NOVEL TECHNOLOGIES FOR WEAR PROTECTION AND MONITORING IN DREDGING

Michael Magerstaedt[1], Stefan Forster[2], Rainer Altmeppen[3], Nils Rentmeister[4], Larry Lai[5], Erin Garcia[6]

ABSTRACT

Dredging equipment in contact with dredged water/sediment mixtures are exposed to wear. Costs associated with the replacement of worn equipment can range from insignificant to very high, depending on the individual situation. Besides cutters and pumps, dredge line components can wear quite quickly due to high abrasion caused by sand and rock in the transported mixture. In cases where this mixture needs to be transported over a distance of more than a single pipe or hose (e.g., transport of sediment to onshore deposit sites), the cost of worn pipe and hose replacement can be quite high. The same holds true for line components used in deep sea mining.

During the last eight years, cost-efficient wear protection in mining has been revolutionized by the introduction and development of high-performance polyurethane elastomer coatings and linings. Internal coatings of steel pipes and other line components yielded useful life extension by a factor of ten or more in applications like oil, sands, hydrotransport and tailings. Compared to metallic or ceramic wear protection solutions, these new materials are significantly less costly. In addition, they are not prone to corrosion and erosion-corrosion effects. This breakthrough was made possible by the synthesis of new polyurethane grades allowing not only excellent wear, temperature, and chemical resistance, but also extremely strong adhesion to steel and other substrates, which eliminated the threat of delamination.

This usefulness is not limited to coatings and linings, however, wear parts (screen, valve, pump, and other components) that are made from these same high-performance materials have shown useful life extension and cost savings as well. Over the last two years, high-performance polyurethane coatings and components that include wear monitoring sensor functionality have been applied in the mining industry. Now, these materials not only extend component life, they also monitor wear and help optimize maintenance planning and efficiency by eliminating the need for shutdowns to check for wear. In some cases, this saves operators approximately 25% of maintenance costs.

After nearly three years of successful dredging field trials in Europe, high-performance polyurethane elastomer wear protection technology has proven its value. This presentation aims to inform the dredging industry about capabilities, properties and field performance of these products, which are currently manufactured in both Canada and Germany.

Keywords: Dredging, slurry transport, wear protection, slurry pipes, wear monitoring, useful life extension.

---

[1] Manager, Global Strategy, ROSEN Group, Obere Spichermatt 14, 6370 Stans, Switzerland

[2] Manager, Worldwide Business Line Intelligent Plastics Solutions, ROSEN Group, Am Seitenkanal 8. 49811 Lingen, Germany

[3] Sales Manager Intelligent Plastics Solutions, ROSEN Group, Am Seitenkanal 8, 49811 Lingen, Germany

[4] Leader Applications Development Smart Materials, ROSEN Group, Am Seitenkanal 8, 49811 Lingen, Germany

[5] Manager Sales and New Business Development Intelligent Plastics Solutions, ROSEN Group, ROSEN Canada, 5020 12a Street SE, Calgary, AB T2G 5K9, Canada

[6] Manager New Business Development Realization, ROSEN Group, ROSEN USA, 14120 Interdrive East, Houston TX 77032, USA

INTRODUCTION

Polymeric Coatings and Linings for Steel Pipe Protection

Carbon steel remains the most widely used material for pipelines in the oil and gas industry, as it has been for nearly a century. A number of methods have been developed over the decades to prevent external, as well as internal, corrosion damage to pipeline steel.

The industry segment of slurry pipelines (transporting multiphase streams that contain solids) is growing strongly in oil and gas, but particularly so in the mining industry. The global length of slurry pipelines in operation is currently passing the 10'000 km mark [Alan Rosewall, 2015]; [Ron Derammelaere, 2012].

