High Solids Coatings Performance and Service History

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Background

In the mid-1990's, the Navy identified corrosion repair and preservation within tanks and voids as their primary maintenance cost of corrosion issue, consuming nominally $250 million per year. In response, the Navy instituted an aggressive program to study the root cause of these corrosion problems and implement solutions. The Navy program demonstrated that:

(a) Early 1990's coating installation practices tended to limit the life of the coating systems.
(b) Legacy, solvent-based coating materials being utilized were not state of the art.
(c) Coatings tended to fail initially at "edges" (e.g., stiffeners, welds, etc.) within tanks.

Legacy coating materials were most commonly the solvent-based polyamide epoxy coatings (e.g., those meeting U.S. military specification MIL-DTL-24441 Type III or IV). The multi-coat systems applied at the time required three to five full and stripe coats. These coating systems, and their commercial equivalents based on solvent-based MIL-PRF-23236 tank coatings had an expected service life of roughly five years to eight years (in ballast, fuel/compensated fuel, and potable water tanks), but sometimes as little as two years (as in waste holding tanks and potable water tanks). In the mid-1990's these service life expectations correlated well with ship drydocking maintenance periodicities.

In the mid-1990's the state-of-the-art coating systems for providing long service life shifted from the solvent-based systems to the ultra-high-solids (UHS) coatings that were developed by a number of commercial coatings manufacturers. These UHS coatings were primarily epoxy based products with different chemistry resin systems and hardeners. The Navy defined the term "ultra-high-solids" in the MIL-PRF-23236 tank coating specification to require a volatile organic compound (VOC) content of less than 150 grams per liter of coating. In addition to these low solvent levels, the UHS coatings were also formulated to satisfy all environmental regulations for hazardous air pollutants and hazardous heavy metals (e.g., no UHS system contains hexavalent or trivalent chromium compounds). Thus, both improved corrosion-control performance and compliance with environmental regulations were key factors in the Navy's shift toward UHS systems.

Also in the mid-1990s, the Navy embarked on efforts to extend ship's drydock cycles such that tanks, especially those tanks that can only be accessed in drydock, might no longer be available for maintenance repainting every five to eight years. To satisfy these emerging maintenance schedules, the Navy determined that tank coatings that would last up to 20 years in Navy service would be required. To achieve such extended tank coating service life, the Navy realized that coatings must offer high chemical resistance to in-service coating degradation, high film build to provide an effective barrier coating, and some means of mitigating the observed premature failure of coatings at edges and welds. The Navy determined that the UHS systems satisfied all of these requirements and the first UHS systems were installed in ships 1996. More widespread use of UHS systems began nominally in 1999. Given that these coatings have been in service for less than 20 years, the key question to be answered in this paper is, "do the UHS systems support the postulated 20-year service life envisioned when UHS systems were fielded in the 1990s?"

Data Collection Approach

The Navy began installing UHS coating systems in tanks and voids in the late 1990's. Since the late 1990's, the Navy has maintained several databases that track coating types installed in specific tanks, and the corrosion/coating failure conditions in these tanks over time. These databases are used by the Navy as a basis for estimating and planning tank rework that might be needed at upcoming ship repair availabilities with tanks that exhibit extensive coating deterioration being highly prioritized for rework in a ship's "next" maintenance period. To develop the analyses in this paper, these databases were reviewed and as such the data in the paper is derived from maintenance database information.

Tank inspections are conducted by a trained individual who ranks different areas of the coated surface on a 1 to 4 scale. Table 1 summarizes the specific areas of coating failure related to each of these numerical ratings.

Table 1 – Summary of Coating Ratings

Coating Rating	% Coating Breakdown (nominal)
1	< 0.03%
2	0.03% to 0.3 %
3	0.3 to 10%
4	> 10%

These ratings are applied to four (4) different areas of the tank: sidewalls, tank top, tank bottom, and t-beams (stiffeners). Thus, each tank "rating" actually includes four numerical ratings. Percentage of coating breakdown refers to rust-through, undercutting, and blistering. Blistering is accounted for based on the size and density of the observed blistering. Because tank service has a strong influence on tank coating service life (i.e., the Navy never postulated that any organic coating system would survive 20 years in "sewage" service on Navy ships), the focus of this paper was on seawater ballast tanks. Seawater ballast tanks should be able to provide up to 20 years of service life, are widespread throughout the fleet, and are relatively simple to assess because ambiguous issues like blistering are usually not extensively observed. Thus, the inspection data, original coating system, and the date of specific inspections were culled from Navy databases for seawater ballast tanks.

