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Alternative Rope Systems for Movable Structures

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Introduction

It goes without question that carbon steel wire is the strongest most cost effective and versatile product used in the cable industry today. The main disadvantage of this basic product is the susceptibility to corrode as time passes. The majority of steel wire ropes in use today are removed from service due to the effects of corrosion and lack of maintenance from the owners. The most effective method to overcome this problem is to galvanize the individual wires in the cable forming a zinc layer between the environment and the steel. The use of zinc coated high carbon steel wire in the fabrication of cables for the movable bridge industry has been practiced for many years. However new methods and materials for the galvanization of wires have become prominent in the industry in the past few years providing significant life cycle increases. Another alternative that is taking shape in the cable market is the use of synthetic fiber cables which eliminate the concerns of corrosion while substantially increasing the life cycle of the structural element. The goal of this paper is to educate the industry about advancements in corrosion technology advancements and the growing market of synthetic fibers for use in heavy movable applications.

Structural Components

Corrosion Protection of Wire

The corrosion of the infrastructure is one of the most discussed topics in the bridge industry today. Corrosion of steel is an electromechanical process that occurs when there is a different electrical potential between two points connected by an electrolyte. The most effective method to overcome this destructive process is to galvanize the steel wires forming a protective zinc layer that is alloyed with the steel surface. The galvanizing process protects the steel by removing it from the external agents while the zinc becomes the sacrificial agent.

The majority of the wire supplied for use in structural cables is galvanized with traditional high grade zinc by the hot dip method. This process requires the wire to be submerged in molten zinc providing a very uniform coating with an aesthetically pleasing appearance. This method deposits large amounts of zinc onto the surface of the wire to protect the steel with sacrificial anodes. Structural cables that require additional corrosion resistance can be coated with a newer method which provides a Zn-5% Al protective coating. This coating is also applied to the surface of the wire by the hot-dip method. Basic Zn-5% Al coated carbon steel wire is addressed in ASTM A856 and EN 10244 however there is no current domestic specification for the use of this product on cable. The Zn-5% Al coating is a eutectic alloy that provides a unique temperature-composition point for the elements to solidify and form two-phase microstructures. This also provides a more uniform crystalline microstructure with improved mechanical characteristics. The intermetallic alloy layer that forms between the steel surface and the Zn-5% Al is a very thin ternary Al-Fe-Zn compound. This layer is thinner than a similar layer that is formed during standard galvanizing operations. The thinner layer provides the wire with better formability properties which are critical to the production of structural cables. Figures 1 and 2 below show the traditional Zinc coating and Zn-5% Al coating respectively.

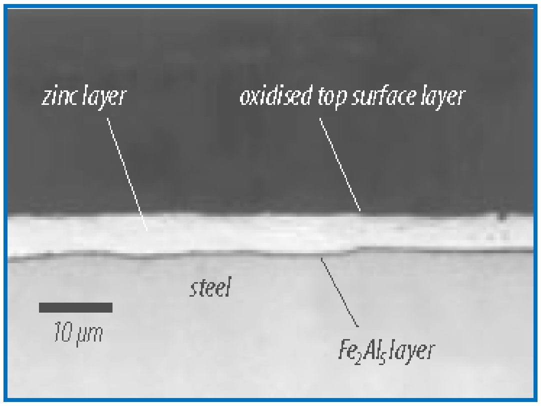

Figure 1: Zinc Coating

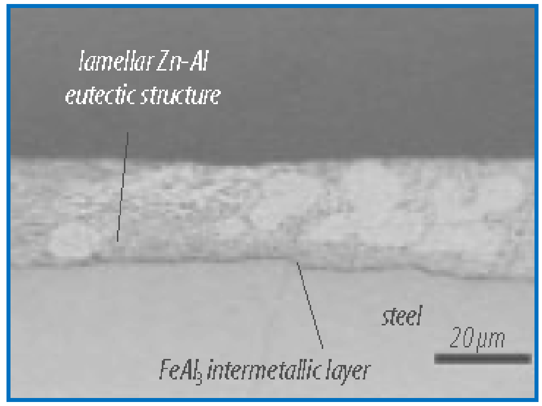

Figure 2: Zn-5% Al Coating

Ageing tests have shown the Zn-5% Al coating to provide improved corrosion resistance in comparison to conventional galvanized coating by as much as three times. This is due to the aluminum content in the product. Aluminum corrodes much slower than zinc due to the surface barrier layer of the very passive aluminum oxide. Combining the passive corrosion inhibition of aluminum oxidation with the active and passive effects of zinc results in approximately three times the amount of corrosion protection compared to standard zinc coated wire. The coating also provides an anodic feature that heals over the exposed steel when the wire is abraded or scratched exposing the base steel. This process was tested and proved in the mid 1980's with the majority of the production and use taking place in Europe.