In dredging, steel pipes, steel-reinforced "mining hoses" and floating hoses are employed to transport sediment slurry or, more generally, sand/water mixtures from dredges to shore or to deposition sites wherever these may be located. In addition, inside dredges, especially larger ones, often use steel pipes on board for conveying the slurry to and from pumps. As opposed to applications in mining, oil and gas, where single slurry pipelines range from 2 km (e.g., inside open pit oil sands mines) to 200 km and more (e.g., copper in Chile or iron ore in Australia), an individual dredge requires only a limited number of steel pipes. Nevertheless, the wear of such pipes can be a significant cost-factor for dredge operators. Due to the smaller volume per customer, vendors of wear protection solutions have not necessarily given this application their full attention.

Solid particles in slurry streams exert abrasion on interior pipeline walls. In most cases, abrasion is highest at and around the 6 o'clock position since solid particle concentration is highest in the lower part of the pipe due to gravity. Although this does not apply to every case, in the majority of cases where abrasion occurs, this holds true. Wear conditions, particle properties, and particle concentration have a strong influence on wear (i.e., pipe wall material loss) in the lower regions of the pipe circumference. Hence, internal wear protection of steel pipes is an important issue in multiphase and particularly in slurry pipelines.

If internal erosion and internal corrosion occur concurrently, the combined effect is stronger than the sum of both individual effects. The so-called erosion-corrosion effect can wear down steel pipe very rapidly.

Polymeric coatings and liners are generally well suited both for corrosion protection and for wear protection of pipelines. Since they are not metallic, these materials cannot corrode. Polymeric internal coatings and internal liners in use today normally have a smoother surface than steel (peak-to-valley height profile approximately 30-35 µm in the case of polymeric internal flow coatings vs. approximately 85 µm in the case of carbon steel).

In the pipeline industry, the term "coating" is commonly used for external coatings of steel pipes whilst the term "liner" describes protective polymer layers inside steel pipes. This is, technically, not entirely correct. The inside of pipes can be protected by polymeric "inner tubes" which are inserted into the pipe mechanically and kept in place by mechanical force. In real, these are HDPE liners which are pulled through a compression ring, inserted into the pipe, and then remain in place by mechanical force which is created by the polymer relaxing and thereby expanding back to its original size. Alternatively, a heated liner is inserted that is soft and flexible and will re-harden upon cooling to ambient temperature.

Polymeric materials that are chemically bound to the interior pipe wall, however, are coatings by nature, regardless of the general "liners" used in the industry. The term "polymeric" encompasses a wide range of materials. Not every polymer coating is suited for every application. Whilst numerous types of polymers are suited as internal flow coating or as internal or external corrosion protection coating, only a very limited range of polymers can be used for internal wear protection.

Desired properties for polymeric internal coatings and linings of steel pipes are:

- High degree of corrosion protection and high barrier function (no penetration of product stream components that could reach the pipe wall)
- Strong adhesion to steel (in case of coatings); stable mechanical force, positioning the liner inside the pipe (in case of linings)

- Flow enhancing surface providing low friction
- Strongest possible abrasion resistance in multiphase/slurry applications
- Strongest possible erosion-corrosion resistance in multiphase/slurry applications
- Compatibility and resistance to product stream chemical composition and product stream temperature
- Option of in-field repair

Polymeric Protection for Other Equipment Exposed to Wear

Manufacturers of slurry pumps, nozzles, drill pieces, shovels, valves, and other equipment in contact with moving slurry are acutely aware of the strong wear that can occur if a slurry stream slides over a steel surface or impacts steel structures. Applied wear protection solutions range from hardened steel, ceramics, weld overlays, and other hard materials to polymeric coatings and wear plates. Typical examples are hardened shovel teeth or polymeric liners for centrifugal pumps.

Generally, the requirements for polymeric protection of equipment surfaces made from steel are quite similar to those for the protection of steel pipelines:

- High degree of corrosion protection, high barrier function (no penetration of product stream components that could reach the underlying equipment surface;
- Strong adhesion to steel (in case of coatings); stable mechanical force attachment (in case of wear plates, etc.);
- Low friction surface;
- Strongest possible abrasion resistance;
- Strongest possible erosion-corrosion resistance;
- Compatibility and resistance to chemical environment and equipment temperature;
- Option of in-field repair.

