

Naval Surface Warfare Center Carderock Division

Philadelphia, PA 19112-1403

NSWCCD-61-TR-2014/35

October 2014

Survivability, Structures, and Materials Department
Technical Report

U.S. Navy Alternative Fuels Program - Metallic Materials Immersion Corrosion Study - Phase 2

by

Steven Murray



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ADMINISTRATIVE INFORMATION

The Naval Surface Warfare Center, Carderock Division (NSWCCD), Code 614, Corrosion and Coatings Engineering Branch with Code 612, Metallurgy and Fasteners Branch, and Code 615, Naval Fluids Branch accomplished this work. Overall program management and funding was provided by Commander, Naval Air Systems Command HQ under Work Request N0001912WX06844 of 07 March 2012 and N0001914WX03568 of 19 November 2013.

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EXECUTIVE SUMMARY

Per the test protocol for this corrosion evaluation, acceptance criteria were based on comparison of corrosion rates and metallurgical findings for fuel system metallic materials immersed in a Direct Sugar to Hydrocarbon-76 (DSH-76) and a Hydro-treated Depolymerized Cellulosic Diesel (HDCD) alternative fuel blends being no worse than that determined for the standard F-76 petroleum fuel currently used. The HDCD fuel originally sent for metallic tests was from a pilot plant batch. During the course of this study, it was determined by NAVAIR that the provided HDCD fuel did not contain some lighter distillation fractions which would be present in the full production fuel. The decision was made to continue testing the original HDCD fuel from the pilot plant (known as HDCD-1) and rerun a new HDCD fuel (known as HDCD-2) from a 3000 gallon batch received 31 October 2013 that was refined with the lighter distillation fractions included. From a corrosion and metallurgical perspective, based on the data obtained from this study, it is concluded that there will be no negative corrosion effects from any of the biomass fuel blends used as an F-76 replacement. In addition, there was no appreciable difference between the HDCD-1 and 2 fuels from a corrosion or metallurgical analysis perspective. Corrosion rates for the metallic materials tested were extremely low, ranging from “not detected” to much less than 0.1 mil per year in most cases.

In phase 1 of this work [1] that evaluated F-76 against the original algae based alternative fuel blend, known as Hydro-processed Renewable Diesel (HRD-76), the 1010 carbon steel coupons coated with zinc (electroplated and hot dipped galvanized) and electroplated cadmium exhibited the most corrosion with the F-76 fuel showing higher corrosion rates than the algae based fuel. For this phase 2 testing of the DSH and HDCD-1 and 2 fuels, the zinc and cadmium electroplated coupons also showed the highest corrosion rates; however, they were lower compared to F-76. Corrosion rates associated with the 360 leaded brass alloy exposed to DSH were higher than that determined for F-76. The leaded brass coupons exposed to the DSH developed a black tacky coating on the surfaces and on the walls of the jar that contained the samples. White sediment was also found in the bottom of the jar. Removal of the tacky coating revealed a gray-blue coloring on the coupon surface. Scanning Electron Microscopy (SEM) analysis of the surface indicted major amounts of copper and zinc, along with minor amounts of lead, carbon, oxygen and silicon. The copper, zinc and lead are all expected since they are part of the base 360 leaded brass alloy chemistry. The carbon, oxygen and silicon constituents would appear to be a component of the dark surface film. The 360 leaded brass alloy was rerun in DSH resulting in similar SEM findings; only the blue surface coloring was lighter in appearance. These coupons, in addition to other copper containing coupons and DSH oil samples, were submitted to the NAVAIR Code 4.4.5 Fuels and Fuels Systems group for further analysis. Despite the film and color change to the 360 leaded brass alloy coupons, no corrosion or metallurgical anomalies were found.

The metallurgical analysis performed on the corrosion coupons pre- and post-exposure between the DSH and the HDCD-1 and 2 fuels did not determine any observed metallurgical changes with the materials and showed no evidence of crevice or corrosive attack. The metallurgical findings did note that for the previously evaluated F-76 fuel, the electroplated zinc applied to carbon steel coupons showed evidence of pitting; however, the pits did not penetrate through to the base metal. The DSH, and HDCD-1 and 2 fuels did not show any evidence of pitting on the electroplated zinc coupons from this study.

ABSTRACT

This report documents a corrosion evaluation of U.S. Navy and Coast Guard shipboard fuel system metallic materials immersed in two fuels derived from biomass sources. One fuel is a 50/50 blend of Direct Sugar to Hydrocarbon-76 (DSH-76) ¹ and F-76 petroleum based fuel (MIL-DTL-16884M). The second fuel is a 20/80 ratio of Hydro-treated Depolymerized Cellulosic Diesel (HDCD) and F-76 fuel. Both fuel blends meet military specification MIL-DTL-16884M requirements. The immersion testing was performed with corrosion coupons in both static and flowing conditions (approximately 1 ft. /sec) at 120 °F for 180 days. Corrosion coupons were evaluated metallurgically pre- and post-exposure. The pre-exposure evaluation consisted of a visual and low magnification examination using a stereomicroscope with magnifications up to 50X and transverse metallographic cross-sections to document the surface condition before any testing was conducted. The post-exposure metallurgical analysis consisted of a visual examination, stereoscopic examination, and Scanning Electron Microscopy (SEM) evaluation for evidence of pitting, stress cracking and crevice corrosion in addition to metallographic analysis to determine if any microstructural changes occurred. The fuel oil temperature of 120 °F is considered the maximum expected shipboard fuel temperature. Corrosion rates in mils per year were calculated based on corrosion coupon dimensions and weight loss values.

BACKGROUND

This report discusses the second phase of a metallic material corrosion evaluation conducted in accordance with the test protocol [2], included as Appendices A-E, on biomass produced alternative fuels. For this study, the Naval Air Systems Command (NAVAIR), Patuxent River, MD, Code 4.4.5 determined that the hard faced materials and chrome plated brass previously evaluated in the phase 1 testing [1] would not be evaluated with the current fuels. This study evaluated: 1) 50/50 blend of Direct Sugar to Hydrocarbon-76 (DSH-76) and F-76 petroleum based fuel (MIL-DTL-16884M) and 2) a 20/80 ratio of Hydro-treated Depolymerized Cellulosic Diesel (HDCD) and F-76 fuel. The alternative fuel must meet the MIL-DTL-16884M requirements plus other fitness for purpose (FFP) properties. One of the FFP requirements includes evaluation of metallic and non-metallic materials used in shipboard fuel

¹ The commercial industry uses the term SIP - Synthesized Iso-Paraffins produced from Hydro-processed Fermented Sugars because it better defines the actual process and materials being qualified. The U.S. Navy, which embarked on diesel qualification work prior to the commercial sector, chose at that time to use the terminology DSH – Direct Sugar to Hydrocarbon. In this report the terms DSH and SIP are used interchangeably.

systems such as piping, valves, diesel engine parts, fuel nozzles and injectors that would be exposed to the fuel. This study focuses on the metallic materials only to determine corrosion rates and if any metallurgical effects occur from exposure.

The alternative fuels were provided by the NAVAIR Code 4.4.5. The metallic materials were procured per the Table 1 listing that was based on Navy and Coast Guard shipboard fuel and engine system materials. The corrosion study consisted of immersion of these materials in both fuel blends, under static and flow conditions for a 180 day period at 120 °F; considered the upper temperature limit for shipboard fuel systems. Each fuel was evaluated to determine if any significant differences in corrosion rates or metallurgical properties resulted between the fuel types when compared to previous findings for the F-76/HRD-76 fuel study [1]. For the static exposure, each metallic material was placed in a sealed glass jar in triplicate, filled with the respective fuel and placed in a constant temperature water bath. For the flow testing, all coupon material types were placed in a 20 liter glass cylindrical tank filled with each type of fuel and fitted with a stirrer/heating element apparatus to provide flow and maintain temperature. In addition, corrosion coupons of each type were assembled with Teflon® crevice washers to determine if crevice corrosion occurred at the contact points under the static and flowing conditions. A limited immersion study of fuel/water mixtures was also conducted to determine the extent of corrosion, especially at the fuel water interface and if biological growth occurred. This test was carried out on 1010 carbon steel, 304L stainless steel and 5052-H32 aluminum. Three coupons of each material type were placed separately in 8 ounce square glass jars, one set containing deionized water and the other natural seawater filled to the middle of the corrosion coupon and then filled to the top with the respective fuel oil. These samples were also exposed for the 180 day period at 120 °F.

