Use of Polysiloxane Coatings for Topside Applications on US Navy Ships

J. Peter Ault, P.E.[1] (M)
Pete Lockwood[2] (M; AM; or V)
Robert Cloutier[2] (M; AM; or V)
David Kinee[2] (M; AM; or V)

1. Elzly Technology Corporation
2. General Dynamic Bath Iron Works

Polysiloxane coatings are the most recent highperformance coatings developed to take advantage of the heat and oxidation resistant properties of silicone-based materials. Commercially available polysiloxane coatings predominately consist of organic-inorganic siloxane materials (though some pure siloxane materials are available). Recently, the US Navy has approved polysiloxane coatings as "High Durability" in their specification for exterior weather resistant coatings (MIL-PRF-24635 Type V and VI). Navy approval comes after over 20 years of industry development of polysiloxane coatings for high performance industrial and marine applications, yet issues remain with their cost-effective implementation in the Navy fleet. This paper will review experiences of the offshore and marine industry with polysiloxane coatings and provide an update on the Navy adoption of the technology.

KEY WORDS: Coating; polysiloxane; corrosion; topside; durability.

INTRODUCTION

Polysiloxane coatings became commercially available to the marine industry in the mid-1990's. This relatively new class of weather-resistant coatings was purported to provide improved weathering properties and be easier to use than the historically specified alternatives. While the coating materials do offer some significant advantages, experience has demonstrated that polysiloxane coatings have their own set of challenges. This paper will discuss the polysiloxane coating materials and practical issues associated with their use for both commercial and military applications.

POLYSILOXANE COATING CHEMISTRY AND SYSTEMS

For over 70 years, coating technologists have sought to improve the properties of organic coatings by incorporating silicon into coating chemistry. In the 1940's, heat-cured alkali silicate inorganic zincs became the first commercial use of silicone-based coating binders (Kline 1996). Over the next 20 years, the inorganic zinc silicate coating technology evolved as post-cure and self-cure ethyl-silicate inorganic zincs were introduced. During this same timeframe, heat-cured silicone coatings were developed for high temperature applications such as exhaust stacks, boilers, heat exchangers, mufflers, engines and aircraft components (Finzel 1995).

In the 1950's, silicone alkyd coatings became the first organic-inorganic hybrid industrial maintenance coatings. Incorporation of the silicone resin dramatically improved the weatherability of alkyd coatings. Silicone alkyd coatings are still used for protection of steel structures, including US Navy ships.

A 1981 patent describes binders based on interpenetrating polymer networks (IPN) comprised of a polysiloxane network and an epoxy-amine network which overcame the need for heat curing (Foscante 1981). Unfortunately, these early coatings were expensive, unstable and prone to intercoat adhesion problems. In the mid 1990's, a patented epoxy siloxane hybrid was commercialized as the first of the current generation of polysiloxane coatings (Mowrer 1997). Since that time, interest in polysiloxane coatings has increased as evidenced by the number of patents issued for epoxy-polysiloxane coatings (Figure 1). Most recently, silicone amine resins are being developed to make polysiloxane coatings more stable and user friendly. (Witucki, 2012) One reported goal of the new technologies is to "reduce potential embrittlement of polysiloxane hybrids."

Polysiloxanes have a strong silicon-oxygen-silicon backbone which provides more resistance to thermal oxidation (heat), photo-oxidation (sunlight) and chemical attack than conventional organic coatings (e.g., epoxies). Modification with an organic resin such as epoxy or acrylic provides flexibility, toughness, gloss, adhesion, and reduced cost. Polysiloxanes do not contain isocyanates, which have been banned by some owners/ jurisdictions for health reasons.

