**Analysis and Case Study of Polymer Coatings as an Alternative to Galvanized and Bituminous Coated Steel Liner Plate Supports in Railroad Tunnels and other Railroad Crossing Tunnels.**

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## ABSTRACT

Steel liner plates have been an essential component of initial underground support systems since the mid-19th century. In many modern railroad applications, steel liner plates have been galvanized for corrosion protection and oftentimes bituminous coated for an additional measure of protection.

It is generally accepted that a galvanized and bituminous coated liner plate placed in nominal underground conditions has a service life of about 75 years.

Steady advances in molecular chemistry and development of long chained polyamides have brought forth the potential use of polymer coated liner plates in railroad tunnels and other railroad crossing tunnels.

The use of galvanized and bituminous coated liner plates utilizes both products and processes that are difficult to manage in an era of increased environmental oversight and corporate environmental conscience. Utilization of galvanized and bituminous coated liner plates also presents unnecessary effort during construction as they are heavier and more difficult to handle while mining is taking place. Additionally, storage of the coated plates prior to installation is further complicated in hot and cold environments with bitumen flowing or cracking during storage. Lastly, shipping costs are escalated by increased weight.

Conversely, polymer coated liner plates consume fewer raw materials and provide comparable durability while lowering installation costs due to improved handling and lower component weight. Additionally, hardware, namely

nuts and bolts, can be polymer coated, if necessary for extended and uniform use.

This paper will review the coating processes and environmental costs in production of both products and compare the advantages and disadvantages of each.

Polymer coated liner plates are a value added substitute for galvanized and bituminous coated liner plates that provide an equal service life for less financial cost and a reduced environmental impact.

## PRODUCT DESCRIPTION AND HISTORY

Use of steel liner plates in tunnels and shaft construction are a frequently selected alternative due to the ease with which they are installed as well as their variability for use in both hand mining and machine mining applications. There are two types of liner plates: four flange and two flange liner plates.

This paper addresses the use of four flange liner plates as they are the only liner plates suitable for use in both hand mining and machine mining of tunnels without alteration and addition of structural stiffening elements. Figure 1 shows the general shape of a four flange liner plate and the connecting bolt pattern optimizing its use from inside any tunnel.

***Figure 1:  Typical Four Flange Liner Plate***

As the radius is variable, the shape of liner plate tunnels can vary from circular, elliptical, to horseshoe types as shown in Figures 2a, 2b and 2c respectively.

***Figure 2a:  Assembled Circular Liner Plate Tunnel***

***Figure 2b:  Assembled Elliptical Liner Plate Tunnel***

***Figure 2c:  Assembled Horseshoe Liner Plate Tunnel***

The liner plate use is dictated by a determination as to whether the liner plate installation is intended for use as an “initial support system” or as a “final support facility”.  As an initial support system, the liner plates need only provide for the safe excavation area while permanent facilities are constructed within the protected space, such as water and sewer final tunnel liners and final transportation tunnel facilities.  An initial support system is designed for years of service while a final support facility is designed for decades of service.

When used as a final support facility, additional design consideration is given to the liner plate steel gage, additional protective measures necessary such as galvanizing and other ancillary structural components to support utilities, piping, communications, etc.  In this use, access and other maintenance considerations become important.

There are however, a significant number of locations and agencies nationally that require either galvanized liner plates or galvanized liner plates with a bituminous coating when used as an initial support system.

The explanations for applying galvanizing and/or bituminous coatings for initial support vary from ground conditions that exhibit acidic or basic soils creating conditions for accelerated corrosion of the steel or the simple presence of groundwater or excessive moisture contents similarly accelerating corrosion.  There are also agencies that, based upon prior experience, simply require the additional measures from a policy standpoint or “have simply always done it this way”.

Figure 3 shows the physical makeup of a galvanized and bituminous coated four flange liner plate.  The bitumen creates a less than desirable working element which is difficult to handle and install in any advancing tunnel.  Additionally, as shown, the bitumen attracts and retains deleterious materials including the dirt and debris visible.

***Figure 3: Typical Galvanized and Bituminous Coated Liner Plate***

## POLYMER HISTORY

Natural polymers exist as tar and shellac and can be derived from tortoise shells, horns as well as tree saps that produce amber and latex. During the 18$^{th}$ and 19$^{th}$ centuries these natural polymers were processed through heat and pressure to produce vanity objects such as hair ornaments and jewelry.

Modification of natural polymers advanced with the creation of vulcanized rubber, gun cotton and celluloid. Development of synthetic polymers advanced into the 20$^{th}$ century culminating in the creation of rayon by Dr. Bakelite in 1911. (1)

World War II created additional demand for natural polymers which fostered the expanded use and creation of additional long chained synthetic polymers. As natural polymers such as latex, wool, silk and others were depleted, the void filled with nylon, acrylic, neoprene and polyethylene. As the 20$^{th}$ century advanced, so too did the development of more complex long chained polymers. The most notable synthetic polymer advancement of the 20$^{th}$ century was culminated in 1946 with the creation of polytetrafluoroethylene (PTFE), trademarked as Teflon ®. (2)

Since then, other important and largely proprietary chemistry has advanced adding hardness, ductility, impermeability and durability to the polymer chemistry. These advancements and qualities have brought synthetic polymers to the world of underground construction, including railroad and other tunnels.