High-Performance Polyurethane Elastomer Coatings

High Performance Polyurethane Elastomers fulfill all of the requirements for internal coatings listed above more or less perfectly. Polyurethanes possess high abrasion and tear resistance, high barrier function against hydrocarbons and water, as well as very high elasticity. In addition, polyurethanes are known for their "building kit" synthesis. By combining two different main components plus adding different other components (cross linkers, chain extenders, and others), a vast number of different materials can be synthesized. Each one of these different material grades has a different property profile. Figure 1 shows a schematic formula of polyurethane and the "building kit" chemistry of polyurethane synthesis:

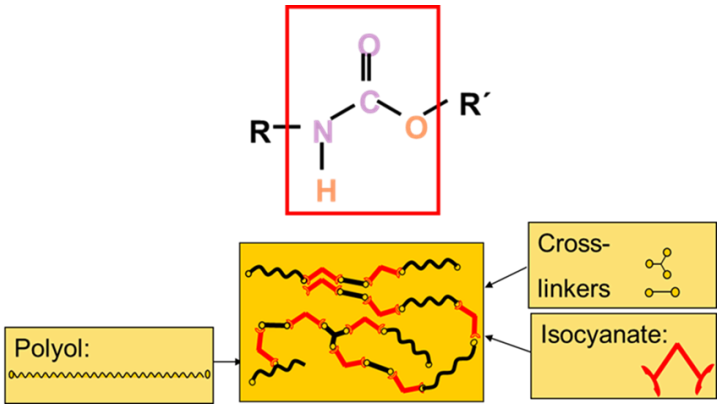

Figure 1. Formula and synthesis of polyurethane.

Interior Pipe Coatings Made From High Performance Polyurethane Elastomers

Decades ago, numerous attempts were made to apply interior pipe coatings made from standard polyurethanes to high-wear applications. In service, the rather weak adhesion of standard polyurethane to steel, caused some dramatic

cases of coating disbondment. Due to the high tear resistance of polyurethane elastomers, in some cases even localized small-area disbondment lead to removal of long stretches of coating and clogging up of the entire pipeline system.

Novel High Performance Polyurethane Elastomers exhibit such strong adhesion to steel that the issue of disbondment does not occur, even under extreme conditions, e.g., the so-called cold-wall effect. When above-ground slurry pipelines are exposed to freezing climate and there is an aqueous product stream inside the pipe (e.g., in oil sands mining), an interior coating with high adhesion to steel and with high barrier function will not allow water to reach the frozen pipe wall. If water reached the pipe wall, it would freeze and thereby expand. This expansion would cause mechanical coating disbondment. Initial blister formation would be followed by coating disbondment, eventually clogging pipes and pumps. High Performance Polyurethane Elastomer coatings have proven resistance to the cold-wall effect over years of application in Canadian oil sands operations where outside temperatures range between -20 and -40 °C in winter [Magerstaedt, Blitz, Raeth, Lai, 2013].

In situations where the oxygen content of aqueous slurries is high, erosion-corrosion occurs in metallic pipes (steel, alloys, or even chromium carbide overlays). This phenomenon is observed when erosion caused by solid particles and corrosion caused by oxidizing agents in the product stream occur together. The erosion-corrosion effect is often much stronger than the effect that would result by simple addition of the effects of erosion and of corrosion, respectively. The reason for this synergistic effect is that erosion-caused small scratches in the metal surface are providing a local surface area that is less resistant to corrosive attack. Hence, corrosion occurs quicker and more severely in these locations before spreading to more and more of the metallic surface. By the same token, microscopically small regions of surface corrosion provide a less wear resistant attack point for erosion by particles.