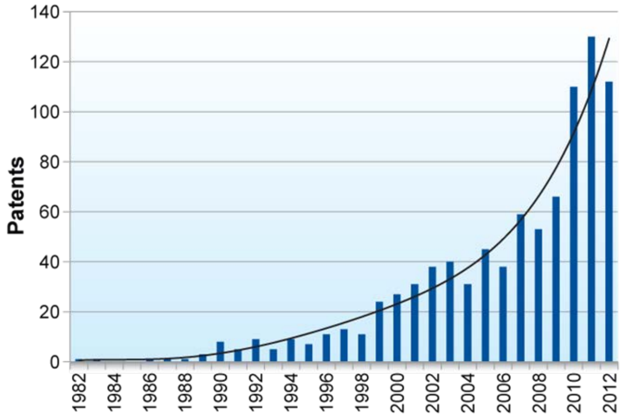

Figure 1. U.S. Patents Issued for Polysiloxane-Epoxy Hybrid Coatings Per Year. (Witucki 2012)

Commercially available coatings marketed as "polysiloxane" vary considerably in chemistry. Manufacturers vary the organic modification and the polysiloxane resin content as well as other aspects of the formulation in order to balance cost and performance parameters. According to a recent survey of the available products, organic modifications may include epoxies, acrylics, or urethanes. Depending on the formulation, the polysiloxane resin content can vary from 37 to 77% by weight. (Andrews 2005) Naturally, the difference in chemistry impacts a wide array of properties. Color retention, gloss retention, recoat window,[1] and flexibility have been reported to vary considerably among what are marketed as generically similar products. (Andrews 2005, Graversen 2007) Figure 2 illustrates the range of color and gloss retention of various products after an accelerated test. Manufacturer's product data sheets show recoat intervals between weeks and months depending on the products involved and curing conditions.

For industrial maintenance, polysiloxane coatings are generally applied as part of a multi-coat system. While polysiloxanes can be applied direct to metal, epoxy or zinc-rich primers are commonly used to enhance corrosion protection for steel. Since primers do not need to have weathering characteristics, epoxy primers are typically used in a two-coat system since they are more economical than polysiloxanes. Zinc-rich primers are used in applications which demand improved corrosion protection. Polysiloxane coatings can be applied directly to zinc-rich primers whereas polyurethane coatings require an epoxy tie-coat. As a result, two-coat systems can be used in place of more traditional three-coat systems for industrial applications (Figure 3). The resulting labor and schedule savings associated with one less coat can be significant.

[1] Recoat window refers to that period of time required for a coating to cure before the polysiloxane can be applied over the coating and achieve proper adhesion.

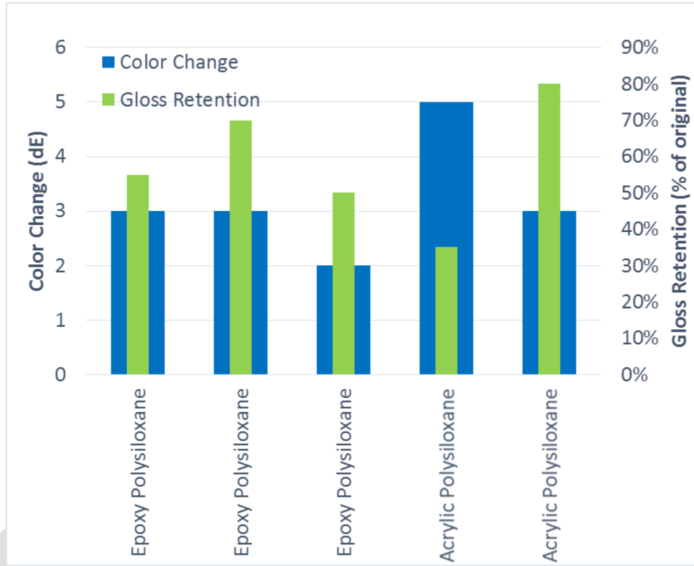

Figure 2. Color and Gloss Retention of Various Polysiloxane Coatings after 6500 hours QUV-A Exposure. (Graversen 2007)

