consideration of each test setup as an overall system

In the following sections, each test arrangement is considered as a stand-alone system, i.e. as if it were a crane system equipped with the same number of sheaves and materials as described in the previous chapters. The next figures show the results obtained from the tests of **Table 2** in graphical from.

3.1.1 Comparison of the different sheave orders

Figure 9 displays the two reference systems. Compared to the full-steel setup, the lifetime of the rope to failure increased by a factor of 2.61 and the time to discard increased by a factor of 5.40 with usage of plastic sheaves only. In addition, within the

[3] Only 30d published, discard state according to reference length of 6d was visible later than 30d.
[4] ^{T} =TOP, ^{B} =BOTTOM according to Figure 2.

full-steel system the rope achieves an average residual lifetime of 53%, whereas the rope in full-plastic system achieves 2% only.

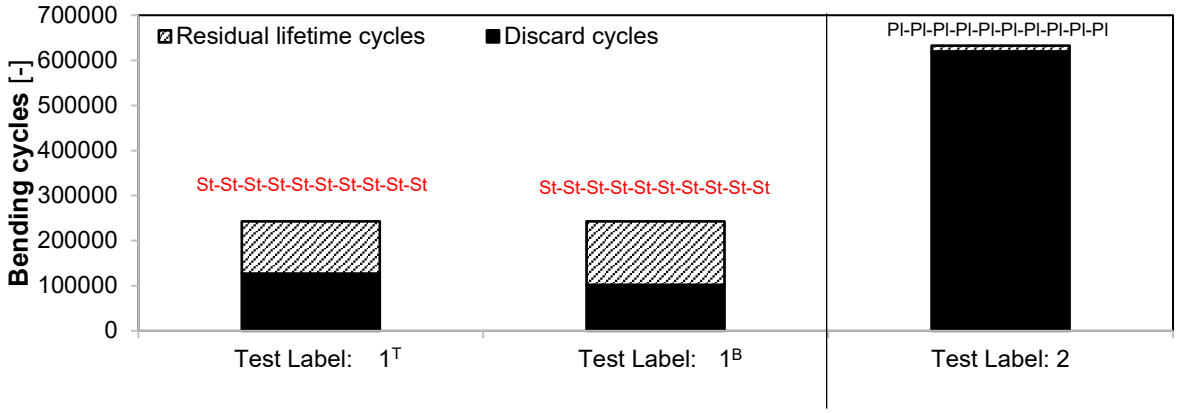


Figure 9: Full steel | Plastic

Figure 10 visualizes the comparison of the rope performance in the full-plastic system and the system where the plastic sheave in the middle (Pos. 3) was replaced with a steel sheave to maintain a symmetrical structure. This was intended to simulate a reeving system in which some sections of the rope run exclusively over plastic sheaves, while other sections, previously damaged by the plastic sheaves, then pass over a steel sheave and further plastic sheaves.

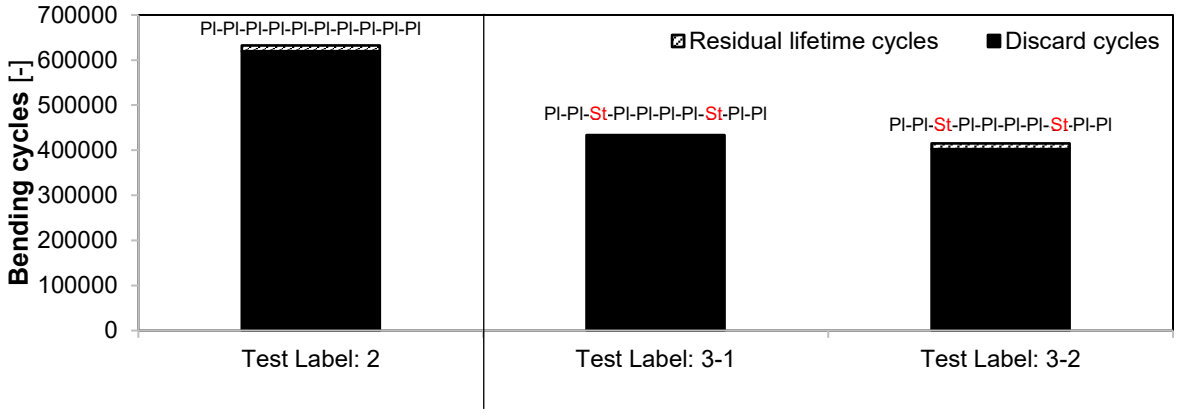


Figure 10: Full plastic | Steel sheave in the middle (Pos. 3)

As can be seen, the residual lifetime is almost non-existent in both configurations, i.e. the rope fails suddenly. If the sheave in the middle (Pos. 3) is replaced by a steel sheave, the lifetime of the rope is reduced to 67%, compared to the full plastic sheave arrangement.