Steel pipes internally coated with High Performance Polyurethane Elastomer coatings are immune to erosion-corrosion since the elastomer cannot corrode.

Wear Parts Made From High Performance Polyurethane

Similarly, wear parts made from High Performance Polyurethane Elastomers can be designed to withstand a wider temperature range than standard polyurethanes. Likewise, recipes can be synthesized that have a high resistance to alkaline and acidic streams, or that have specific mechanical property profiles, e.g., low intrinsic heating upon dynamic stress, strong rebound resilience, specific surface properties, and others.

Examples are disks and cups used to propel pipeline inspection and cleaning (pigging) tools made from High Performance Polyurethane Elastomers that are routinely applied in chemical product streams. Application examples are ammonia, or in offshore pipelines where a temperature gradient from 125 °C to 4 °C can occur in a line that is only a few km long. Figure 2 shows typical pipeline inspection tools carrying High Performance Polyurethane disks (white) and cups (blue).

Figure 2. Pipeline inspection tools (pigs).

FIELD EXPERIENCE WITH HIGH PERFORMANCE POLYURETHANE ELASTOMER COATINGS

Oil Sands Tailings and Hydrotransport

For more than 5 years now, steel pipes with internal High Performance Polyurethane Elastomer Coatings have been in service in the Canadian oil sands industry. In open-pit mines, oil sand ore is transported to the separation plant by pipeline. The sand/rock/bitumen mixture is mixed with hot water and pumped through steel pipelines. From the separator, tailings consisting of water, sand, and rocks are transported to tailings ponds by steel pipelines as well.

Under the flow conditions present in these lines (flow velocity range 3-5 m/s; screen size up to 5"; temperature 45-65 °C; pipe diameter 24-36"; outside temperature down to below – 40 °C in winter and up to 30 °C in summer without thermal pipe insulation), carbon steel pipes have a life of 2'500-3'000 hours. To extend pipe life, lines are shut down after this interval, and the pipes are rotated in a way that the previous 6 o'clock position is moved to another position on the circumference. Gravity causes solid particles to slide along the bottom of the pipe and hence, the area between 5 and 7 o'clock on the circumference is exposed to much stronger wear than the rest of the pipe. By rotating the pipe 4-5 times, useful life of the steel pipes used can be extended proportionally.

Very expensive wear protection solutions like hardened steel, alloys, and chromium-carbide overlays are used to extend useful life of steel pipes in oil sands hydrotransport and tailings. Over the last decade, polymeric wear protection has become more commonly used in this application. Predominantly, rubber and polyurethane are used. To overcome the rather weak adhesion of standard polyurethanes to steel, polyurethane wear protection coatings applied in oil sands were cast onto a rubber base layer that served as intermediate between steel and polyurethane (essentially a rather thick "adhesive").

Only the development of High Performance Polyurethane Elastomers led to material grades exhibiting an extremely strong adhesion to steel. Such materials require no rubber base layer and have been in use in oil sands for close to 7 years now under the name RoCoat™. Useful life of steel pipe spools in oil sands hydrotransport and tailings has been extended to the range of 30'000 hours when a 1" thick coating was employed inside pipes in the diameter range described above. I.e., a useful life extension by a factor of 10 or higher is achieved. Similar relative life time extensions were achieved with pipeline segments that are exposed to significantly higher wear; particularly elbows and area of high turbulence. Although useful life of such components is normally a lot shorter than that of straight line pipe, the factor by which life is extended remains in the same range of approx. 10-fold.

In erosion-corrosion situations, High Performance Polyurethane Elastomer coatings not only beat steel in terms of useful life, they even significantly outlast very expensive weld overlays, often by a factor of 5 or more.