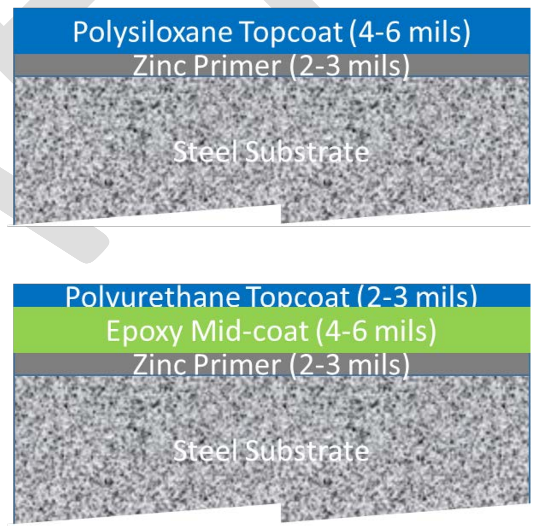

Figure 3. Typical 2-coat Polysiloxane system (top) and 3-coat Polyurethane system (bottom).

INDUSTRY EXPERIENCE

After being commercially introduced in the mid-1990's, polysiloxane coatings found use as an alternative to polyurethane topcoats in a number of industrial maintenance applications on structures such as storage tanks, offshore platforms, bridges, petrochemical facilities, and water / waste-water facilities. While some significant issues with polysiloxane coatings were reported, the material was successful enough for more than 25 suppliers to introduce competing products within 10 years of its initial commercial use. (Huffman and Hower 2003)

While polysiloxane technology has been condsidered a truly innovative technology with much promise, problems have been experienced in the field and challenges remain to be overcome. (Wilson 2012) Moisture sensitivity and adhesion issues seem to be the primary causes of “catastrophic” failures, but issues with gloss and color retention have also been reported. The significant differences among polysiloxane chemistries contributes to confusion in the industry regarding the performance of these materials. As with all coatings, the generic chemistry does not sufficiently describe the material – a problem whose consequences are magnified by the number of polysiloxane patents and formulations and the rapid evolution of the technology.

Reported on adhesion problems with polysiloxane coatings have been attributed to product formulations as well as application and cure conditions. A series of papers have explored the mechanical properties and internal stresses generated in polysiloxane coatings as they may relate to adhesion issues. (Axelsen 2010a, 2010b, 2010c) The papers report research aimed at explaining cracking and flaking of polysiloxane topcoats applied to Norwegian offshore structures after a relatively short time in service. The papers explore the mechanical properties, internal stresses, and adhesion of polysiloxane coatings under various conditions postulated to impact coating performance. The testing demonstrated:

- Tensile properties of polysiloxane films changed with exposure to wetness and/or UV exposure. Specifically, tensile strength and elastic modulus increased with a corresponding decrease in elongation at break.
- Polysiloxanes subjected to cyclic loading may fail at lower loads than under static loading conditions.
- Internal stresses in polysiloxane coatings increased with increasing temperature and relative humidity.
- Coating adhesion was reduced when exposed to wetness or applied under unfavorable condition.

Despite these observations, the authors concluded that none of the environmental effects were of sufficient magnitude to explain the observed cracking and flaking. The authors note that the coatings which were tested were a newer generation of materials than those which failed. It is possible that either the older generation of materials was more susceptible to the mechanical effects or there was another contributing factor for the failures. Given the industry concern with longer term stability of polysiloxane films, it is possible that the mechanical properties change over a longer timeframe (months to years) versus the shorter timeframe of the laboratory testing discussed above (days to weeks).

US COAST GUARD AND US NAVY USE

In the early 2000’s the US Coast Guard (USCG) began evaluating polysiloxane coatings for boat and cutter topside application and application on Aids-to-Navigation. USCG has since approved several two-coat and three-coat systems incorporating polysiloxane coatings. USCG experience with polysiloxane coatings has been positive as evidenced by its widespread use within the fleet. However, issues with application conditions in Alaska have led them to investigate additional topside coating options.