Previous corrosion studies of a limited number of metallic materials exposed to F-76 fuel were conducted by the Naval Ship Systems Engineering Station (NAVSES), Philadelphia, PA in 1985 [3]. This testing was in support of David W. Taylor Naval Ship Research and Development Center (DT-NSRDC) efforts involving earlier formulations of alternative fuels to determine baseline corrosion rates. This evaluation involved static and modified loop flowing fuel testing of various metallic materials exposed to F-76 fuel for a longer time period (684 days static, 88 days dynamic), but at room temperature versus the higher 120 °F temperature used for the current testing. Corrosion rates from this evaluation were extremely low, on the order of 1×10^{-3} mils per year (mpy) for the following tested materials:

- ductile iron
- 1010 carbon steel
- 4130 alloy steel
- 304L stainless steel
- 655 copper silicon
- 353 leaded brass
- 510 phosphor bronze

For the current phase 2 evaluation, following the exposure period, coupon analysis consisted of a visual examination, stereoscopic examination of the surface condition, Scanning Electron Microscopy (SEM) examination of any pitting or stress cracking conditions, and crevice

corrosion analysis, in addition to metallographic analysis for determining any microstructural changes of the materials. The results will be compared to the previous baseline findings for the F-76 fuel exposure [1] to determine if any significant differences exist.

During the corrosion testing of the fuels, it was determined by NAVAIR Code 4.4.5 that the HDCD fuel provided for the evaluation from a pilot plant batch did not contain all of the lighter distillation fractions. NAVAIR requested that the initial submitted HDCD fuel test be completed and a retest of the HDCD containing all expected distillation fractions be accomplished. This report documents the DSH and initial pilot plant HDCD fuel (known as HDCD-1) and the retested full production HDCD fuel (known as HDCD-2) corrosion and metallurgical analysis results.

METHOD OF APPROACH

Materials

The following materials were required for this evaluation:

1. 50/50 blend of Direct Sugar to Hydrocarbon-76 (DSH-76) and F-76 petroleum based fuel.
2. 20/80 ratio of Hydro-treated Depolymerized Cellulosic Diesel (HDCD) and F-76 fuel, with and without the light distillation fractions.
3. Metallic materials shown in Table 1. All coupons were 0.5"W x 3" L x 1/16" thick with a 1/4" hole located 1/2" from one end.

Static Immersion Testing

Prior to the fuel oil immersion, the corrosion coupons were measured for surface area, cleaned per ASTM G1-03 [4], and weighed to the nearest 0.0001 grams. ASTM G31 [5] immersion testing guidelines were used for the test set-up. For the static immersion corrosion study, three cleaned and weighed coupons of each material type listed in Table 1 were suspended on Teflon® coated wire in 475 milliliter (16 oz.) wide-mouth glass jars fitted with a Teflon® coated sealing liner in the lid. Each jar was filled with the alternative fuel blend as shown in Figure 1. To suspend the coupons, holes were punched in the lid sealing liner and the coupon support wire inserted between the liner and the lid. This allowed for a complete seal when the lid was screwed onto the jar eliminating water intrusion from condensing water bath steam. For the crevice corrosion study, two cleaned and weighed metallic coupons of each material listed in Table 1 were sandwiched together, separated by Teflon® crevice washers. Each assembly was held together by nylon bolts/nuts to preclude any galvanic interaction, Figure 2. The nylon nuts/bolts were torqued with a torque wrench to 0.28 N-m (2.5 lb.-in) as discussed in ASTM G48, Method D [6]. Each assembly was placed in a 475 milliliter (16 oz.) wide-mouth sealed glass jar filled with the respective fuel and capped with a lid fitted with a Teflon® coated liner.

Table 1. Representative Metallic Materials for Navy Immersion Testing

GENERIC DESIGNATION	SPECIFIC MATERIAL ²
Aluminum & Alloys	• 356-T6, uncoated • 2024-T3, uncoated • 7075-T6, uncoated • 7075-T6, anodized (chromic acid) • 7075-T6, anodized (sulfuric acid) • 7075-T6, chromate conversion coated • 5052-H32, uncoated
Copper & Alloys	• 651 silicon bronze alloy, or equivalent • 360 leaded brass alloy, or equivalent. • Copper, unalloyed, Electrolytic Tough Pitch (ETP), uncoated • 90-10 CuNi
Steel (Carbon, Alloy)	• 1010 carbon steel, uncoated • 1010 carbon steel, hot dipped galvanized • 1010 carbon steel, with Ion Vapor Deposition (IVD) aluminum (Class 3 thickness 0.0003 to 0.0008”) • 1010 carbon steel, with Ion Vapor Deposition (IVD) aluminum (Class 10 thickness-0.0010 to 0.0015”) • 1010 carbon steel, with electroplated tin • 1010 carbon steel, with electroplated silver • 1010 carbon steel, with electroplated cadmium • 1010 carbon steel, with electroplated nickel • 1010 carbon steel, with electroplated zinc
Stainless Steel	• 440C, heat treated • 304L, uncoated
Nickel & Alloys	• IN 200, uncoated
Titanium & Alloys	• 6Al-4V
Solder	• 60-Sn – 40 Pb

² See test protocol , Appendix C for Base Metal Specifications and Appendix D for Plating Requirements.

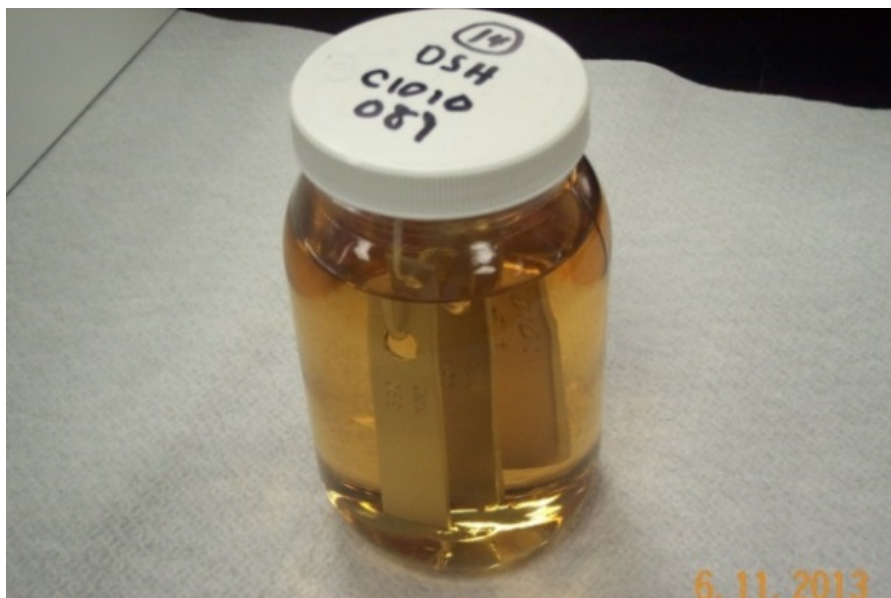


Figure 1. Typical corrosion coupon set-up for static immersion testing. Coupons suspended on Teflon® wire.