A field welding system exists that allows joining pipes by one filet weld per pipe joint without need for cooling or re-coating after welding. By employing a sleeve filet-welded to one end of the pipe and with coating overlapping the pipe butt on both ends, a tight connection is achieved by bringing the two pipes together and filet-welding the sleeve to the outside of the male pipe end. A heat dissipation ring with underlying insulation layer located at the position of the field weld prevents the coating from overheating during welding. Pressure tests up to 250 bar (3000 PSI) was performed. This system significantly reduces the cost of RoCoat™ spools compared to flanges or other connecting solution used for lined or internally coated pipes. Figure 3 shows the principle of this field weld joining system.

Figure 3 Models of male and female end of the field weld joining system.

Summary Case Study Oil Sands:

- Field application since more than 7 years;
- Useful life extension by a factor of 10 or more both in tailings and hydrotransport;
- Applicable to straight pipes, elbows, specialty spools;
- Under erosion-corrosion conditions, outlasting overlays and hardened steels;
- A single-weld field joining system allows fast and cost-efficient pipe joining.

Figure 4 shows typical spools as used in open-pit oil sands mines in Alberta, Canada.

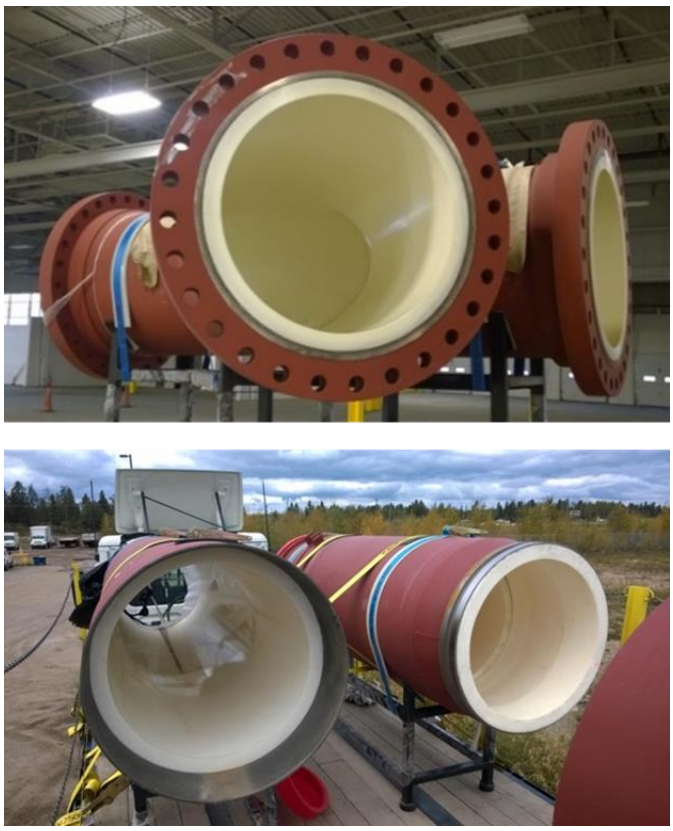

Figure 4. Spools for oil sands service; top: flanged wye-piece; bottom: male and female end of proprietary field weld connection.

Figure 5. Laying and welding of coated pipes in an open-pit oil sands mine at Fort Mac Murray, AB, Canada.

Other Cases in Mining (Synopsis)

As in oil sands, useful life extension was extended by factors ranging up to 15 and more in other applications; some examples:

- Phosphate slurry (flanged pump station piping covering areas of highest turbulence);
- Shotcrete slick line for vertical transport into underground mine;
- Hydrocyclone runoff at a limestone plant.

Phosphate

At a major phosphate slurry transport line in Morocco, more than 700 m of flanged RoCoat™ spools were installed to enable the operator to reach a useful life of pump station piping in the same range as that of the main line. With much higher turbulence inside pump station piping, only a material with highest possible wear protection and strong adhesion to steel was acceptable. The High Performance Polyurethane Elastomer coated pipes are in operation since 2012. Figure 6 shows coated pipe before installation.

Figure 6. Internally coated phosphate station piping.