The marketplace today offers competitive products based upon polymer improvements from a number of companies. This paper compares the existing galvanized and bituminous coated products with the Obduro AP Coatings (3).

## GALVANIZING AND BITUMINOUS COATING PROCESSES

Presently, liner plates are galvanized in accordance with the requirements or ASTM A 123/A 123M-12. This specification covers the requirements for zinc coating by the hot-dip process on iron and steel products made from rolled pressed and forged shapes, castings, plate, bars and strips. The specification covers both un-fabricated products and fabricated products; for example, assemblies of steel products, structural steel fabrications, large tubes, already bent or welded before galvanizing, and wire work fabricated from uncoated steel wire.

Galvanizing requires three steps:

1. Surface Preparation is the most important step in the application of any coating. First the steel component is placed into a hot alkali solution, mild acidic bath or biological cleaning bath to remove organic contaminants such as dirt, paint, grease and any oils from the metal surface.

Secondly, the component is placed into a dilute solution of heated sulfuric acid or ambient hydrochloric acid to remove mill scale and iron oxides (rust) from the steel surface. Sometimes, this step can be replaced with sand blasting. Lastly, the component is placed into a zinc ammonium chloride solution to remove any remaining oxides while depositing a protective layer on the steel to prevent any further oxides from forming prior to immersion into the molten zinc.

2. Galvanizing is the process wherein the component is immersed in a bath of molten zinc. The bath chemistry is specified by ASTM B6 and requires at least 98% pure zinc maintained between 815 degrees F and 850 degrees F. While immersed in the kettle, the zinc reacts with the iron in the steel to form a metallurgically bonded zinc-iron intermetallic alloy layer of impact-resistant pure zinc. Once the alloy growth of the layers is complete, the component is withdrawn slowly from the galvanizing bath and the excess zinc is removed by draining, vibrating, and/or centrifuging. The metallurgical reaction continues after the component is withdrawn from the bath. The process ceases when the component is either air cooled or cold dipped in water.
3. Inspection consists of direct measurement of the coating thickness and visual observation of the appearance/surface condition. (4)

Bituminous coating also requires three steps:

1. Cleaning requires removal of all dirt, debris, lubricants and other deleterious materials affecting the adherence of the bitumen to the steel plate component. Detergents are typically used, followed by water rinsing and thorough drying.
2. Coating is the process wherein, the components are dipped into vats of asphalt. The vat temperatures are maintained between 392 degrees F and 410 degrees F. The component must remain submerged in the vats until the component temperature reaches 374 degrees F. Depending upon the gage of the component material, the time necessary to achieve this temperature and coating requires 2 minutes to 14 minutes. Following ambient cooling the component is dipped for the second time to achieve the specified thickness.
3. Inspection consists of direct measurement of the coating thickness and visual observation of the appearance/surface condition. (5)

Bituminous coating of liner plates adds approximately ten pounds of additional weight per liner plate. (6)

It has been determined that exposure of workers to the heated bituminous batches and applying the bituminous coatings is potentially dangerous work and has been cited by the National Institute for Occupational Safety and Health as a hazardous occupation. (7)

## POLYMER COATING MATERIALS AND PROCESS

New polymer coatings have been developed and tested in highly acidic and electromagnetic underground solutions from two underground gold mines in Nevada, USA. The new coating was also tested in extreme pH conditions, using chemicals, such as sulfuric acid, hydrochloric acid, and sodium hydroxide.

Figure 4 shows the appearance after a typical four flange liner plate is polymer coated.

***Figure 4: Typical Polymer Coated Liner Plate***

Table 1 lists the more volatile solutions tested. Also included in testing were hydrogen peroxide, hypochlorous acid, and sodium hypochlorite.

**Table 1: Acid-base types**

| | |
|---|---|
| $H_2SO_4$ | Sulfuric Acid (15%, 32%, 50%, 93%) pH of .3 – 1.3 |
| HCl | Hydrochloric Acid (15%, 32%, 70%) pH of .7 – 1.5 |
| NaOH | Sodium Hydroxide (32%, 50%) pH of 11.7- 13.2 |
| M1 | Mine Sample 1 (Sulfuric acid pH 1.5, 14%) |
| M2 | Mine Sample 2 (Sulfuric acid pH 1.5, 13% + other acids) |

Based on field information provided, the following chemical resistance testing was performed on the Obduro AP coating. Coated panels were exposed to the vapors of the following chemicals at a temperature of 95 degrees F for 24 hours.

18% HCl
3% H2O2
5% NaClO

Results: no blistering or loss of adhesion was recorded.

Test bolts, as samples, were placed in the following acid baths for 60 -120 days:

15%, 32%, 50% (pH of .3 – 1.3) H2SO4
15%, 32%, 70% (pH of .3 – 1.3) HCl
32%, 50% (pH of 11.7- 13.2) NaOH

Results for all solutions above: no blistering or loss of adhesion, no reaction visible and no discoloration.