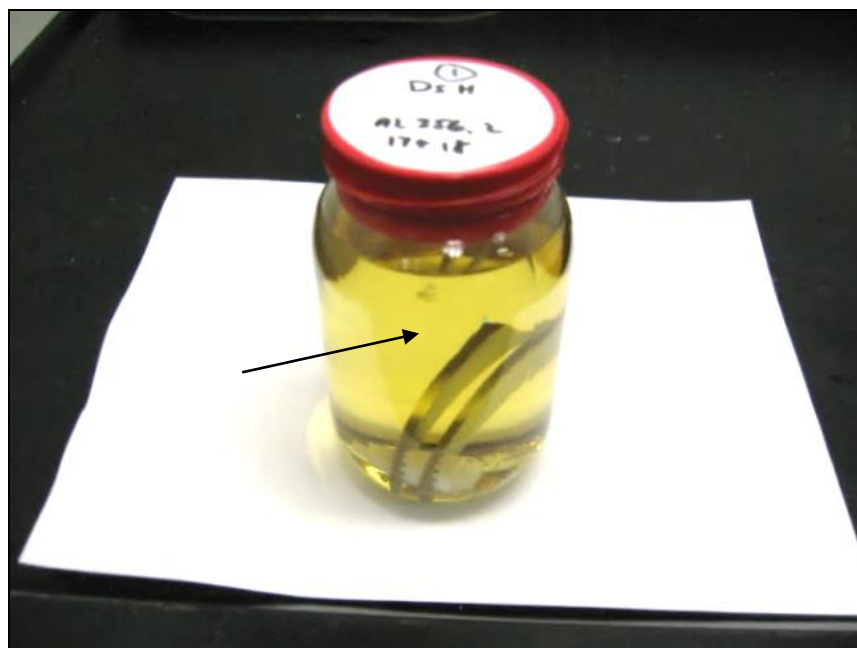


Figure 2. Typical corrosion coupon assembly for crevice corrosion testing. The arrow points to the white crevice washer assembly

All static immersion samples were placed in a constant temperature water bath, Figure 3, set to 120 °F for the 180 day exposure period. The baths were covered to maintain temperature and minimize water evaporation. Water was added weekly to account for any evaporation. Post exposure, all coupons were re-cleaned to remove any fuel oil and corrosion products and weighed in order to determine the corrosion rate in mils per year (mpy).

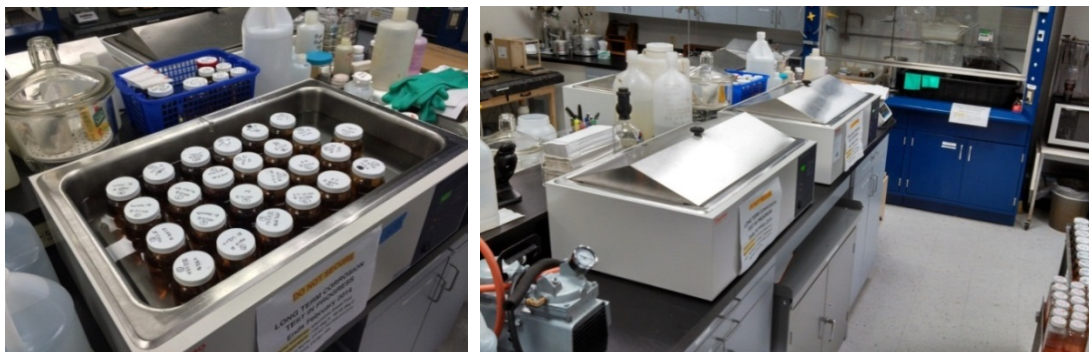


Figure 3. Typical set-up of static immersion samples in constant temperature bath

Flowing Fuel Immersion Testing

Three cleaned and weighed coupons of each material listed in Table 1 in addition to two coupons of each material assembled for crevice corrosion determination were exposed to the fuels. All coupons were suspended in a 20 liter glass cylindrical tank of each fuel type equipped with a circulating pump with a heating element to maintain the 120 °F temperature for the 180 day period, Figure 4. The general corrosion coupons were strung through the hole on each coupon on a length of polyethylene tubing, with each coupon separated by a polyethylene spacer (Figure 5, left). The tubing diameter allowed for a snug fit of the coupons that would not allow any swaying or contact with each other in the circulating fuel. Due to the number of samples, multiple rings of coupons were assembled and stacked within the fuel oil baths with each stack separated by Teflon® supporting wire. The crevice coupons were assembled (Figure 5, right) along a threaded rod, covered with polyethylene tubing to secure the coupons with each coupon separated by the Teflon® crevice washer that also inhibited any contact between coupons. Nuts on each end of the rod were tightened to a torque of 0.28 N-m (2.5 lb.-in) discussed in ASTM G48, Method D [6]. The bath was circulated at a roughly measured flow rate of 1 foot per second, based on the average time for a floating marker to make one revolution around the tank wall. Following the exposure period, the removed coupons were cleaned and weighed as previously described. Corrosion rates were calculated in mils per year (mpy) and the metallurgical evaluation performed.



Figure 4. Laboratory set-up for flow test. Unit on tank is a combination circulator pump and heating element.

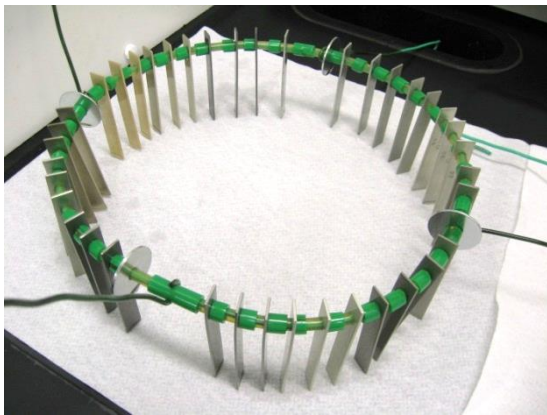


Figure 5. Typical coupon mounting for flowing fuel corrosion testing. Left photo shows coupons for determining general corrosion. Right photo is for determining crevice corrosion with each coupon separated by a Teflon® crevice washer.

Biological Effects Immersion Testing

There was concern of corrosion from biological processes that may occur aboard ship in water/seawater compensated fuel tanks. As performed in phase 1 of this project [1], a very limited scope test was conducted to determine if any visual biological growth occurred or corrosion deposits formed on 1010 carbon steel, 304L stainless steel and 5052-H32 aluminum corrosion coupons suspended in jars containing half fuel (each type) and half water (deionized and seawater). The static exposure period was for 180 days and 120 °F. The waters used were natural seawater from the New Jersey shore (Wildwood, NJ) and de-ionized water with a conductivity of 1.1 micro-siemens/centimeter ($\mu\text{S}/\text{cm}$) from the NSWCCD Code 614 laboratory. Cleaned and weighed metallic coupons (3 each) of each coupon type were suspended in 240 milliliter (8 oz.) sealed glass jars (one coupon per jar) containing an equal volume of fuel/seawater and fuel/deionized water. There was no attempt to replenish the fuel or water during the test period. Any deposits or growth would be documented and photographed, but would be removed with no further analysis. The extent of corrosion was assessed by visual inspection and SEM examination (metallographic sectioning for microstructure analysis), if necessary. Figure 6 depicts the fuel/water set-up.

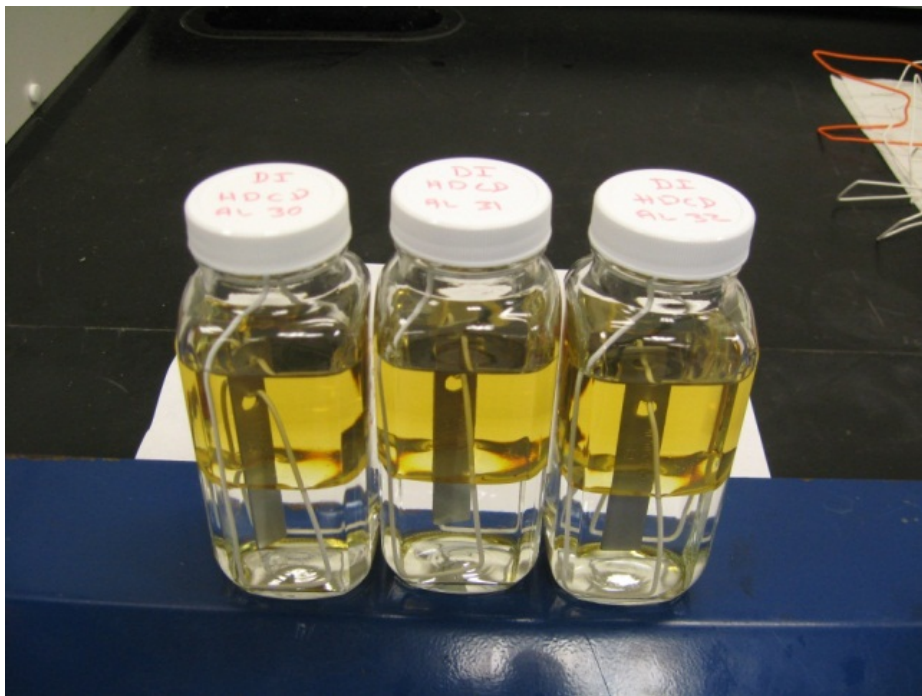


Figure 6. Sample set-up of fuel oil/water mixture to determine if biological film formation or corrosion is present at the oil/water interface.