Shotcrete

A copper mine in Portugal employs a vertical 8" slick line, almost 400 m long, to transport shotcrete down into the mine. The line saves a very large amount of transport cost versus the previous method of trucking the shotcrete into the mine.

The line consists of individual pipes that are joined by pin-and-box joints. The shotcrete contains metal fibers which strongly erode the pipe walls. The operator exchanged worn pipes by unscrewing the lowest individual pipe joint at the bottom of the line and attaching a new one to the top. With uncoated steel pipes, useful life of individual joints was only less than two months. After application of High Performance Polyurethane Elastomer coating, the line has been in operation for approx. 2 years now without exchanging or re-coating. A pipe and parts of the installation are shown in figure 7.

Figure 7. Shotcrete slick line and coated pipe with connecting gear.

Limestone

A 12" hydrocyclone runoff line at a limestone plant in Colombia is running successfully for close to 2 years now. Without High Performance Polyurethane Elastomer coating, the pipe did not last longer than 3 months. Incoming slurry at the tees causes strong turbulence, and hence wear. Conditions and Performance are listed below:

Original Solution:

Lifetime of prior spool	3 months
Required time for replacement	16 hours
Repair jobs per spool	8 times before replacement
Repair time	8 hours each
Flow rate	270 to/hr

With RoCoat 3000TM Coating:

Availability of test spool	100%
Operation time (still in operation)	21 months
Saved repair time	600 hours approx.

Lifetime Extension Factor 7+ (spool remaining in operation)

Figure 8 shows a coated pipe in operation at this plant.

Figure 8. 12” Hydrocyclone runoff line at Colombian limestone processing plant.

INTELLIGENT COATINGS PROVIDING WEAR MONITORING

For metallic materials there are numerous methods of non-destructive testing and condition monitoring available. However, such testing and monitoring proves very difficult for nonmetallic coatings and linings of steel pipes. The most prominent reason for this is that methods like ultrasound, eddy current, electromagnetic acoustic transducer, and others will receive strong signals from the steel layer which will prevent any (much weaker) signal or attenuation from the internal polymer coating or lining the wear of which is to be determined.

Although High Performance Polyurethane Elastomer wear protection coatings extend the life time of steel pipes in such applications by factors of 5-10 and sometimes even longer, the point at which the wear limit is reached needs to be known. Until very recently, the only way to determine wear was to shut down the pipeline and physically inspect the inside.

We have developed a method to determine internal coating or liner wear from the outside of the pipe. It involves sensors placed inside the polyurethane coating, thereby rendering the coating “intelligent”. These sensors do not require a hole through the pipe wall for data transmission to the outside world. Development of this concept took a number of years and extensive testing. So-called “instrumentation spools” with such embedded sensors are in operation in tailings lines of oil sands mines in the Athabasca basin of Alberta, Canada for more than 2 years now. Data obtained from these spools exactly match wear data measured directly when the pipes were accessible during shutdowns.

Figure 9 shows a schematic of these “instrumentation spools”.

