Wrapping with Butyl Rubber Tapes—An Innovative Corrosion Protection for Bridge Cables

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Abstract

According to the codes of the German Ministry of Traffic, the surface of new and existing locked coil ropes has to be protected against corrosion by an approximate 400 μm thick layer of paint. For the preparation of the rope surface and for the application of the different paint layers by a brush, access has to be granted over the entire rope length by fixed or movable scaffoldings—what in existing bridges may lead to important traffic disturbances. If, instead, the ropes are protected against corrosion by butyl rubber tapes—as known since a long time from the protection of pipelines etc.—the requirements for the preparation of the rope surface and thereby the amount of work and equipment may be reduced substantially. Owing to the application of these tapes by automotive and automatic wrapping robots, scaffoldings and lifting equipment are not needed any more, whereby important time and cost savings are achieved and the impact on the traffic is widely reduced. General considerations with reference to this innovative, robust and economic corrosion protection system are presented; the successful applications for two cable stayed bridges—across the Rhine between Kehl (Germany) and Strasbourg (France) and across the Köhlbrand in the Port of Hamburg—are described. An outlook on further possible applications is given.

Keywords: corrosion protection; health monitoring; locked coil ropes; butyl rubber tapes; testing; visual inspection; wrapping robot.

Introduction

State of Art—Corrosion Protection by Painting

According to the German codes and guidelines[1–3] for the external corrosion protection of locked coil ropes, only a protective system consisting of various layers of paint is permitted. Its adequacy has to be verified by tests and permission—general or for a special application. Similar protective systems are applied in other countries.

The basic requirements are:

- preparation of the rope surface by brushing, sweeping or blasting, with a very careful treatment of the galvanised wires;
- four layers of paint for galvanised wires and five layers for non-galvanised wires, with a total minimum thickness of 410 and 460 μm, respectively;
- application of the corrosion protection—at least of its outer layers—after erection and stressing of the cables;
- application of all layers by brushes;
- sufficient time for the hardening of one layer prior to the application of the next one;
- minimum surface temperature of the cable 5°C and 3 K above the dew-point.

These requirements imply that access to the cables over their entire length by means of movable or fixed scaffoldings is mandatory. With respect to the protection of the environment, these scaffoldings generally need an airtight cover and their cost represents an important percentage of the total cost of the corrosion protection, especially if the towers are high and/or the cables have a complex geometry.

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Reasons for Searching for an Innovative Corrosion Protection of Locked Coil Ropes

The pedestrian and bicycle bridge across the Rhine between Kehl and Strasbourg with spans of 43,72 + 183,37 + 43,72 m = 270,81 m[4] (*Fig. 1*) was an integral part of the 2004 German–French garden exhibition[4].

For the final design and construction of the bridge, only 16 months were available. The erection of the bridge deck and cables mostly took place during severe winter, so the external corrosion protection of the ropes could not be applied before the opening of the exhibition in April 2004.

For their protection after the exhibition, the contractor made a claim which was substantially higher than the cost according to the contract. About 75% of this claim was for scaffoldings and only 25% for corrosion protection.

Therefore, a basically different system of corrosion protection was sought for. After intensive testing, it was decided to protect the cables by wrapping them with butyl rubber tapes as described in more detail hereunder.

Description and Testing of the Butyl Rubber Tapes

Description

Build-up, Details and Behaviour of the Tapes

The corrosion protection consists of two layers of butyl rubber tapes which are wound around the cable with 50% overlapping (*Fig. 2*). Their total thickness is about 2,6 mm.[5,6]

In the overlapping areas, a cold welding between the two layers is achieved as a result of an interdiffusion of the butyl rubber molecules (*Fig. 3*). Thereby a hermetically closed, tube-like sheath is achieved which has high resistance against mechanical damages and is virtually water-, vapour- and airtight. The tapes are directly wrapped onto the rope surface which must, of course, be dry and free of loose elements. But blasting or sweeping is not required and existing, well-adhering paints need not be removed.