Data were gathered from nineteen ships of seven different ship classes that had UHS coatings installed resulting in an overall data set of eighty-five (85) seawater ballast tanks. A similar data pull was performed of tanks with solvent-based coatings resulting in a data set of 133 seawater ballast tanks. These data are not surprising considering that the Navy operates some ships for 50 years and the UHS coatings have only been available for the past decade. An additional key point in these data is that because UHS systems were “required” (i.e., solvent-based coatings were no longer authorized) for use in seawater ballast tanks in the mid-2000’s any solvent-based coating systems in tanks must be at least this old or older. It is also important to note that the Navy, as part of the UHS process implementation enhanced the controls on coating application processes. For example, when UHS coatings were applied, surface for salt content was controlled, SSPC SP-10 near white metal blast cleanliness was confirmed, relative humidity and tank temperatures were controlled, and each coating application step had some quality assurance. So, the process for applying the UHS coatings included more inherent controls than the processes used decades ago to apply legacy, solvent-based coatings. Thus, the database results reflect that the UHS coatings are applied using these improved coating application practices. A corollary of the improved application processes is that all UHS coatings, regardless of age are included in the data, potentially including coatings that were not applied following the improved practices, while the only solvent-based coatings included in the data have already survived at least 5 years of service. The longer life inherent in the solvent-based coatings suggests that any of these coatings that were applied improperly, would already have failed and been repainted and as such do not appear in the database.

The Navy defines coating “failure” as those tanks that exhibit a three (3) rating on at least a single one of the four numerical rating. For example, a tank with sidewalls, overheads, and stiffeners rated as 1,1, & 1, but a tank bottom rated as a 3, the tank would be classified as a failed coating system. Given that overall Navy policy, the data in the current evaluation were evaluated more analytically with the rankings of the individual walls being added together to produce a possible 4 (i.e., ratings of 1 all around) to 16 possible total rating; failure was defined as any value exceeding a total of eight (8). This more analytical approach provided for a bit more fidelity in the data analysis and also eliminated situations where only one wall was severely deteriorated as discussed above (i.e., a 1,1,1, and 3). Such unbalanced or atypical ratings were considered perhaps more indicative of coating application problems rather than the inherent coating performance that is of concern in this paper. The estimated percent coating loss in the tank was also normalized by applying the equivalent percent coating breakdown times the area of the individual tank section divided by the total tank area. The data are then expressed in terms of “Percent Loss” in the remainder of this paper. Finally, the tanks with multiple data points over time were reviewed to show the failure rate trends in the plots presented in the Results section of this paper.

Results

Figure 1 shows the typical appearance of a legacy coating system after about five years of service. From a performance standpoint, these coatings tend to suffer from pinhole rusting and poor protection of sharp edges, welds, and other complex "edges."

Figure 1 – Legacy Polyamide Epoxy Coatings Previously Favor for Navy Ship Tank Applications (approximately five years service)

Figure 2 shows typical performance of some of the early installations of UHS coatings in seawater ballast tank service.

Figure 2 – Ultra High Solids Coating Performance After Three Years (left) and Eleven Years (right). At Three Years, Discoloration is Staining. At Eleven Years there is less than 1% Coating Damage

Figure 3 shows a graph of breakdown rate for legacy, solvent-based epoxy coatings including the Navy MIL-DTL-24441 coating system as well as commercial, solvent-based coatings qualified to MIL-PRF-23236.