In November 2006, the US Navy added Type V and Type VI, High Durability classifications to *MIL-PRF-24635D, COATING SYSTEMS, WEATHER-RESISTANT, EXTERIOR USE*. Several demonstration projects were completed prior to 2009, when the Navy qualified three polysiloxane coatings to the specification. Figure 4 illustrates the legacy three-coat system (two coats of epoxy followed by a coat of silicone alkyd) and newer two-coat system (epoxy primer and polysiloxane topcoat) specified by the Navy. Polysiloxane use has expanded rapidly – over 30 navy ships now have polysiloxane topside coating. The 2014 version of the NAVSEA Standard Item for painting specifies a polysiloxane coating system for topside application.

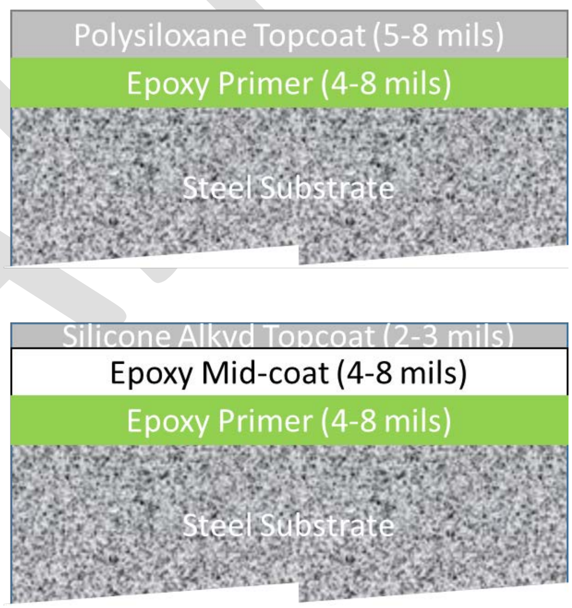

Figure 4. Legacy Navy 3-coat system (bottom) and new 2-coat Polysiloxane system (top).

The Navy will recognize savings in both the installed cost and life cycle maintenance cost by transitioning to polysiloxane topcoats. While the reported material cost of the polysiloxane coating system is approximately 32% higher, the labor savings associated with the two-coat system more than offsets the increased coating material cost. Overall project savings of 26% have been reported. (Kuljian 2011) In addition, the polysiloxane coatings tend to retain their color longer and resist staining better than the silicone alkyd coatings. Figure 4 sows data comparing color and gloss retention of legacy, silicone alkyd coatings and newer polysiloxane coatings after approximately 3 years at NRL’s Key West exposure site. Note that the silicone alkyd color change is more than three time the polysiloxane change. Gloss retention is also significantly lower for the silicone alkyd coatings. As a result, less touch-up painting will be required. When discoloration occurs, it is often possible to clean the coating instead of painting. This enhanced durability provides a life-cycle cost savings.

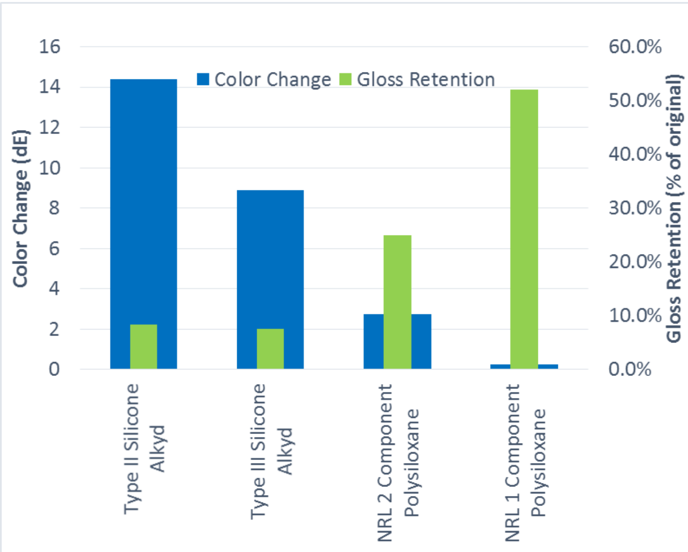

Figure 5. Color change and gloss retention of silicone alkyd and polysiloxane Navy ship coatings. (Iezzi 2014)

CHALLENGES BEING ADDRESSED BY THE NAVY

Adoption of polysiloxane topcoats is not without challenges for the Navy. The Navy has had some of the adhesion problems experienced in other industries. In addition, they are addressing challenges associated with polysiloxane use during operational level maintenance and new construction.