These tapes are used since over 40 years for different applications in the

Fig. 1: Pedestrian and bicycle bridge Kehl–Strasbourg

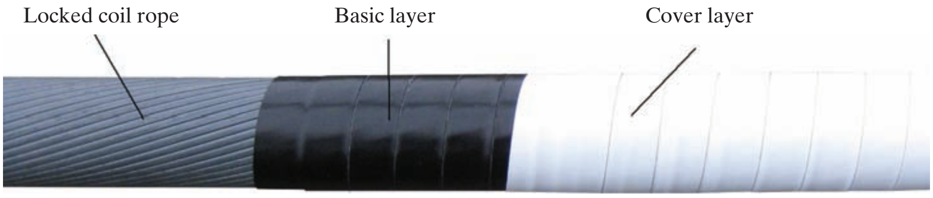

Fig. 2: Corrosion protection system with butyl rubber tapes

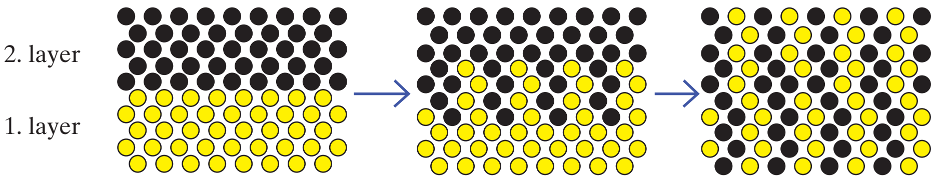

Fig. 3: Cold welding of the butyl rubber tapes

field of corrosion protection and have been optimised for this special purpose (*Table 1*).

The three layer black base tape (*Fig. 4*), which is in direct contact with the rope surface, consists of a stabilised foil of polyethylene (PE) with a cover of permanently plastic butyl rubber on both sides. It forms a protective sheath according to DIN 30672 and DIN EN 12068 and thereby becomes the actual corrosion protection, even for high corrosive loads.

The butyl rubber adapts well to the surface configuration of the ropes and forms by adhesion and gearing an excellent connection with it (*Fig. 5*).

The two layer outer tape (*Fig. 4*), consisting of a stabilised bearing PE foil with a cover of butyl rubber on one side, forms an additional protective sheath according to DIN 30672 and DIN EN 12068 and is, furthermore, a robust mechanical protection against all attacks from outside. Its outer PE foil is available with a variety of colours.

Health Monitoring and Repairing of the Tapes

To ensure ease while taking samples of the tape without damaging the existing protection, additional tapes are wrapped without adhesion over a length of about 500 mm onto the normal protection, at specific places. Thus, the long-term behaviour of the tapes can be checked with specimens exposed to exactly the same influences as the normal tape.

In case of damage, for example due to accidents, fire or vandalism, the damaged part is simply cut out, removed and replaced by new tapes overlapping the existing tapes. In order to optimise the adherence of the tape, the rope surface is painted with a primer. Additional works like blasting and sweeping are not required.

Application with a Wrapping Robot

The tapes are wrapped completely automatically around the cables by using a robot. Owing to the automation of the whole process, no scaffolding, protective coverings or other major equipment are needed, which reduces substantially the required working time, the cost and the impact on the traffic.[7,8]

For this, an equipment system has been developed which travels automatically along the cables. Depending on the intended purpose, it can be supplemented with additional modules like a visual inspection unit, magnetic induction (MI) unit, thermographic unit, PE welding unit, automatic wrapping robot and so on (*Fig. 6*).

With this robot, the 50 mm wide butyl rubber tapes are applied under a certain pre-stress onto the ropes so that a uniform layer is achieved without wrinkles and air inclusions. The required joints in the free length are realised by electronic steering so that no direct human access to the working area is necessary.

Experience shows that about 20 m^2 of the cable surface can be protected (both layers) per 10 h shift and per equipment.

By means of monitoring equipment, all works are controlled from the ground and, if necessary, documented for reference.

Testing

Long-Term Behaviour

The long-term behaviour of the butyl rubber tapes was checked at the Otto-Graf-Institute of the University of Stuttgart.[9] For this type of corrosion protection, no appropriate standards or guidelines were available. Therefore, the investigation was performed on the basis of DIN 12944, Parts 1–6, TL/TP-KOR-Seile/RKS Seile and TL/TP-KOR-Stahlbauten with galvanised and non-galvanised steel pipes ($Ø$ = 59 mm, l = 210 mm) by the tests listed in *Table 2*. Additional investigations under a light microscope and by Energy Dispersive X-ray Spectroscopy (EDX) analysis were also performed.