Metallurgical Evaluation

As part of this study, metallurgical evaluation of the fuel and the fuel/water exposed corrosion coupons was required to determine if any metallurgical differences existed between the two fuel types between the unexposed metals and the exposed metals, i.e. were there any microstructural changes, and were there any substantial differences between these fuels and the standard F-76 fuel evaluated in phase 1 [1] of this project. The metallurgical evaluation included the following:

Surface Evaluation. Visual inspection and at low magnification, utilizing a stereomicroscope with magnifications up to 50X, for evidence of staining, deposits, and gross corrosion with photographic documentation,

Scanning-electron Microscope (SEM) Evaluation. Examination at 100X of worst case coupon for each material (as required) for degree of pitting per ASTM G46 [7], stress cracking conditions and crevice corrosion for the crevice prepared coupon sets with photographic documentation; and,

Microstructure Evaluation. Cross sectioning, mounting and polishing using standard metallurgical analysis techniques for the materials being examined. Samples would be examined at 100-1000X for evidence of microstructure changes, corrosion or other effects. Based on findings, further evaluation would be conducted via scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDXA) to analyze corrosion products. Photographic documentation of findings as required.

Acid Number, pH and Dissolved Metals

Samples of new and used (from the flow testing) alternative fuels were analyzed for Total Acid Number per ASTM D974 [8] and dissolved metals per Institute of Petroleum, Method IP-501 [9]. The metals included iron, copper, aluminum, zinc, nickel, cadmium, lead, chromium and silicon. The flow test fuels were used for these analyses because they contained all of the metallic materials in one container exposed to the same fuel for the entire period. The purpose of the metals analysis was to determine if any significant differences occurred between the unused base fuels and the exposed fuels that would be cause for concern for long term operation of shipboard equipment using the alternative fuel blends.

RESULTS

Static and Flowing Fuel Immersion Corrosion Findings

At the conclusion of the exposure period, the removed coupons were cleaned, reweighed and the corrosion rate calculated in mpy. The corrosion rate was based on the average of the three coupons (two for crevice assemblies) of each material type. The calculated corrosion rates are found in Table 2 for the DSH fuel and Table 3 for the HDCD-1 initial and the HDCD-2 retested fuel. Both tables show the corrosion rate comparison against the previously evaluated F-76 fuel. Within each table, the designation of “nd” stands for “No Corrosion Detected.” This was annotated where the average of the three coupon weights showed no detectable weight difference between the pre- and post-exposure measurements resulting in no detectable corrosion within the scope of this test, or where the average of the coupons showed a weight gain. Table 4 shows the weight gain or losses (in parentheses) in grams, of the DSH exposed materials and Table 5 is for the HDCD-1 and HDCD-2 exposures. For each fuel type, review of the static conditions data shows the largest losses associated with the cadmium plated, the zinc plated and the galvanized zinc coupons which are below the values obtained for the prior evaluated F-76 baseline fuel. The corrosion rates of the steel coupons with ion vapor deposited (IVD) aluminum; the various plating’s and galvanizing were calculated using the coating material density. Minimal weight gains on the order of ten-thousandths of gram’s were associated with a number of aluminum materials, the ion vapor deposited aluminum, and other plating’s on the 1010 carbon steel. The weight gain may be attributed to some type of surface oxidation process associated with the fuels, not investigated as part of this study and were on the same order of magnitude determined for the prior F-76 fuel. This is not considered a corrosion issue for system integrity, but is noted here for documentation purposes.

The Table 2 DSH and Table 3 HDCD-1 and HDCD-2 corrosion rate data for the static condition testing shows that the majority of the metallic materials, excluding the hot dipped galvanized, electroplated zinc and cadmium coupons had very low corrosion rates. For the DSH fuel, the maximum corrosion was found for the 360 leaded brass alloy (0.048 mpy), the electroplated cadmium on 1010 carbon steel (0.064 mpy), the electroplated zinc on 1010 carbon steel (0.023 mpy) and the hot dipped galvanized on 1010 carbon steel (0.014 mpy) coupons. The results show the values obtained for the leaded brass and the cadmium plated coupons were elevated above the previous F-76 values and the zinc plated and galvanized values were below the F-76 results.

For the static HDCD-1 fuel, the only significant corrosion rates were for the electroplated cadmium (0.116 mpy) and electroplated zinc (0.015 mpy) on 1010 carbon steel coupons which were below the previously determined F-76 values, 0.136 and 0.065 mpy respectively. For the static HDCD-2 fuel, the most significant corrosion rates were associated with the copper electrolytic tough pitch (ETP) (0.012 mpy), the electroplated cadmium on 1010 carbon steel (0.021 mpy) and the electroplated zinc on 1010 carbon steel (0.014 mpy). Only the copper ETP alloy had a corrosion rate above the F-76 baseline of 0.002 mpy.

For the 360 leaded brass alloy coupons exposed to the static DSH, a thick black tacky coating formed on the coupon surface and the walls of the jar as shown in Figure 7. White sediment also collected in the bottom of the jar. The sediment was not sticky, moving into the

fuel layer when the jar was swirled. The exposed DSH with the leaded brass coupons also smelled like turpentine whereas the unexposed fuel had the expected petroleum odor. When the coupons were cleaned to remove the black film, the coupon surfaces were a gray blue color, Figure 8. It was decided to rerun the leaded brass alloy in DSH with new coupons to confirm the results. The coupon surfaces did darken considerably; however, the tacky coating did not form. Cleaning of these coupons also showed the blue surface color which was lighter, Figure 8. Another interesting finding is that 360 leaded brass alloy coupons assembled for static crevice corrosion studies and exposed to the same temperature and time conditions did darken like the second DSH sample run, but the tacky coating did not form. The copper ETP, copper-nickel (70/30 and 90/10) and the silicon bronze did not darken appreciably in the DSH, but darkened in both HDCD fuels. Multiple DSH fuel samples exposed to copper containing alloys were submitted to NAVAIR Code 4.4.5.1 Fuels and Fuels Systems group for further analysis. Review of phase 1 alternative fuels work showed that the leaded brass coupons had darkened in the F-76 fuel; however, were not as dark in the HRD/F-76 blend. The copper, copper-nickel and silicon bronze materials also darkened in the F-76 fuel.

The flow test corrosion rates between the F-76 and the DSH fuel were essentially equivalent, varying by only 0.001-0.002 mpy, except for the electroplated zinc on 1010 carbon steel that had a lower corrosion rate (0.014 mpy) than the F-76 fuel (0.022 mpy). For the flowing HDCD-1 and HDCD-2 fuels, the only significant findings were for HDCD-1 electroplated zinc on 1010 carbon steel (0.009 mpy, F-76 was 0.022 mpy) and for HDCD-2 electroplated zinc on 1010 carbon steel (0.016 mpy, F-76 was 0.022 mpy) and electroplated silver on 1010 carbon steel (0.013 mpy, F-76 was 0.001 mpy).