The Navy operational level maintenance community must undergo a paradigm shift to fully recognize the life-cycle cost savings. Current Navy practices involve a significant amount of painting for cosmetic purposes. It is important that Navy ships maintain their appearance; application of a coat of silicone alkyd paint has historically been the most expedient way to keep a ship looking good. Polysiloxane topcoats retain color and gloss longer than silicone alkyd coatings and tend to resist staining better than the silicone alkyd coatings. However, staining still tends to drive more touchup painting than is desirable. The Navy is working to develop and implement practical cleaning procedures which will continue to reduce the amount of touch-up painting performed by sailors.

Despite best efforts to improve cleaning practices, some degree of operational level touch-up painting is inevitable. Since polysiloxane coatings are two component and silicone alkyd coatings are one component, the latter tends to be used for touch-up. Obviously, any benefits of the more expensive polysiloxane coatings are lost once they are covered with the older technology. The Naval Research Laboratories have developed a single component polysiloxane coating that does not require the mixing of components before application, can be applied direct-to-metal or over an epoxy primer, and outperforms all Qualified Product Database (QPD) silicone alkyds and 2K polysiloxane coatings when tested for color stability in accelerated weathering tests. (Iezzi 2013)

As the maintenance community begins to take advantage of the longer service life and life cycle cost reduction associated with polysiloxane topcoats, color matching of existing coatings is becoming a more significant issue. Field activities have found that despite tight specifications for color, touch-up coating does not always match existing coating. Differences can exist from batch to batch and supplier to supplier. As a result, larger areas than necessary may be painted so that the new coating ends at an edge or other feature which masks the mismatch. The Navy is presently exploring ways to deal with this challenge and further decrease the amount of touch-up painting.

Polysiloxane coating systems have been promoted as a cost savings because only a single coat of epoxy primer is required under the polysiloxane topcoat when applied over steel surfaces and no epoxy primer is required on aluminum structure prior to top coating with polysiloxane. However, during Navy new construction, primed steel is exposed in the shipbuilding environment for a sufficiently long time to dictate the need for a second coat of epoxy before topcoating. Since two coats of epoxy are applied rather than one, the cost savings that is recognized during ship maintenance is not recognized in new construction. In addition, the Navy typically requests an additional dress coat prior to sail away. If a polysiloxane topcoat were applied, it would be preferable to clean the coating to "like new" conditions, eliminating the necessity to recoat prior to sail away. However, it is unclear whether satisfactory levels of cleaning can be achieved.

The National Shipbuilding Research Program Surface Preparation and Coatings Panel (SPC) has initiated a project to generate cost-benefit data based on activities and build sequences which are relevant to new ship construction. The study will help to identify and quantify the cost benefits in new construction for application of the polysiloxane topcoat.

CONCLUSIONS

1. Polysiloxane coatings are a relatively new chemistry which offers an alternative to polyurethane and silicone alkyd finish coatings for ships, offshore structures and other industrial maintenance applications. Tradeoffs among application requirements, coating cost, durability, and health/safety concerns should be considered when selecting among the three materials.

2. Polysiloxane topcoats offer the Navy a more durable finish coat for ship exteriors than current silicone alkyd coatings. In depot maintenance, it can be installed at a lower cost than the

legacy silicone alkyd system.

3. Polysiloxane topcoats should offer the Navy life-cycle cost savings. However, there are challenges which need to be overcome to fully recognize the benefits of this more durable coating throughout the ship life cycle. These challenges include implementation of cleaning procedures, improving color-matching and developing materials which are more practical for application by ships' forces.

4. Sufficient financial advantages of applying polysiloxane topcoats in new construction need to be identified to offset the increase in material cost before it will be implemented in new construction.

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