In another experimental setup the first plastic sheave (Pos. 1) was replaced by a steel sheave, it is ensured that the rope is damaged by a steel sheave in all its sections throughout its entire life, labelled as 4^T in **Table 2**.

The next tested arrangement differs from the previous one in that the second sheave in the setup (Pos. 2) has also been replaced by a steel sheave. As a result, the rope is now continuously damaged by two steel sheaves, labelled as 5^T in **Table 2**.

These two results achieved from the previous mentioned configurations are shown in **Figure 11** in comparison with the setup where the plastic sheave in the middle (Pos. 3) was replaced by a steel sheave.

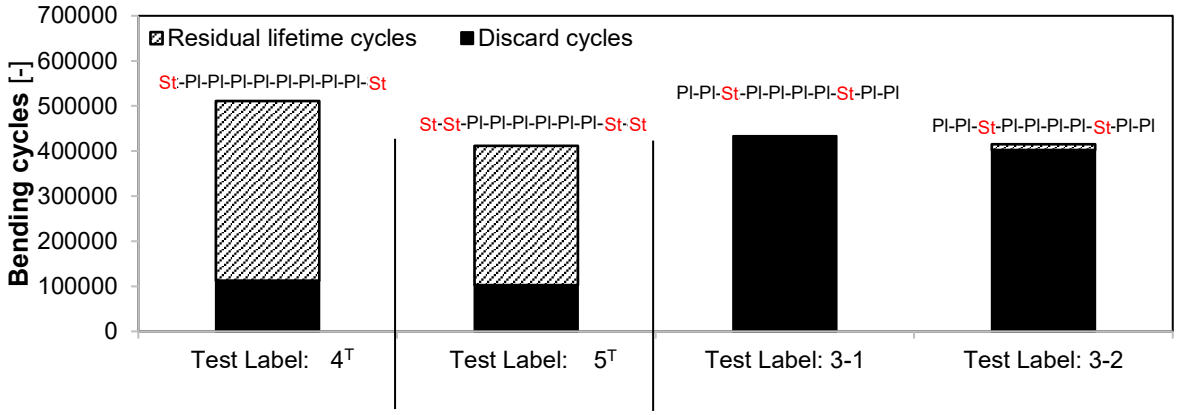


Figure 11: Steel sheave at the beginning/end (Pos. 1 / Pos. 2) | Steel sheave in the middle (Pos. 3)

In the configuration ($4^T/5^T$) which ensured that the rope is damaged by minimum one steel sheave in every section throughout its entire life, the lifetime of the rope is increased by a factor of 1.20 / reduced to 97% and the discard state of the ropes could be clearly detected, compared to the configuration where the plastic sheave was replaced by a steel sheave in the middle (Pos. 3).

3.1.2 Influence of the amount of steel sheaves and their position

Figure 12 shows the influence of the number/percentage of steel sheaves in the system on the bending cycles to discard and failure, based on the data from **Table 2**.



Figure 12: Lifetime and discard depending on the number/percentage of steel sheaves

Based on the observation that the discard state, of the tests at 4^T and 5^T was detected in sections that were bent exclusively over steel sheaves, the values were accordingly assigned to 100% steel sheaves in the system.

Several conclusions can be made from these data:

1. As the number of steel sheaves increases from the starting point (Pos. 1), the lifetime of the rope decreases.
2. As the percentage of steel sheaves in the system increases, the service life of the rope decreases.
3. Correlations can be found between the individual reached lifetime and the time to discard of the rope in dependence of different sheave arrangements.
4. Even a single steel sheave in the system, correctly placed, can make the rope operation considerably safer by increasing the residual lifetime (the number of bending cycles between reaching the discard state and the rope failure).

It can be noted that the lifetime of the rope decreases by ≈17.50% for every additional 20% of steel sheave in the system and vice versa. Therefore, if the steel sheaves are arranged in a row, the following relationship emerges:

$$Reduction\ factor\ rope\ life = e^{-0.959 * \frac{number\ of\ steel\ sheaves}{total\ number\ of\ sheaves}} \quad (1)$$

Figure 13 shows the expected residual lifetime of the rope according the values from the previous figure.