The new polymer coating, Obduro AP, is capable of handling both highly acidic and corrosive mine water solutions, as well as sodium hydroxide 50 percent or less, hydrochloric acid 36 percent or less, and sulfuric acid 32 percent or less. The Obduro AP coating was tested in extreme conditions to identify weaknesses. None of the acids or bases tested exists in nature above 30 percent concentration.

There are three key reasons polymer coated liner plates meet or exceed the performance of galvanized and bituminous coated liner plates.

1. Molecular or covalent bonding occurs between the polymer and the steel. This ensures that the coating does not peel or scrape easily. It also prevents the polymer from acting as a containing cell for the acid if the acid should break through due to the lack of adhesion or bonding. Without this bonding the acid could corrode along the inside of the coating.
2. The polymer is highly flexible and therefore accommodates differential tunnel stresses. This, coupled with the high scratch resistance, makes it very advantageous in hard rock conditions, ensuring the integrity of the product.
3. Most importantly, the polymer coating is resistant to the most extreme pH levels and greater than what is typically found underground. This makes the Obduro AP polymer coating ideal for sites where corrosive conditions are anticipated. The Obdura AP polymer coating is already a widely utilized product in the rock bolting environment with varying conditions. The application to tunneling is evident as the coating is not only physically durable but exceptional in corrosive soil, rock or groundwater environments.

While the exact nature and process of applying polymer coatings cannot be fully publicized due to confidentiality, the following standards have been met which signify that the component handling, process employed and final products meet or exceed industry standards for material handling, polymer production, product application and environmental compliance:

ISO 9001:2008 Certification
SAE Aerospace Standard AS7003

Four flange liner plates with polymer coatings applied only increase the nominal liner plate weight by less than one pound. Additionally, polymer coated liner plates do not attach to or retain deleterious materials such as dirt and debris during handling and installation. In nominal ground conditions, polymer coated liner plates are expected to provide 75 years of service life.

## PROCESS AND MATERIAL COMPARISON BY COATING TYPE AND ENVIRONMENTAL IMPACT

In evaluating the processes described previously, there are significant environmental considerations for galvanized and bituminous coating of liner plates. In addition to the fumes and air quality degradation caused by open vats of molten zinc and heated asphalt, worker safety is brought into question with the supervision and handling of components as they make their way through the process.

In contrast, polymer coatings are applied in controlled environments. The polymer constituents are more manageably assembled and contained at the point of application.

## COATED LINER PLATE WEIGHT AND CONSTRUCTABILITY COMPARISON

Whether in shipping products or handling them, weight is a significant cost component. As such, galvanized bituminous coated liner plates are heavier by about nine pounds per plate as compared to polymer coated liner plates. As such, they are more costly to transport. Additionally, once delivered onsite, labor is required to manually install the liner plates in the tunnel structure. In that effort, liner plate weight is a consideration in the efficiency of installation. Once again, as the polymer liner plate is lighter than a galvanized and bituminous coated liner plate, the efficiency of installation is higher as well.

Furthermore, when the surface qualities of bituminous coated liner plates are compared to polymer coated liner plates, the difference is significant. In the handling of bituminous coated liner plates, workers must work with a very sticky component, whereas with the polymer coated liner plates, the component is smooth and non-stick to the touch. This too provides opportunity for improved productivity during installation.

So, whether by a direct component weight comparison or by a handling and installation comparison, polymer coated liner plates provide cost efficiency to overall tunnel construction.

## APPLICATION OF GASKETS TO LIMIT SHAFT OR TUNNEL WATER INTRUSION

In some instances, liner plates are required to include neoprene gasket material along the exterior flange perimeter to reduce/impede infiltration of groundwater during installation and follow up construction activity. Gasket material must be applied to a clean and uniform surface. In the use of polymer coated liner plates, the exterior perimeter flange is clean and uniform in finish to receive the neoprene gasket material. In the case of the bituminous coated liner plate, the asphalt prohibits the gasket bond and the exterior flange perimeter is not uniform and will not receive the gasket material. Bituminous coated liner plates can only include gaskets by omitting the bituminous coating where the gasket is applied. This provides a significant area unprotected and susceptible to corrosion.

## GENERAL PRODUCT AVAILABILITY

Over recent years, bituminous coating facilities have dwindled to only a few and there is some doubt as to how long the process will remain available or capable of meeting present coating demands for the tunneling industry and others.

Polymer coating facilities are smaller in general and lighter in facility footprint with less capital requirements and environmental oversight so it is expected that demand for polymer coated liner plates will continue to increase and eventually replace galvanized and bituminous coated liner plates.

## CONCLUSIONS

This paper presented summary work on the use and production of galvanized and bituminous coated four flange liner plates in comparison to polymer coated four flange liner plates. Polymer coated liner plates represent the next step forward in liner plate tunnel construction. Polymer coated liner plates are lighter, as durable, easier to handle and demonstrate a reduced environmental impact during the coating process when compared to galvanized and bituminous coated liner plates.

Anticipated demand for cost effective tunnel liner plates of exceptional long term durability will only be met by the increased use of polymer coated liner plates.

## REFERENCES

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