Tables 2 and 3 data also show very low corrosion rates associated with the crevice corrosion coupons (static and flowing conditions). While the focus of these coupon sets was not overall corrosion but corrosion at the crevice washer touch points, the overall corrosion was very low. As noted above for the static and flowing HDCD-2 results, the electroplated silver and electroplated zinc 1010 carbon steel coupons did show corrosion in the HDCD-2 fuel, 0.012 mpy and 0.015 mpy respectively. The HDCD-1 electroplated zinc on 1010 carbon steel had the highest corrosion rate, 0.011 mpy. This trending is similar to the other exposure conditions noted above for these fuels. More importantly, as will be discussed in the metallurgical analysis findings below, crevice corrosion was not found for any of the materials for any of the three fuels. For metallic materials that did show a corrosion rate greater than the baseline F-76 value, mainly associated with the electroplated steels, it must be determined if any corrosion values above those for F-76 would be detrimental, based on the material usage within the shipboard fuel system. For example, the materials chosen for testing may not be wetted with fuel and therefore any corrosion found would not be considered detrimental to the fuel system. It should also be noted that all of the corrosion rates found are on a very low order of magnitude and may be insignificant when compared to the installed material thickness. The highest corrosion rate for any of the materials/fuel combinations was associated with the electroplated cadmium on 1010 carbon steel coupons; 0.136 mpy in static F-76, 0.064 mpy in static DSH, 0.116 mpy in static HDCD-1 and 0.021 mpy in static HDCD-2. Flowing conditions showed lower corrosion rates for the electroplated cadmium and zinc on the 1010 carbon steel coupons.



Figure 7. 360 leaded brass alloy exposed to DSH for 180 days at 120 °F became coated with a thick, black, tacky material.

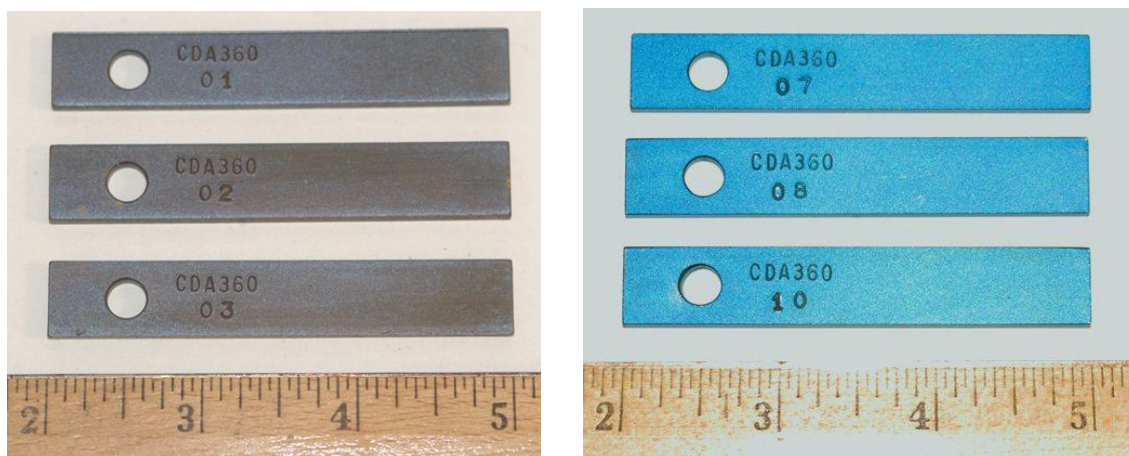


Figure 8. 360 leaded brass alloy coupons exposed to DSH for 180 days at 120 °F. Left photo was the initial run after the black tacky coating shown in Figure 7 was removed. The right photo was the condition after the rerun of the samples. The black tacky coating did not appear on the rerun samples; however, the coupons were a dark brown/black after the exposure

Table 2. Static, Flowing Fuel DSH Corrosion Rates, mils per year (mpy) Compared to F-76 Fuel³

Coupon Type (1)	F-76 Static -Prior Data	DSH Static	F-76 Crevice Static Prior Data	DSH Crevice Static	F-76 Flow Prior Data	DSH Flow	F-76 Crevice Flow Prior Data	DSH Crevice Flow
356-T6 aluminum, uncoated	nd	nd	nd	nd	nd	nd	nd	nd
2024-T3 aluminum, uncoated	nd	nd	nd	nd	nd	nd	nd	nd
7075-T6 aluminum, uncoated	nd	nd	nd	nd	0.003	nd	0.001	0.003
7075-T6 aluminum, anodized, chromic acid	nd	nd	nd	nd	nd	nd	nd	nd
7075-T6 aluminum, anodized, sulfuric acid	nd	nd	nd	nd	0.003	nd	nd	nd
7075-T6 aluminum, chromate conversion coated	0.003	nd	nd	nd	nd	nd	nd	0.003
5052-H32 aluminum, uncoated	nd	0.001	nd	0.001	0.003	nd	nd	nd
651 silicon bronze alloy	0.002	0.002	0.007	0.004	nd	0.001	nd	nd
360 leaded brass alloy	0.013	0.048	0.012	0.007	0.001	0.001	0.001	nd
Copper, unalloyed, Electrolytic Tough Pitch (ETP), uncoated	0.002	nd	0.004	0.007	0.001	nd	0.001	nd
90-10 copper nickel	0.001	0.001	0.002	0.003	nd	nd	nd	nd
1010 carbon steel, uncoated	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, Ion Vapor Deposition (IVD) aluminum (Class 3 thickness 0.0003-0.0008")	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, Ion Vapor Deposition (IVD) aluminum plating (Class 10 thickness 0.0010-0.0015")	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, electroplated tin	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, electroplated silver	nd	0.001	0.001	nd	0.001	0.001	nd	nd
1010 carbon steel, electroplated cadmium	0.136	0.064	0.187	0.059	0.001	0.002	0.002	0.001
1010 carbon steel, electroplated nickel	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, electroplated zinc	0.065	0.023	0.042	0.022	0.022	0.014	0.017	0.013
1010 carbon steel, hot dipped galvanized	0.069	0.014	0.090	0.017	nd	nd	0.002	nd
440 stainless steel, heat treated	nd	nd	0.001	nd	nd	nd	nd	nd
304L stainless steel	nd	nd	nd	nd	nd	nd	nd	nd
IN200 nickel, uncoated	nd	nd	nd	nd	nd	nd	nd	nd
6Al-V4 titanium	nd	nd	nd	nd	nd	nd	nd	nd
60-Sn – 40 Pb solder	nd	0.001	0.001	nd	nd	nd	0.001	nd

³ The mpy for plated and coated coupons was calculated using surface material density.

nd-No Detected Corrosion.

Table 3. Static, Flowing Fuel HD CD-1 and 2 Corrosion Rates, mils per year (mpy) Compared to F-76 Fuel⁴