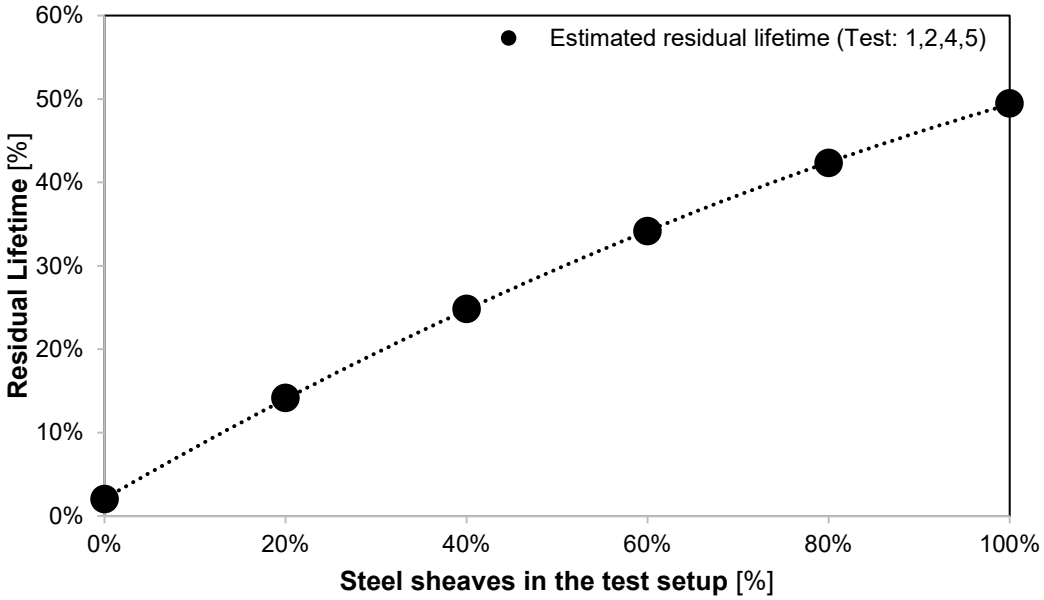


Figure 13: Lifetime and discard depending on the position of steel sheave

It can be noted that the residual lifetime of the rope increases continuously for every additional 20% of steel sheave in the system and vice versa. Therefore, if the steel sheaves are arranged in a row, the following relationship emerges:

$$Residual\ life = N * (1 - \left(0.98 * e^{-0.662 * \frac{number\ of\ steel\ sheaves}{total\ number\ of\ sheaves}}\right)) \quad (2)$$

These correlations apply to arrangements where the rope was pre-damaged by a steel sheave. However, they do not apply to the configuration where the middle plastic

sheave (Pos. 3) was replaced by steel. In this case, the results deviate from the other data.

Surprisingly, however, the two tests where the steel sheave was placed in the middle (Pos. 3) showed a 20% shorter lifetime, compared to the test where the first sheave (Pos.1) was replaced by steel, although the total number of steel sheaves in the system was the same.

This leads to the assumption that the expected rope life to discard and failure is dependent on the position of the steel sheave. A possible explanation for this dependency could be found in the sheave order when examining multiple consecutive machine cycles, as shown in **Table 3**, or in the type of failure/ internal damage of the rope.

Sheave Position	**Sheave order per 3 machine cycle**					
Rope movement	forward	backwards	forward	backwards	forward	backwards
Pos. 1	St-Pl-Pl-Pl-Pl-	Pl-Pl-Pl-Pl-St-	St-Pl-Pl-Pl-Pl-	Pl-Pl-Pl-Pl-St-	St-Pl-Pl-Pl-Pl-	Pl-Pl-Pl-Pl-St-
Pos. 3	Pl-Pl-St-Pl-Pl-	Pl-Pl-St-Pl-Pl-	Pl-Pl-St-Pl-Pl-	Pl-Pl-St-Pl-Pl-	Pl-Pl-St-Pl-Pl-	Pl-Pl-St-Pl-Pl-

Table 3: Sheave order after multiple machine cycles

However, due to the limited amount of data, the cause of this could not be conclusively determined and these general correlations should be interpreted with caution as they are more difficult to determine.

3.1.3 Inner wire break distribution and remaining breaking load

Table 4 shows the change of the breaking load of the individual rope sections from test setups, involving full steel-, full plastic-, and the middle sheave (Pos. 3) replaced by steel, after bending fatigue tests.