In a second series of tests, the behaviour of repairs—see previous section

Tape		Unit	Base	Top	Standard
Tape thickness	Total thickness	mm	≥0,8	≥0,5	ISO 4591 ASTM D-1000
	Carrier film	mm	approximately 0,28	approximately 0,3	
	Butyl rubber, inside	mm	approximately 0,44	approximately 0,2	
	Butyl rubber, outside	mm	approximately 0,08	—	
Elongation at break		%	600	≥500	DIN EN 12068
Tensile strength at 23°C		N/10 mm	100	≥65	ASTM D 149 DIN EN 12068
Modulus at 10% elongation		N/10 mm	35	50	
Dielectric strength		kV/mm	35	35	ASTM D 149
Water absorption at 23°C after 1 day/30 days		%	≤0,1 / ≤ 0,4	≤ 0,1 / ≤ 0,4	ASTM D-570
Saponification value carrier film and adhesive		mg KOH/g	1	1	DIN EN 12068
Permeability to water vapour		g/m^2 24 h	$\leq 2 \times 10^{-1}$	$\leq 2 \times 10^{-1}$	DIN 53122
Permeability to oxygen			$\leq 10^{-4}$	$\leq 10^{-4}$	DIN 53536
Brittleness temperature		°C	–46 ± 4	–46 ± 4	DIN 53372
			–58 ± 4	–58 ± 4	GOST 10354
Continuous operating temperature		°C	–60 to 50°C	–60 to 50°C	
Electrical insulation resistance		$\Omega\ m^2$	$>10^{10}$		
Peel strength on steel 100 mm/min (at 23°)		N/10 mm	45		

Table 1: Tape properties

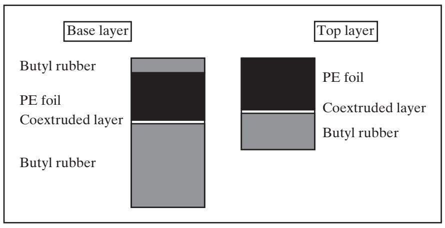

Fig. 4: Set-up of the corrosion protection tapes

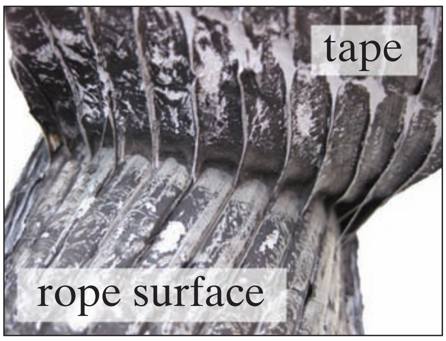

Fig. 5: Adhesion and gearing of the base layer to the rope surface

on 'Repairing'—was also checked with the same criteria.

For all relevant properties, positive test results were achieved and the requirements for the traditional painting of locked coil ropes were met and partly exceeded by far (*Table 2*).

The new corrosion protection proved to have an excellent density against

Fig. 6: Wrapping robot

vapour. According to DIN EN 1062, the equivalent air layer thickness of a 0,5 mm thick butyl rubber layer can be estimated at s_D ~ 105, whilst that of a 400 µm thick epoxy resin or polyurethane coating is s_D ~ 10 only.[10] The equivalent air layer thickness of the complete new corrosion protection system is, hence, more than 50 times bigger than that of painting systems normally used.

Behaviour in Case of Fire

The behaviour of the tapes in case of fire was tested at the University of Stuttgart by tests according to DIN 4104-1:1998-05, Section 6.2.5.

The requirements for normally inflammable materials of material class B2 were met; this means that the specimen did not fall down burning or smouldering, and the flames were self-extinguished after about 23 s (*Table 3*).

First Application at the Pedestrian and Bicycle Bridge Kehl–Strasbourg

Rope Controls

Starting in July 2008, the ropes were visually inspected by cameras and the findings were filed.

In this inspection, no broken wires were detected, but partial damage of the galvanising with beginning corrosion of some outer wires was found.

Work Realisation

After the successful tests, it was decided in August 2008 to start the wrapping of the ropes.

First, the ropes were cleaned by rotating brushes fixed to the self-travelling equipment or manually by rope access technicians.

Test		Test specimen			Test parameters	Duration	Results
		A	B	C			
1	Condensed water test	4	4		40 ± 3°C 100 % humidity. Constant climate acc. DIN EN ISO 6270-2	A: 120, 240, 480, 720 h B: 240, 480, 720 h	No cracks, no bubbles, no scaling off, no corrosion, no color change
2	Salty fog test	4	4		35 ± 2°C acc. DIN EN ISO 9227 spraying with NaCl-lotion, pH-value between 6,5 and 7,2	480, 720, 1440 h	No cracks, no bubbles, no scaling off, no corrosion, no color change
3	Artificial weathering with Xenon radiation			4	Weathering acc. DIN EN ISO 11341, cycle A, Black-standard temperature 65°C, colour measurement acc. DIN 6174 with light type D65	2000 h	Color difference ΔE^*_{ab}: 2 (allowed 3,5)
4	Artificial weathering with UV test		3		0,5 h irrigation at 15°C and UV light 0,5°C cooling-down to −20°C 4 h storing at −20°C and 20% humidity 1 h heating to 55°C 5,5 h irrigation at 55°C and UV light 0,5 cooling-down to 15°C and UV light	2000 h 167 cycles	No changes like brittleness, colour changes, no scaling off, bubbles or distortions
5	Shore D			3 3**	Acc. DIN 53505-D		Neither hardening nor brittleness of the material