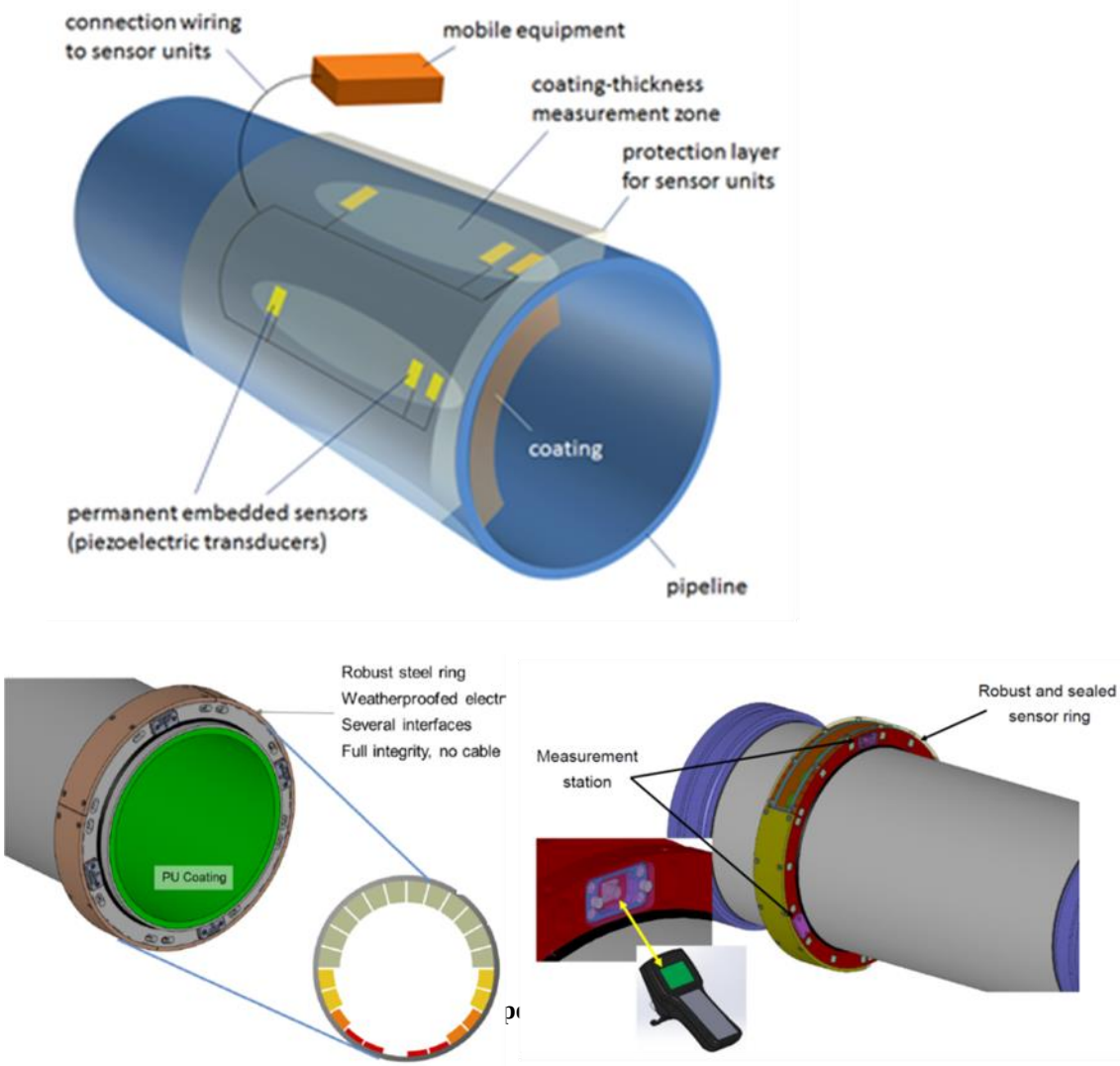

Figure 9. Schematics of Instrumentation Spools.

With cost of a single shutdown often reaching the million dollar range, even just 2 or 3 months of postponement of a shutdown can mean significant savings for the operator. If the actual wear status of a pipe (or of its internal coating, respectively) is not known, shutdowns need to be performed earlier to reduce the risk of unexpected leaks due to worn pipe. With continuous monitoring by instrumentation spools, shutdown can be timed when they are really needed. Calculations by operators and engineering consultants estimate savings of to 25 % or more of maintenance cost by such a system.