Sheave order (per machine cycle)		**Lifetime N**	**ABL / MBL**	**$B_{O\ 30d}$: $B_{I\ 30d}$**	**Test Label**	**Test No.**
St	St	20%	2,7%	13:0	1^B	1
St-St	St-St	40%	0,1%	≈2:1		
St-St-St	St-St-St	60%	-10,1%	≈2:1		
St-St-St-St	St-St-St-St	80%	-26,4%	≈2:1		
St-St-St-St-St	St-St-St-St-St	100%	-100,0%	not countable		
Pl	Pl	20%	-20,5%	≈1:115	2^B	2
Pl-Pl	Pl-Pl	40%	-16,2%	≈1:63		
Pl-Pl-Pl	Pl-Pl-Pl	60%	-9,2%	≈1:63		
Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl	80%	-6,3%	≈1:55		
Pl-Pl-Pl-Pl-Pl	Pl-Pl-Pl-Pl-Pl	100%	-100,0%	not countable		
Pl	Pl	20%	-30,0%	≈1:53	$3\text{-}2^B$	3
Pl-Pl	Pl-Pl	40%	-26,1%	≈1:16		
Pl-Pl-St	St-Pl-Pl	60%	-35,7%	≈1:11		
Pl-Pl-St-Pl	Pl-St-Pl-Pl	80%	-36,0%	≈1:8		
Pl-Pl-St-Pl-Pl	Pl-Pl-St-Pl-Pl	100%	-100,0%	not countable		

Table 4: Remaining breaking load and wire failure ratio

The notation “$B_{O\ 30d}$: $B_{I\ 30d}$“ represents the ratio of external 'visible' to internal 'invisible' wire failures on a length of 30 times the diameter, which were detected upon disassembling the rope.

The test in which all the rope sections ran over steel sheaves only, showed significantly more rope damage on the rope surface than inside. The analysis of the distribution of wire breaks, in the sections that ran over plastic sheaves only, showed significantly more damage on the inside of the rope than on the rope surface. Furthermore, the ratio of outer to inner wire failures decreases, as the number of bending cycles increases.

Similar behaviour was observed in the test with the steel sheave in the middle (Pos. 3) of the test arrangement. However, it is noteworthy that the ratio of external 'visible' to internal 'invisible' wire failures varies with increasing percentage of lifetime compared to the previous mentioned test.

The behaviour described above is also reflected in the results of the determined residual breaking load of the individual rope sections (**Figure 14**). For the sections which ran only over steel sheaves, the actual breaking force of the rope increases slightly at first and then decreases continuously. When the rope reaches its discard, it still retains its original breaking force.

On the other hand, the actual breaking force of the sections that have run exclusively over plastic sheaves, initially drops sharply and then rises again with increasing lifetime. In the test setup where the sheave in the middle (Pos. 3) has been replaced by a steel sheave, the influence on the remaining breaking load of the plastic, the steel sheaves as well as the combination of both, is visible.