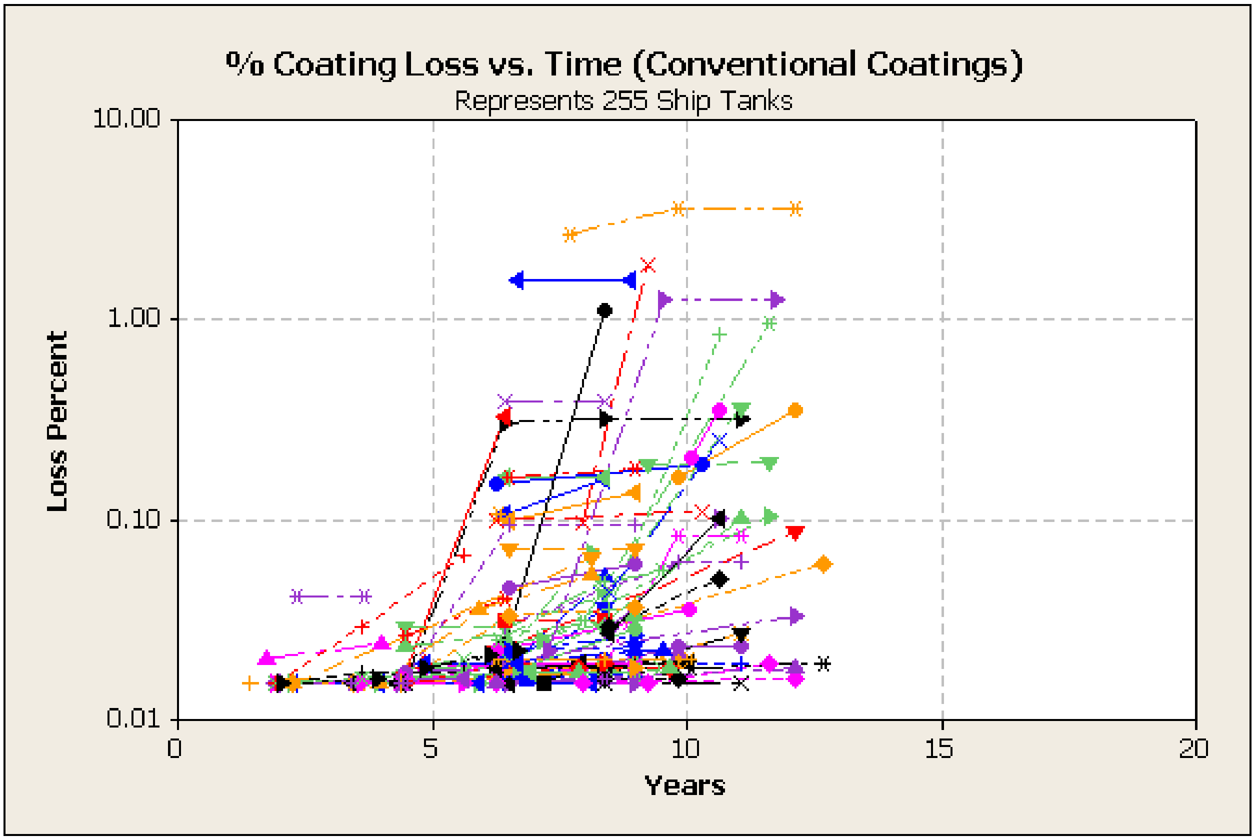

Figure 3 – Percent Coating Loss vs. Time for Conventional Coatings

Figure 4 shows breakdown rate for UHS coating systems installed since 1999. Both Figure 3 and Figure 4 were compiled using data from the database.