Coupon Type (1)	F-76 Static- Prior Data	HD CD- 1 Static	HD CD- 2 Static	F-76 Crevice Static Prior Data	HD CD- 1 Crevice Static	HD CD- 2 Crevice Static	F-76 Flow Prior Data	HD CD- 1 Flow	HD CD- 2 Flow	F-76 Crevice Flow Prior Data	HD CD- 1 Crevice Flow	HD CD- 2 Crevice Flow
356-T6 aluminum, uncoated	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2024-T3 aluminum, uncoated	nd	0.001	nd	nd	nd	nd	nd	nd	0.002	nd	nd	nd
7075-T6 aluminum, uncoated	nd	nd	nd	nd	nd	nd	0.003	nd	nd	0.001	nd	nd
7075-T6 aluminum, anodized, chromic acid	nd	nd	nd	nd	nd	nd	nd	nd	0.002	nd	nd	0.001
7075-T6 aluminum, anodized, sulfuric acid	nd	nd	nd	nd	nd	nd	0.003	0.001	0.005	nd	nd	0.007
7075-T6 aluminum, chromate conversion coated	0.003	nd	nd	nd	0.001	nd	nd	0.001	0.002	nd	nd	0.001
5052-H32 aluminum, uncoated	nd	nd	0.004	nd	nd	0.003	0.003	nd	nd	nd	nd	0.002
651 silicon bronze alloy	0.002	0.004	0.005	0.007	0.002	0.007	nd	nd	nd	nd	0.001	0.001
360 leaded brass alloy	0.013	nd	0.004	0.012	0.002	0.008	0.001	nd	0.002	0.001	0.001	nd
Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000, uncoated	0.002	nd	0.012	0.004	0.002	0.008	0.001	nd	0.001	0.001	0.001	nd
90-10 copper nickel	0.001	nd	0.003	0.002	nd	0.005	nd	nd	nd	nd	0.001	0.001
1010 carbon steel, uncoated	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, Ion Vapor Deposition (IVD) aluminum (Class 3 thickness 0.0003-0.0008")	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, Ion Vapor Deposition (IVD) aluminum (Class 10 thickness 0.0010-0.0015")	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, electroplated tin	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1010 carbon steel, electroplated silver	nd	0.001	0.002	0.001	nd	nd	0.001	0.001	0.013	nd	0.001	0.012
1010 carbon steel, electroplated cadmium	0.136	0.116	0.021	0.187	0.059	0.019	0.001	0.001	0.002	0.002	0.003	nd
1010 carbon steel, electroplated nickel	nd	0.001	nd	nd	nd	nd	nd	nd	nd	nd	0.001	nd
1010 carbon steel, electroplated zinc	0.065	0.015	0.014	0.042	0.016	0.015	0.022	0.009	0.016	0.017	0.011	0.015
1010 carbon steel, hot dipped galvanized	0.069	0.003	0.007	0.090	0.001	0.009	nd	nd	nd	0.002	nd	nd
440 stainless steel, heat treated	nd	nd	nd	0.001	0.001	nd	nd	nd	nd	nd	nd	nd
304L stainless steel	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
IN200 nickel, uncoated	nd	nd	nd	nd	nd	0.001	nd	nd	nd	nd	nd	nd
6Al-V4 titanium	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
60-Sn – 40 Pb solder	nd	nd	nd	0.001	nd	0.001	nd	0.001	nd	0.001	nd	nd

⁴ The mpy for plated and coated coupons was calculated using surface material density.**nd**-No Detected Corrosion.

Table 4. Average Weight Change of Metallic Materials Following Exposure to DSH, grams⁵

Coupon Type (1)	F-76 Static Prior Data	DSH Static	F-76 Crevice Static Prior Data	DSH Crevice Static	F-76 Flow Prior Data	DSH Flow	F-76 Crevice Flow Prior Data	DSH Crevice Flow
356-T6 aluminum, uncoated	0.0003	0.0011	0.0001	0.0027	0.0000	0.0004	0.0000	0.0006
2024-T3 aluminum, uncoated	0.0002	0.0001	0.0000	0.0001	0.0000	0.0001	0.0002	0.0000
7075-T6 aluminum, uncoated	0.0000	0.0001	0.0000	0.0003	(0.0002)	0.0000	(0.0001)	(0.0002)
7075-T6 aluminum, anodized, chromic acid	0.0016	0.0004	0.0019	0.0008	0.0010	0.0005	0.0011	0.0002
7075-T6 aluminum, anodized, sulfuric acid	0.0006	0.0011	0.0008	0.0012	(0.0002)	0.0001	0.0004	0.0000
7075-T6 aluminum, chromate conversion coated	(0.0002)	0.0000	0.0002	0.0001	0.0001	0.0000	0.0000	(0.0002)
5052-H32 aluminum, uncoated	0.0003	(0.0001)	0.0002	(0.0001)	(0.0002)	0.0000	0.0002	0.0003
651 silicon bronze alloy	(0.0005)	(0.0004)	(0.0020)	(0.0009)	(0.0001)	(0.0002)	0.0001	0.0001
360 leaded brass alloy	(0.0036)	(0.0127)	(0.0033)	(0.0019)	(0.0002)	(0.0002)	(0.0002)	0.0001
Unalloyed, Electrolytic Tough Pitch (ETP)-CDA 110, UNS C1100, uncoated	(0.0005)	(0.0001)	(0.0009)	(0.0017)	(0.0002)	0.0000	(0.0002)	(0.0001)
90-10 copper nickel	(0.0003)	(0.0003)	(0.0005)	(0.0007)	0.0000	0.0000	0.0001	(0.0001)
1010 carbon steel, uncoated	0.0003	0.0000	0.0000	(0.0001)	0.0001	0.0001	0.0000	0.0001
1010 carbon steel, Ion Vapor Deposition (IVD) aluminum (Class 3 thickness 0.0003"-0.0008")	0.0007	0.0013	0.0007	0.0013	0.0005	0.0007	0.0005	0.0005
1010 carbon steel, Ion Vapor Deposition (IVD) aluminum (Class 10 thickness 0.0010"-0.0015")	0.0015	0.0024	0.0014	0.0028	0.0021	0.0022	0.0020	0.0029
1010 carbon steel, electroplated tin	0.0003	0.0000	0.0005	0.0001	0.0000	0.0000	0.0003	0.0002
1010 carbon steel, electroplated silver	0.0003	(0.0003)	(0.0003)	0.0000	(0.0003)	(0.0003)	0.0000	0.0000
1010 carbon steel, electroplated cadmium	(0.0327)	(0.0154)	(0.0450)	(0.0140)	(0.0003)	(0.0004)	(0.0006)	(0.0002)
1010 carbon steel, electroplated nickel	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
1010 carbon steel, electroplated zinc	(0.0129)	(0.0045)	(0.0083)	(0.0043)	(0.0044)	(0.0028)	(0.0035)	(0.0025)
1010 carbon steel, galvanized, hot dip galvanized	(0.0138)	(0.0028)	(0.0179)	(0.0034)	0.0000	(0.0001)	(0.0004)	0.0000
440 stainless steel, heat treated	0.0005	0.0003	(0.0002)	0.0000	0.0000	0.0001	0.0000	0.0000
304L stainless steel	0.0003	0.0000	(0.0001)	(0.0001)	0.0000	0.0001	0.0002	0.0001
IN200 nickel, uncoated	0.0002	0.0001	(0.0001)	0.0000	0.0000	0.0001	0.0000	0.0001
6Al-V4 titanium	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	(0.0000)	0.0000
60-Sn – 40 Pb solder	0.0000	(0.0002)	(0.0003)	(0.0001)	0.0000	0.0001	(0.0002)	0.0001

⁵ Red values within parentheses represent weight loss in grams.

Table 5. Average Weight Change of Metallic Materials Following Exposure to HDCD-1 and 2, grams⁶