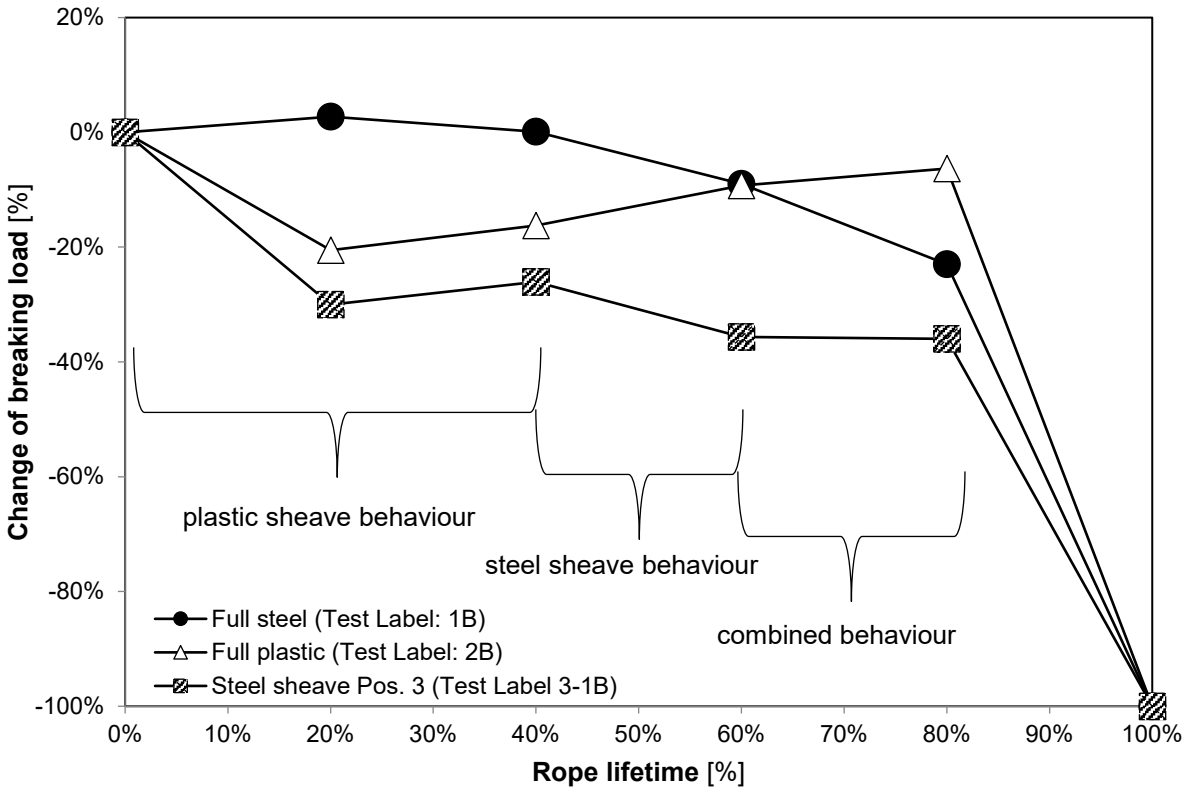


Figure 14: Change of breaking load after bending fatigue test

It is notably observed that sections of the rope bent exclusively over plastic sheaves show less loss in breaking load, compared to the original breaking strength, as their lifetime increases.

According to Reference [3], a similar behaviour was observed in a non-lubricated rope bent over steel sheaves only, attributed to fretting corrosion developing inside the rope. In the present test series, fretting corrosion was also detected inside the rope parts that were bent over plastic sheaves.

Figure 15 shows the change in breaking load over the lifetime of the rope as a function of the number of bending cycles.