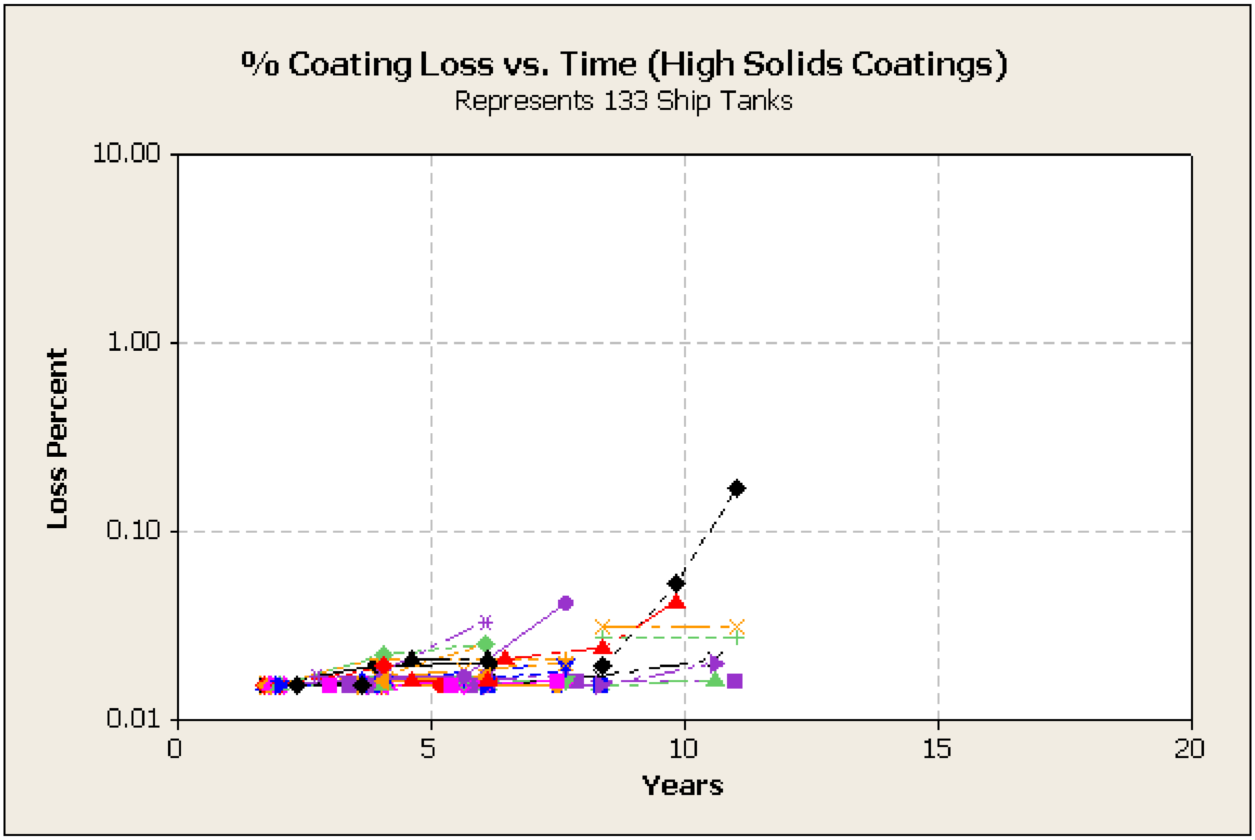

Figure 4 – Percent Coating Loss vs. Time for Ultra High Solids Coatings

The first key observation in comparing Figures 3 and 4 is that the population of seawater ballast tanks with coating loss rates in excess of 0.10% is far higher for the legacy, solvent-based coating population than for the UHS coating population. In fact, careful examination of the Figure 4 data show only a single tank to have >0.10% coating loss. The Navy has no specific data on this tank, but as noted earlier, all tanks, regardless of tank service life are included in the UHS data pull while simply because of the history of UHS implementation, all tanks in the solvent-based population are inherently more than five years old. Again, understanding that the authors have no data on the one UHS tank with the >0.10% failure, one could easily postulate that this one tank had improper surface preparation, poor environmental controls during coating application, or any number of other "problems" that could lead to premature coating failure. Thus because all tanks are included in the Figure 4 data, including those that may be failing prematurely, while only tanks that have survived for five years or more (i.e., those tanks that had poorly applied coatings have failed already and been replaced) are included in Figure 3, the trend toward higher coating loss percentages in Figure 3 is clear.

One other key point in comparing the figures is that there are plenty of tanks in Figure 3 that have coating loss rates of <0.10%. Again understanding that coating application practices has a profound influence on coating service life, one could argue that solvent-based coatings, when applied properly can provide a level of performance similar to UHS systems. However, the data show that most tanks with solvent-based coatings did start to experience coating breakdown after five years of service.

While the most obvious difference between the Figure 3 and Figure 4 data sets is the paint technology, it should be noted that the institutionalization of these new coatings was done in parallel with implementation of enhanced QA techniques and procedures. It is not entirely possible to separate the two effects. As discussed above the coating application workmanship is always important and can have a profound influence on overall coating system service life.