Coupon Type (1)	F-76 Static-Prior Data	HDCD-1 Static	HDCD-2 Static	F-76 Crevice Static Prior Data	HDCD-1 Crevice Static	HDCD-2 Crevice Static	F-76 Flow Prior Data	HDCD-1 Flow	HDCD-2 Flow	F-76 Crevice Flow Prior Data	HDCD-1 Crevice Flow	HDCD-2 Crevice Flow
356-T6 aluminum, uncoated	0.0003	0.0005	0.0005	0.0001	0.0005	0.0003	0.0000	0.0007	0.0002	0.0000	0.0004	0.0002
2024-T3 aluminum, uncoated	0.0002	(0.0001)	(0.0001)	0.0000	0.0001	0.0001	0.0000	0.0002	(0.0001)	0.0002	0.0000	0.0000
7075-T6 aluminum, uncoated	0.0000	0.0007	0.0000	0.0000	0.0004	0.0000	(0.0002)	0.0000	(0.0001)	(0.0001)	0.0000	0.0002
7075-T6 aluminum, anodized, chromic acid	0.0016	0.0003	0.0002	0.0019	0.0007	0.0005	0.0010	0.0005	(0.0001)	0.0011	0.0004	(0.0001)
7075-T6 aluminum, anodized, sulfuric acid	0.0006	0.0011	0.0008	0.0008	0.0007	0.0006	(0.0002)	(0.0001)	(0.0004)	0.0004	0.0000	(0.0006)
7075-T6 aluminum, chromate conversion coated	(0.0002)	0.0000	0.0000	0.0002	(0.0001)	0.0001	0.0001	(0.0001)	(0.0001)	0.0000	0.0000	(0.0001)
5052-H32 aluminum, uncoated	0.0003	0.0002	(0.0003)	0.0002	0.0001	(0.0002)	(0.0002)	0.0000	0.0001	0.0002	0.0000	(0.0001)
651 silicon bronze alloy	(0.0005)	(0.0009)	(0.0012)	(0.0020)	(0.0004)	(0.0016)	(0.0001)	(0.0001)	(0.0001)	0.0001	(0.0002)	(0.0002)
360 leaded brass alloy	(0.0036)	(0.0003)	(0.0012)	(0.0033)	(0.0005)	(0.0020)	(0.0002)	(0.0001)	(0.0005)	(0.0002)	(0.0002)	(0.0001)
Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000, uncoated	(0.0005)	(0.0010)	(0.0028)	(0.0009)	(0.0005)	(0.0021)	(0.0002)	0.0002	(0.0003)	(0.0002)	(0.0003)	0.0001
90-10 copper nickel	(0.0003)	0.0018	(0.0008)	(0.0005)	0.0000	(0.0011)	0.0000	0.0004	(0.0002)	0.0001	(0.0002)	(0.0004)
1010 carbon steel, uncoated	0.0003	0.0001	(0.0002)	0.0000	0.0000	(0.0002)	0.0001	0.0003	(0.0001)	0.0000	(0.0001)	0.0001
1010 carbon steel, IVD aluminum (Class 3 thickness 0.0003-0.0008")	0.0007	0.0015	0.0017	0.0007	0.0010	0.0010	0.0005	0.0009	0.0003	0.0005	0.0011	0.0003
1010 carbon steel, IVD aluminum (Class 10 thickness 0.0010-0.0015")	0.0015	0.0039	0.0021	0.0014	0.0040	0.0014	0.0021	0.0041	0.0013	0.0020	0.0047	0.0011
1010 carbon steel, electroplated tin	0.0003	0.0000	(0.0001)	0.0005	0.0000	0.0000	0.0000	0.0001	(0.0001)	0.0003	0.0000	0.0000
1010 carbon steel, electroplated silver	0.0003	(0.0004)	(0.0004)	(0.0003)	0.0003	(0.0003)	(0.0003)	(0.0004)	(0.0039)	0.0000	(0.0004)	(0.0034)
1010 carbon steel, electroplated cadmium	(0.0327)	(0.0277)	(0.0050)	(0.0450)	(0.0141)	(0.0046)	(0.0003)	(0.0002)	(0.0004)	(0.0006)	(0.0007)	(0.0001)
1010 carbon steel, electroplated nickel	0.0001	(0.0002)	0.0000	0.0000	(0.0001)	(0.0001)	0.0001	0.0001	0.0000	0.0000	(0.0002)	0.0000
1010 carbon steel, electroplated zinc	(0.0129)	(0.0029)	(0.0028)	(0.0083)	(0.0032)	(0.0030)	(0.0044)	(0.0018)	(0.0031)	(0.0035)	(0.0022)	(0.0030)
1010 carbon steel, hot dipped galvanized	(0.0138)	(0.0006)	(0.0014)	(0.0179)	(0.0003)	(0.0018)	0.0000	0.0006	0.0001	(0.0004)	0.0004	0.0000
440 stainless steel, heat treated	0.0005	0.0002	0.0000	(0.0002)	(0.0003)	(0.0001)	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
304L stainless steel	0.0003	(0.0001)	0.0002	(0.0001)	(0.0001)	(0.0002)	0.0000	0.0000	(0.0001)	0.0002	0.0001	(0.0001)
IN200 nickel, uncoated	0.0002	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0003)	0.0000	0.0001	(0.0002)	0.0000	0.0000	(0.0001)
6Al-V4 titanium	0.0001	0.0000	0.0000	0.0000	0.0000	(0.0001)	0.0000	0.0000	0.0000	(0.0000)	0.0000	0.0000
60-Sn – 40 Pb solder	0.0000	0.0000	(0.0001)	(0.0003)	(0.0001)	(0.0003)	0.0000	(0.0002)	(0.0001)	(0.0002)	0.0000	(0.0001)

⁶ Red values within parentheses represent weight loss in grams.

Biological Effects Immersion Testing Corrosion Findings

The coupons were visually evaluated for evidence of biological deposit formation at the water/fuel interface and for evidence of corrosion during the metallurgical analysis. In all cases, biological material by visual inspection was not evident at the fuel/water interfaces for the 5052-H32 aluminum, the 304L stainless steel or the 1010 carbon steel materials (Figures 9 and 10). As expected, the carbon steel portion of the coupon in the seawater and deionized water layers had general surface oxidation (rust) formation with evidence of minor pitting. Corrosion was relatively non-existent for the other two materials except for the presence of shallow pitting on the aluminum coupon halves exposed to the seawater for all the fuels. While the DSH, HDCD-1 and HDCD-2 all showed some degree of aluminum pitting on the water exposed surfaces, the F-76 fuel/seawater samples also had one aluminum coupon with a small shallow pit located deeper in the seawater layer but otherwise appeared unaffected. The aluminum pitting is discussed further in this report under the metallurgical findings section.

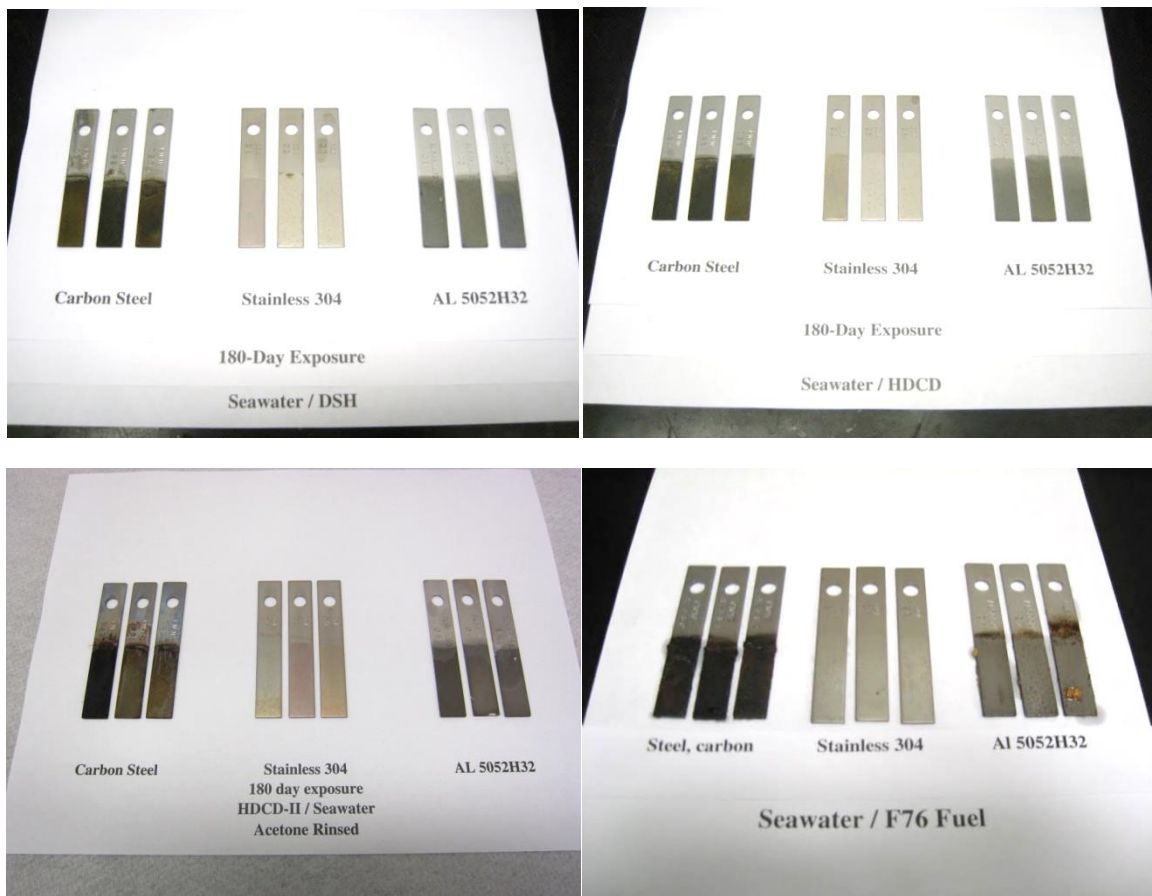


Figure 9. Visual comparison of 1010 carbon steel, 304L stainless steel and 5052-H32 aluminum coupons with the lower half submerged in seawater and the upper half (hole end) in the respective fuel. Visible biological growth was not found at the fuel/water interface for any of the fuel types.