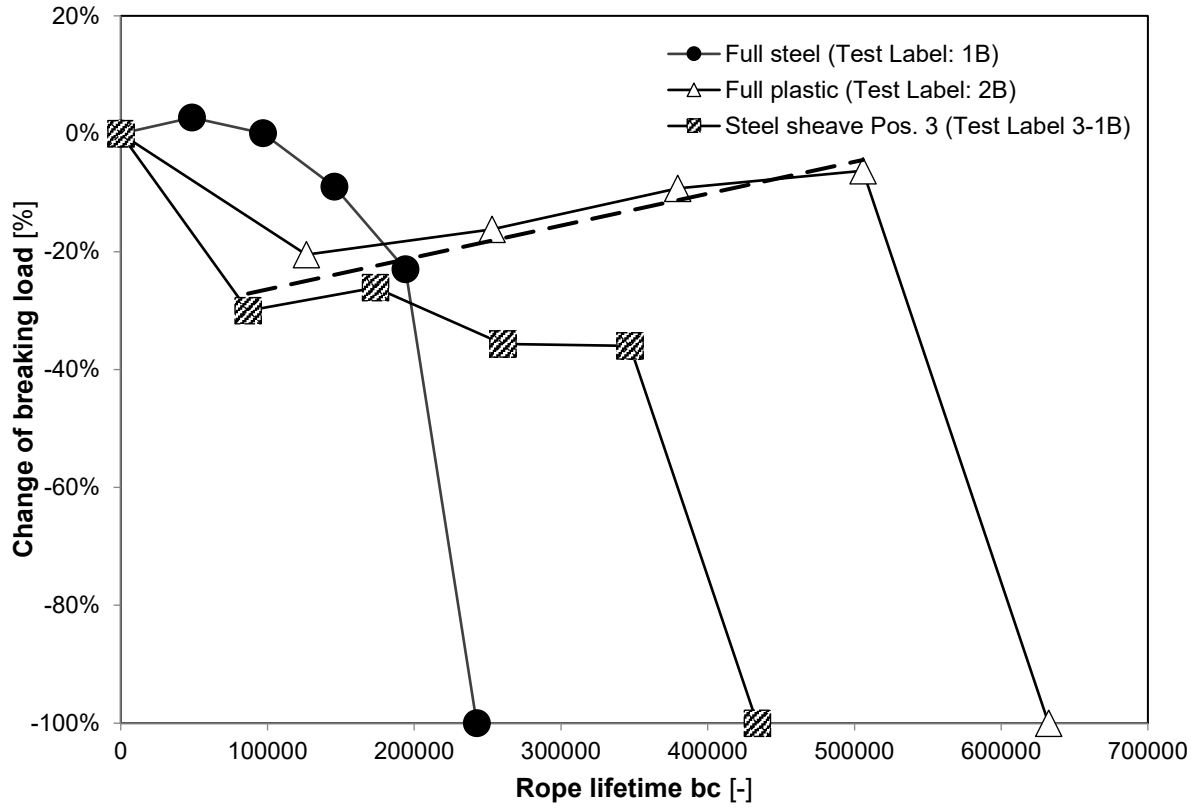


Figure 15: Evolution of the breaking force after bending fatigue test

The dotted line shows the combination of the breaking load data from the full plastic sheave arrangement with the values from the arrangement where the plastic sheave in the middle (Pos. 3) has been replaced by a steel sheave. It shows a linear behaviour, which supports the assumption that, when plastic sheaves are in the system, the breaking load of the sections does not increase purely by chance with increasing rope lifetime.

4 Conclusions

The study reported in this paper investigated the impact of plastic and steel sheave positioning and number on the life and service of ropes, comparing various sheave configurations and their effects on rope the rope lifetime and discard. Multiple bending fatigue tests were conducted with an 8xK26WS – EPIWRC rope construction with different arrangements of plastic and steel sheaves. Each test setup was considered and evaluated as a complete system individually.

Correlations have been identified between the individually reached lifetime and the time to discard of the rope, depending on different sheave arrangements. The general influence of plastic sheaves on the lifetime and time to discard of ropes was confirmed, revealing that plastic sheaves increase the rope's lifetime by a factor of 2.61 and the time to discard by a factor of 5.40 on the expense of the residual lifetime, which reduces to a very low level. It has been observed that as the number of steel sheaves in the system increases the lifetime of the rope correspondingly decreases.

It can be noted that the lifetime of the rope decreases by ≈17.50% for every additional 20% of steel sheave in the system and vice versa. It could also be observed that the more steel sheaves are introduced into the system, the bigger the ratio between discard state and failure of the rope, if they are arranged in a row.

Interestingly, even a single steel sheave placed correctly in the system can significantly contribute to the indication of when the rope is ready for discard, which therefore answers the initial question whether the rope failure of the cable crane could have been avoided if the steel sheave in the system had been positioned in a different part of the reeving system. However, the cause of this contribution could not be sufficiently identified.

Furthermore, the residual breaking load of the ropes was examined after the completion of the bending fatigue tests. Notably, ropes running exclusively over plastic sheaves show less strength loss in breaking load, compared to the original breaking strength, as their lifetime increases. This could potentially be explained by a phenomenon that is paralleled in non-lubricated ropes over steel sheaves, attributable to internal friction corrosion.

Future research could delve deeper into the specific impacts of various sheave materials and arrangements on rope lifetime and discard, broadening the understanding of these dynamics in industrial applications.

5 Acknowledgements

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7 Author introduction



Mr. Marco Elig, M.Eng.

He received his Bachelor of Engineering (B.Eng.) degree in Mechanical Engineering from the University of Applied Science Kaiserslautern in 2015, followed by a Master of Engineering (M.Eng.) degree in the same field in 2023. He began his professional journey as the Head of Testing at the verope Service Center GmbH in 2015, where he honed his skills and expertise in the field of wire rope testing. In 2018, he transitioned to a role as a Research Engineer at KV R&D Center GmbH, further expanding his knowledge and experience.

Since 2021, Mr. Elig has been serving as the Managing Director at KV R&D Center GmbH, leading the company with his extensive expertise in wire rope engineering.

Mr. Elig's professional interests primarily focus on the estimation and monitoring of rope lifetime. His work in this area includes both theoretical research and practical applications, making significant contributions to the field of mechanical engineering, particularly in the durability and reliability of rope-based systems.



Mr. Yeonhwan Bae, B.Eng.

In 2007, he graduated with a Bachelor of Engineering (B.Eng.) degree in Metallurgical Engineering from a university in South Korea. Prior to completing his degree, he began his career in Research & Development engineering in October 2006 at KISWIRE, where he focused on the development and improvement of rope and cable products.

Throughout his career at KISWIRE, Mr. Bae specialized in the optimization of manufacturing processes and enhancement of product quality. His efforts played a crucial role in increasing the efficiency and reliability of rope and cable production.