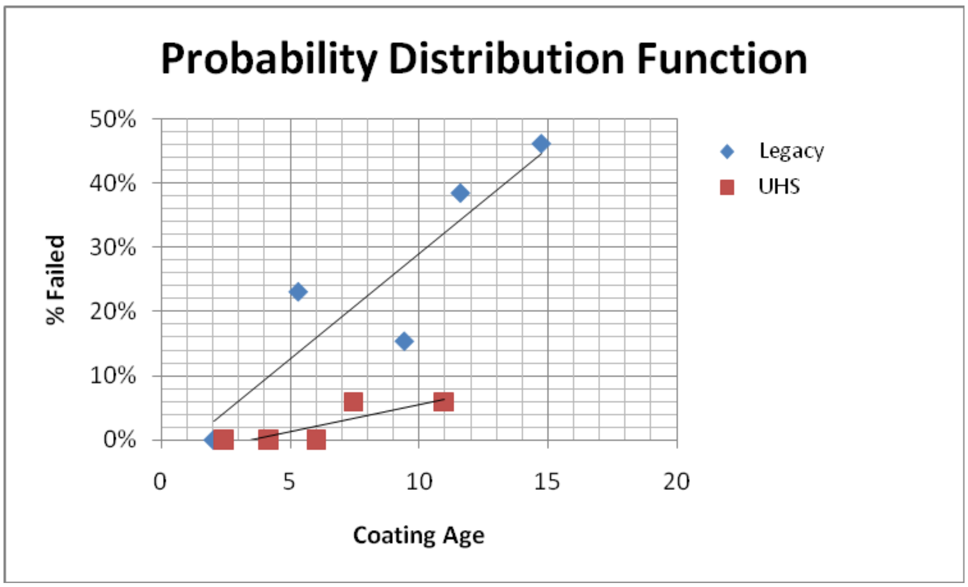

Figure 5 – Probability Distribution Function of Conventional and UHS Coatings

Figure 5 distills the data shown in Figure 3 and 4 into a single data plot showing the performance of the solvent-based legacy coatings and the UHS coatings. The percentage failed data reported in Figure 5 is derived from a sum of all four individual, numerical tank ratings for a given tank with a "cut off" of 8 being used to define failure. Recall that the "best" rating for a tank evaluated in this manner is 4 (i.e., 1,1,1, & 1), while a "worst" tank would be rated as a 16 (i.e., 4,4,4, & 4). Thus, the definition of 8 as failed is conservative in that at least four of the individual numerical tank ratings would be greater than a 2, or some portions of the tank are in really poor condition (i.e., a rating of 1 for tank sides and overheads, 2 for the tank bottom, and 4 for the overhead would still be classed as failed).

Figure 5 data show a large difference in the percent of legacy, solvent-based coatings defined as "failed" based on the criteria presented as a function of time as compared with the percent of UHS coatings considered "failed" as a function of time. Figure 5 shows that the population of UHS coatings is less likely to fail at any particular age, up to 11 years than the solvent-based coatings. Again, the data are not completely consistent and the legacy, solvent-based coating data point at 9.5 years may indicate coatings that were simply applied "better" than other coatings. The Navy has no data on these systems to explain the individual data points, but the trend between the two times of coating systems is clear; at every age included in the Navy databases, there is a higher probability of legacy, solvent-based coating systems being considered failed than UHS coating systems.

The Figure 5 data do not implicitly answer the question about whether the UHS coating systems and enhanced coating system application processes implemented in the late 1990's will satisfy the goal of a 20 year coating service life. Understanding the influence of workmanship and application processes on coating service life, the Navy has long understood that the stated goal of a 20 year service life for seawater ballast tanks represented a statistical proposition with tank coatings that were installed improperly being expected to fail prematurely. However, given the Navy efforts to better control application processes that was initiated concurrent with the introduction of UHS in the late 1990's, the Navy defined "20 year" coatings as 80% of the tank population with UHS coatings being rated as less than 8, with no readings higher than 2, after the 20-year period. Given that the Navy has no data on UHS coatings beyond the 11-year period, a simple, linear extrapolation of the UHS line on Figure 5 does infer that the UHS, seawater ballast tanks should eventually satisfy the Navy's expressed goal of having less than 20% of the population of tanks being considered "failed" at the 20 year period. Thus, there is no trend or data apparent at this point in time that suggests the UHS coatings, applied using the established practices, will not satisfy the Navy's expressed goals for 20 year seawater ballast tank coating service life.

Conclusions

The following conclusions can be drawn for the data presented in this paper.

(a) The data suggest that the population of legacy, solvent-based coating failures includes higher levels of coating loss as a function of time as compared that the UHS coatings.
(b) The implementation of improved UHS coating materials was coincident with the implementation of improved controls on coating application processes (e.g., checking surface for salt content, controlling environmental conditions during coatings installation, etc.) and nothing in this paper allows the conclusions to be drawn about the influence of the paint material vs. the application processes.
(c) The 11 year UHS data presented in this paper does not contraindicate the Navy's goals for a 20 year life span from seawater ballast tank coatings.
(d) Additional data are required over the next ten years to definitively confirm that UHS systems, applied using established Navy practices, can provide 20 year service life in seawater ballast tank service.