Used test specimen, covered with butyl rubber tapes: (A) hot-dip galvanised steel tubes Ø 59 mm; (B) non-galvanised steel tubes Ø 59 mm; (C) Steel plates 150 × 50 × 2 mm.
**From test no. 3.

Table 2: Time accelerated tests

Test no.		1	2	3	4	5	6
Fire exposure*		F	K				
Base		Steel plate					
Combustion		–	Immediately				
Max. flame height achieved after	mm	–	40	40	40	30	40
	s	–	15	15	15	15	15
Flames self extinguished after	s	–	19	31	26	20	20
Flames extinguished after	s	Not required					
Finish of afterglow	s	No afterglow					
Smoke emission		Low					
Filter paper inflames after	s	Not inflamed					

*K: edge flaming; F: surface flame impingement.

Table 3: Fire tests

Fig. 7: Sealing at the deck anchorage

Owing to the vicinity of the lower anchorages to the walkways, vandalism had to be taken into account. Therefore, the first 1,20 m of the ropes were painted with a primer in order to further increase the adherence of the tapes. The joint between the ropes and their anchor sockets was sealed with a permanently plastic material (*Fig. 7*).

In this area, the tapes were applied by a manually operated wrapping equipment, up to a point where the geometry allowed the use of automatic wrapping robot.

First the base layer was applied by the wrapping robot. Immediately after completing the whole cable length, the top layer was wrapped.

The completed wrapping was approved in June 2009 without any objection. The relatively long duration of the works was a result of extended periods of bad weather which interrupted the wrapping for weeks.

Bridge across the Köhlbrand in the Port of Hamburg

Description of the Bridge

The bridge across the Köhlbrand, built from 1969 to 1974, is a cable-stayed bridge with spans of 97,5 + 325 + 97,5 m = 520 m. The steel-orthotropic bridge deck is 17,8 m wide, up to 58 m above the water, has a trapezoidal box girder and is supported by a total of 88 locked coil ropes with Ø = 58 to 118 mm (*Fig. 8*).[11]

The corrosion protection of these ropes consists of the following:

- hot dip galvanising of the three outer layers of wires respectively of all wires;
- a filling of the inner voids of red lead on the basis of linseed oil;
- a base layer of painting of polyurethane with zinc chromates, thickness 150 to 200 µm;
- two covering layers of polyurethane with mica of iron, thickness 150 to 200 µm each.

This 450 µm thick outside corrosion protection was applied on the bridge deck within a tent.

Strengthening of the Corrosion Protection

General

During a regular structural health monitoring of the bridge by the Hamburg Port Authority (HPA), defects in the paint surface were found which had to be repaired. At the time of monitoring in 2009, severe damages in the corrosion protection and corrosion in stadium nascendi were observed on eight ropes and complete rehabilitation had to be arranged for.

As the bridge across the Köhlbrand is a vital link to the Port of Hamburg (*Fig. 8*), complete closing of the bridge to traffic was out of the question.

Fig. 8: Köhlbrand bridge at Hamburg, works under traffic

As the lower cable anchorages are outside the bridge deck, access by means of scaffoldings would be difficult and expensive.

First Phase of Strengthening

In order to check the adequacy of the new corrosion protection for the structural and traffic conditions of the Köhlbrand Bridge, first the strengthening of the eight most severely damaged ropes was performed. These ropes have diameters from 65 to 120 mm, a maximum length of 120 m and a total surface area of 290 m^2. A grey tape was used as it is in harmony with the rest of the bridge and addresses the severe air pollution.

The eight ropes were first visually inspected by the automatic inspection equipment. The findings of this inspection were documented. Then, MI tests were performed. Based on the results of the visual inspection, all loose parts of the existing corrosion protection were removed by rope access technicians.

Owing to the very tight geometry of the cable anchorages at the bridge deck, it was decided to protect this area with a traditional cable protective system and to apply the tapes on top of this area for an overlapping length of 500 mm (*Fig. 9*). At the towers, the tapes could be applied up to about 300 mm inside on account of the rather big recesses.