HIGH PERFORMANCE POLYURETHANE ELASTOMERS FOR DREDGING

The need for wear protection in dredging depends to a large extend on the individual dredging equipment used as well as on the actual project. In some cases, single pipes or short lines on a ship may suffer from extreme wear in which case the use of internal wear protection would enable the operator to significantly extend maintenance intervals. The cost of maintenance down time is a lot higher than the cost difference between an internally coated pipe and a standard carbon steel pipe. In such cases, the high price of pipes cladded with hard metal overlays or pipes made from hardened steel are easily justified. In this case, the use of High Performance Polyurethane Elastomer coated pipes will not only further reduce maintenance cost, but more importantly it will increase life time of pipes even more than metallic solutions, as dredging-specific tests by independent laboratories have shown, see below.

In cases where pipes and pontoons are used to transport dredged material from ship to shore, life extension of the pipes used makes sense only in cases where the dredging operation takes longer than the useful life of the pipes used. Examples are dredging of longer channels or larger harbor projects.

Laboratory Results

General wear test data from industry standard tests were obtained. In all cases, test results exceeded the test standard requirements. All these data were obtained either by independent laboratories or by pipeline operators. Figure 10 is an excerpt from a high performance polyurethane elastomer datasheet shows a list of the most prominent tests performed.

- Abrasion tests ASTM G 75; ASTM B611; DIN EN ISO 53516; EN ISO 598; ASTM D4060/7;
- Adhesion tests EN10290; ASTM D 4541
- Flexibility, bending, gouge tests CSA Z245.20-10, Clause 12.11; CSA Z245.20-10 , Section 12.15 ;
- Cold wall effect: Atlas Cell Test
- Slurry Jet Test
- Hot water immersion adhesion test ASTM D 870; EN 10290
- Various other tests
- Detailed data available from ROSEN

Figure 10. Standard tests performed on RoCoat High Performance Polyurethane Elastomers (source: ROSEN datasheet).

Test according to Mens and deGee [Mens, deGee, 1991] showed results exceeding these of alloys and overlays by a factor of more than 2 and these of carbon steel by a factor of approximately 30.

Ongoing Field Trials Dredging

A quartz sand dredge (continuous operation on a lake in Germany, slurry with 30% water content) had wear issues in their piping at 4 and 8 o'clock position (Operator assumes that there is sliding bed formation at the bottom). RoCoat test spools showed no wear after two and a half years; still in operation to the full satisfaction of the operator.

On-board piping test on a large dredge is in progress; an update will be given in the ppt presentation of this paper at WEDA Dredging Summit.

CONCLUSIONS

- Internal pipe coatings made from High Performance Polyurethane Elastomers can extend the useful life of slurry pipes by a factor of 10 or higher compared to carbon steel.
- In oil sands tailings and hydrotransport, this cost saving effect has been proven in multi-mile lines for more than half a decade.
- In other mining applications (e.g., phosphates, shotcrete, limestone), similar results have been achieved.
- A single-weld field joining process allows quick and low cost installation of internally polyurethane-coated steel pipes.
- Intelligent internal elastomer coatings enable operators to monitor coating wear and hence to schedule maintenance much more efficiently, translating into savings of approx. 25-35 % of maintenance cost.
- Lab tests and field trials running since more than 2 ½ years indicate that in dredging applications, intelligent High Performance Polyurethane Elastomer coatings can generate significant savings for dredge operators.

REFERENCES

Rosewall, Allan, November 2015. *Proc. Slurry Pipelines and Flow Equipment Conference.* Perth, WA, Australia

Derammelaere, Ron, November 2011. *Proc. 1st Slurry Pipelines Summit*. Perth, WA, Australia

CITATIONS

Magerstaedt, M., Blitz, G., Raeth, T., Lai, Larry K.L. (2013). *Field Experience With Novel High Performance Polyurethane Elastomers For Wear Protection In Slurry Pipelines And In Ball Mills*, Proc. World Mining Congress, Montreal, QC, Canada

Mens, J.W.M., deGee, A.W.M.(1991). *Friction and Wear Behaviour of 18 Polymers in Contact with Steel in Environments of Air and Water,* Wear, Volume 149, pages 255-268