Since the wire ropes are dynamic systems the steel wires must be protected from abrasion and fatigue with lubricants. These lubricants are typically petroleum based and applied annually for maintenance of the system. In most standard applications the lubricant also serves as the main source of corrosion protection. However what typically occurs is heavy accumulation of the lubricant on the wire rope systems resulting in water entrapment and accelerated corrosion. This also limits the visual inspection of the wire rope due to the coating. The addition of the of a Zn-5% Al protective layer would eliminate the need for heavy grease type lubricants and provide a cleaner rope system for operation and inspection.

Synthetic Fiber Rope Materials

Synthetic ropes are rapidly becoming standard products in the global cable market. They provide unique set of properties improving on the weaknesses the hinder the traditional products. However synthetic cables come with their own rules and limitations which will be discussed below.

Two high performance fibers that are commonly used in lifting applications are aramid co-polymers and high modulus polyethylene (HMPE). There are numerous producers of these items located around the world. Each fiber provides unique advantages and shows the performance value when compared to traditional steel. One of the largest concerns surrounding the use of a fiber rope is the elongation of the product in service. The initial stiffness of a new HMPE rope increases with load level in a bedding-in process resulting from both molecular alignment and construction reorientation. The aramid fiber rope is less sensitive to this effect and shows a high stiffness from first loading. This concern can be overcome with proper prestretching and measuring of the rope in the fabrication process. Bending over sheave tests also indicate longer lifetime cycles for the aramid fibers in comparison to the HMPE. Aramids have very high tensile strength and low elongation characteristic, are non-conductive, and provide excellent resistance against heat.

Synthetic Fiber Rope Comparisons

For years the ASHTO and AREAMA standards required a polypropylene or natural fiber core be used in the wire rope system. This is still prevalent today for many of the wire ropes used in movable structures. This requirement was based on historical success of the product design and the ideas behind using a fiber in combination with steel outer strands. Today fiber core wire ropes are as rare as a carbureted engine due to significant advancements in steel and the design capabilities available for rope engineers. Not only can the core fibers now be used as tension members but the ability to produce fully synthetic lifting components is becoming more prevalent as standards are developed. High strength synthetic fibers are utilized across most industries due to their unique properties and performance over steel. These fibers are used to produce high performance ropes and cables in demanding applications, with proven reliability and safe usage. Figures 3 and 4 below show a traditional 6 strand steel wire rope and a 12 strand braided synthetic rope surface respectively. These two figures quickly point out the differences in materials but also the similarities in construction of the rope.

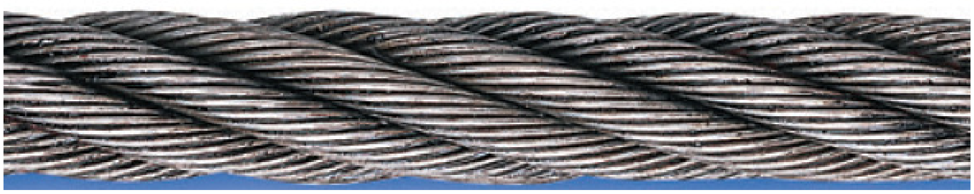

Figure 3. Wire Rope Surface

Figure 4. Synthetic Fiber Rope Surface

In all lifting applications the rope materials must have low elongation and creep and they cannot change their shape, either temporarily or permanently, while under load. In comparison to steel the fibers are on average 1/7 the weight while providing a marginal increase in tensile strength. Table 1 below lists the average Minimum Breaking Force (MBF) of synthetic and steel rope along with the weight per foot of the product. The differences in the two products are also compared.

Diameter (in)	Synthetic Rope		Steel Rope		Difference	Difference
	MBF (lbs.)	Weight (lb./ft.)	MBF (lbs.)	Weight (lb./ft.)	MBF	Weight
0.5	35500	0.065	26600	0.46	133.5%	707.7%
0.75	63300	0.117	58800	1.04	107.7%	888.9%
1	110000	0.208	103400	1.85	106.4%	889.4%
1.25	164000	0.325	159800	2.89	102.6%	889.2%
1.5	220000	0.457	228000	4.16	96.5%	910.3%
1.75	322000	0.699	306000	5.67	105.2%	811.2%
2	382000	0.833	396000	7.39	96.5%	887.2%

Table 1. Rope MBF and Weight Comparison

The individual fibers are not corrosive therefore no lubricants are required to protect the materials. Removing the corrosion element from the life cycle of the rope significantly adds value to this alternative. The majority of wire ropes in use today show significant signs of corrosion due to the lack of maintenance and protection methods. The synthetic fibers also improve the vibration dampening characteristics of the structures with an estimated Modulus of Elasticity of 18.85 ksi. for the product. The materials and construction lend fiber ropes to be resistant to bending fatigue for operations over sheaves. Numerous fatigue life test cycles have shown a high performance fiber rope will provide a fatigue life cycle 12 times longer than that of steel rope.