In order to complete the repair works one lane had to be closed. To minimise the time of traffic obstruction, two wrapping robots were used so that the wrapping could be successfully finished in just 7 days.

Second Phase of Strengthening

Based on the good experience during the first phase, it was decided to protect the remaining 80 ropes also by butyl rubber tapes.

Prior to this decision, information was collected on:

– whether the results of the MI tests are influenced by the tapes; and
– if the tapes might be damaged by the equipments riding on them.

The corresponding tests were performed with temperatures of 30°C. It was found that even the testing equipment for the ropes with Ø = 120 mm, weighing more than 300 kg, did not damage the tapes. The results of the MI tests were identical to those without tapes.

The contract for the second phase was awarded in September 2009.

Fig. 9: Connection of the tapes to the painted rope at the deck anchorage

After the visual and magnetic induction testing, the wrapping started in May 2010 and was successfully finished on 15 August 2010 after wrapping a total surface of 2200 m^2. During these 13 weeks, one lane per direction was always open so that the traffic obstructions could be limited to an acceptable level.

The Future of the System

General Acceptance of the System

The works on the Kehl–Strasbourg Bridge and on the Köhlbrand Bridge were awarded on the basis of the tests and expert opinions. In the meanwhile, a general acceptance has been awarded by the Deutsches Institut für Bautechnik (German Institute for Construction Technology DIBt), see Ref. [12], and the Bundesanstalt für Straßenwesen (Federal Institute of Roads) has published a guideline for the system[13]. This allows now to wrap the cables of the Obere Argen Bridge of the German Federal Highway A96 (24 cables, Ø 126 mm, max. length 95 m) in autumn 2012 on the basis of valid codes.

Future Applications

The presented corrosion protection system has been developed primarily for locked coil bridge ropes. In the meantime, other fields of application were identified; some of them are presented hereunder.

For the stays of towers and similar structures situated, for example, within the flight path of airports, a signal-marking is required. This can be achieved by:

– wrapping of the ropes, alternating with white and red tapes or
– simultaneous wrapping with white and red tapes (*Fig. 10*).

Fig. 10: Wrapping method applied for signal marking

The wrapping method also offers a possibility to cover PE pipes, used as casing of parallel wire and strand cables, economically with butyl rubber tapes to modify their colour (e.g. white for reducing the heating up) or to hide possible defects on their surface. Successful tests were also performed with tapes including a helix on the surface against rain- wind- induced vibrations.

Also, the main cables of suspension bridges and concentrated cables of cable-stayed bridges can be treated with butyl rubber tapes. Owing to the use of butyl rubber materials, connections to the hanger clamps can be reliably designed and realised.

Summary

Wrapping with butyl rubber tapes is a procedure having substantial advantages compared to the traditional protection by painting.

The material is practically impermeable to water, vapour and oxygen and is stable in its properties and colours.

The system:

– is based on a corrosion protection technology proved since decades, successfully tested at the University of Stuttgart and officially approved by the German Institute of Construction Technology (DIBt).
– grants—due to the overall thickness of 2,6 mm and the outside PE foil as well as to the automatic cold welding in the overlapping tape areas—a robust and dense hose-like sheath with excellent adherence to the rope surface.
– adopts—due to the elastic behaviour of the butyl rubber—to the elongations and movements of the ropes; even possible “bleeding” of the cable filling material does not affect the adherence of the tapes.

The application:

– is simple and less time consuming by using automatic wrapping robots and is widely independent of climatic conditions.
– does not require—due to the automatic wrapping—environmentally unfriendly blasting and sweeping, nor scaffoldings and housings what reduces the inconvenience to traffic to a minimum.

The quality of workmanship is warranted by the quality assurance according to ISO 9001 and SCC combined with monitoring of the wrapping procedure from the ground. The behaviour during the service life can be supervised by simple visual or automatic inspection, by additional control patches for long-time behaviour as well as by MI testing of the cables. Damages, for example, by vandalism, can be easily repaired by adding additional tape wrapping.

These points result in a cost-effective and safe corrosion protection system for the construction as well as for the long-term maintenance.

Final Remarks

Owing to the constructive and success-oriented cooperation of all parties involved and especially the open-mindedness of the Kehl–Strasbourg Bridge and the Köhlbrand Bridge authorities it was possible to realise successfully the innovative corrosion protection in the first two applications.

With the wrapping of locked coil ropes with butyl rubber tapes a system has been developed which is at least equivalent—but in many aspects superior—to the traditional method of painting and which will impose itself in the long run. Already further fields of application have been identified which promise cost savings for the bridge authorities as well as for the tax payers.

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