The ability to provide a double-braided feature in a synthetic rope provides uniformity and protection to the load bearing fibers. Identical to the processes for making steel wire ropes the production begins be braiding fibers together into strands and strands into rope, this removes the poor efficiency of traditional fiber twists. The braided process adds incredible strength to the product. A well-made braided rope features fibers that are aligned in a single direction and overlap in a way that lock the components together for combined strength. The more pull exerted on the rope, the more the braiding locks each fiber into place. A double braided construction is shown in figure 5. The strength and durability features make it suitable to be used to replace steel wire ropes in most applications.

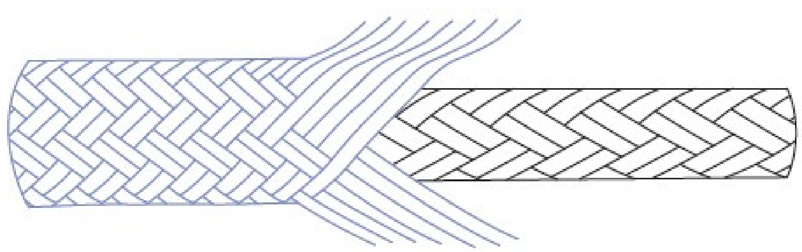

Figure 5 – Double Braided Rope construction

A typical braiding machine is shown in Figure 6. The braid provides protection from foreign elements as well as shelter the rope from ultra violet ray. The external covers also provide stability and can be used as a visual aid element for inspection of the rope in service.

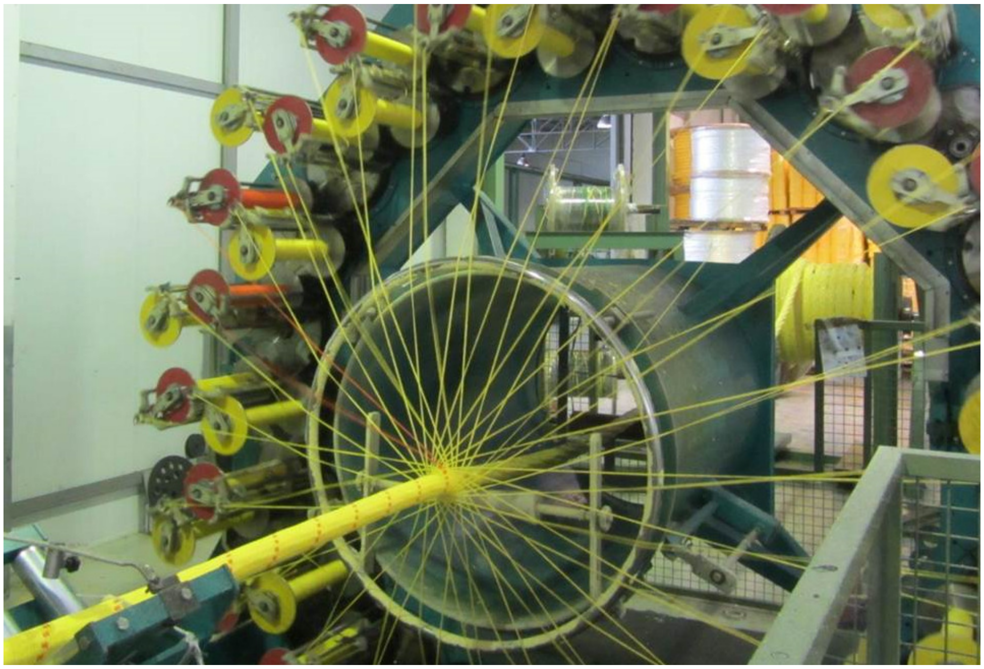

Figure 6

Machinery Application

The trend in most applications is to make the working components smaller and this is possible with the synthetic high performance materials. The strength and resistance to bending fatigue of the fiber ropes will positively impact the costs to the owner. Due to the strength comparison the fiber rope will produce the same capacity with a smaller diameter product; this in turn allows the sheaves to be smaller. With steel wire rope, the AASHTO standard requires the sheaves to be 72 times the rope diameter. With aramid rope technology, which is stronger and more resistant to bending, it is possible to reduce the diameter of the sheave to 25 times the diameter of the rope. If the sheaves are smaller, then a smaller engine can be fitted, because the torque required to turn a sheave is proportional to its size. The smaller engine will cost significantly less than a larger one and in comparison the power required to turn that engine will also be less. The system designer can generate significant cost savings in material and space with this methodology while providing a system that requires less maintenance for the owner.

Conclusion

Application success requires understanding the characteristics of each component in a rope. This paper is by no means a complete analysis of structural cable constructions used for heavy movable structures. This paper was written to educate the bridge engineering community on the developments in the field of rope technology. The current ASTM and Industry specifications covering these types of cables allows the manufacturer the latitude to produce cables without restrictive manufacturing parameters. Innovative materials are now available to increase the corrosion resistance of the cable and greatly increase the life cycle of the products. These products can be shown to provide a significant return on investment as the products discussed in the paper will increase the costs of the components when compared to traditional steel items.

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