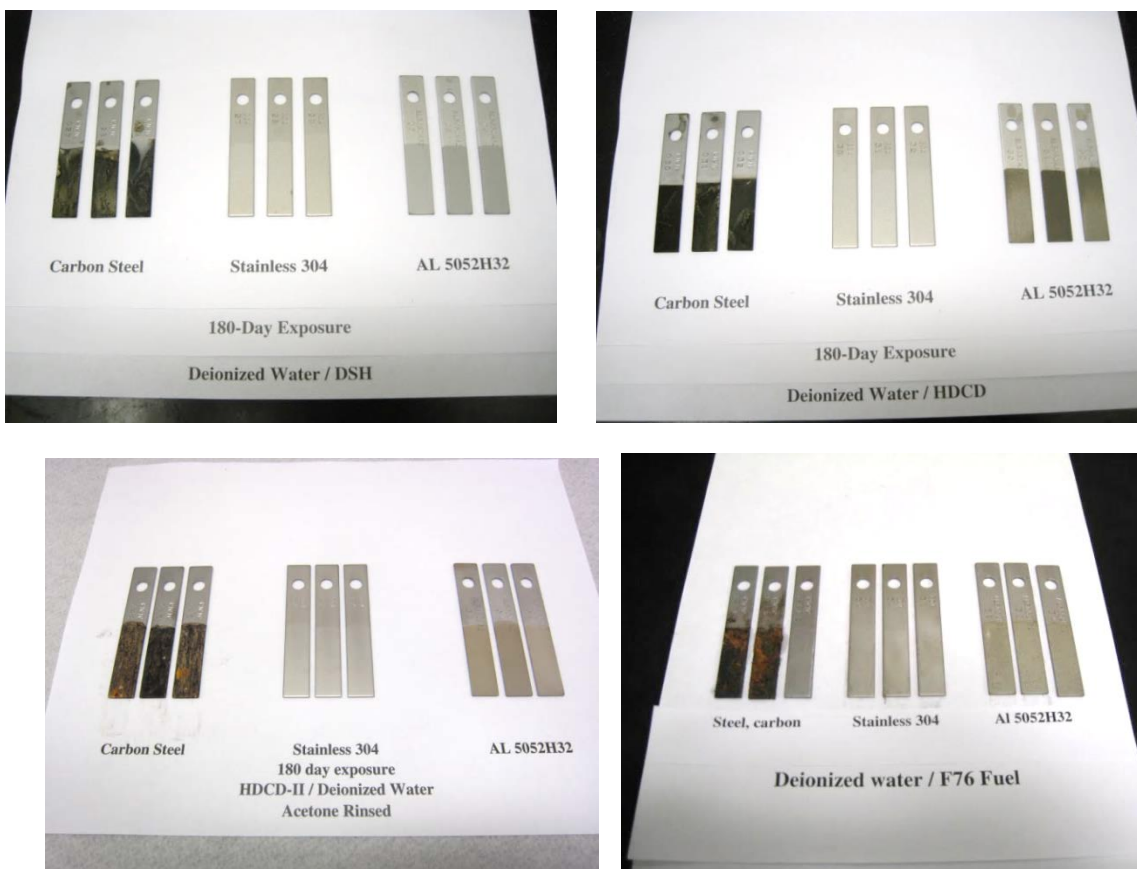


Figure 10. Visual comparison of 1010 carbon steel, 304L stainless steel and 5052-H32 aluminum coupons with the lower half submerged in deionized water and the upper half in the respective fuel. Visible biological growth was not found at the fuel/water interface for any of the fuel types.

For informational purposes, the conductivity and pH of the deionized water and seawater layers was determined from one of the three samples of each metal type, presented in Table 6. For the deionized water layers, the data show that the alternative fuel samples produced an increase in the initial deionized water conductivity with a corresponding increase in pH above the F-76 fuel samples for each metal type. There was no attempt to determine the cause of the conductivity or pH increases. The seawater layer for each metal showed a slight decrease in pH from the raw seawater without much variation between each fuel type and each of the metals tested. The seawater conductivity was relatively constant for the F-76, DSH and HDCD-1 fuels. The HDCD-2 fuel showed an increase in conductivity for all three metals tested.

Table 6. pH of Water Layer from DSH and HDCD-1 and 2 and F-76/Deionized Water/Seawater Immersion Testing⁷

Coupon Material	Fluid Tested	Conductivity (µS/cm)	pH	Temperature ° C
---	Deionized (DI) Water (Note 1)	0.3 (F-76), 1.1 (DSH, HDCD-1/2)	5.36 (F-76, HDCD-1/2)	24 (F-76, DSH, HDCD-1/2)
5052-H32 aluminum	F-76 Fuel/DI Water	56.6	7.01	25
5052-H32 aluminum	DSH/DI Water	63.0	8.17	23
5052-H32 aluminum	HDCD-1/DI Water	58.3	6.86	22
5052-H32 aluminum	HDCD-2/DI Water	56.1	6.09	24
304L stainless steel	F 76/DI Water	31.8	6.20	24
304L stainless steel	DSH/DI Water	65.1	8.74	23
304L stainless steel	HDCD-1/DI Water	45.5	6.04	23
304L stainless steel	HDCD-2/DI Water	46.3	5.91	24
1010 carbon steel	F 76/DI Water	48.9	6.36	24
1010 carbon steel	DSH/DI Water	170	9.67	24
1010 carbon steel	HDCD-1/DI Water	155.5	9.39	25
1010 carbon steel	HDCD-2/DI Water	54.9	5.98	26
---	Seawater, Fresh (Note 1)	47,000 (F-76) 48,700 (DSH, HDCD-1) 48,300 (HDCD-2)	8.05 (F-76) 7.83 (DSH, HDCD-1) 7.76 (HDCD-2)	24 (F-76, DSH, HDCD-1/2)
5052-H32 aluminum	F-76 Fuel/Seawater	48,300	7.70	25
5052-H32 aluminum	DSH/Seawater	48,300	7.53	25
5052-H32 aluminum	HDCD-1/Seawater	48,400	7.63	24
5052-H32 aluminum	HDCD-2/Seawater	49,133	7.66	25
304L stainless steel	F-76 Fuel/Seawater	48,500	7.89	25
304L stainless steel	DSH/Seawater	48,400	7.42	25
304L stainless steel	HDCD-1/Seawater	48,300	7.68	24
304L stainless steel	HDCD-2/Seawater	49,067	7.77	25
1010 carbon steel	F-76 Fuel/Seawater	48,300	7.48	24
1010 carbon steel	DSH/Seawater	48,400	7.56	25
1010 carbon steel	HDCD-1/Seawater	48,500	7.70	25
1010 carbon steel	HDCD-2/Seawater	49,133	7.78	24

⁷ The conductivity and pH values shown for deionized water and seawater reflect each individual test run. The F-76 fuel was analyzed in 2010, the DSH and HDCD-1 were analyzed in 2012/2013 and the HDCD-2 was analyzed in 2013/2014 when the fuel was received.

Acid Number and Dissolved Metals Findings

Samples of the exposed and unexposed fuels were analyzed for total acid number (TAN) per ASTM D974 [8] and dissolved metals included in the metallic materials analyzed per Institute of Petroleum, Method IP-501 [9]. The Table 7 data show a slight increase in the total acid number from the new to the 180 day exposed fuels except for the HDCCD-2 which remained the same. The increase in TAN for the DSH and HDCCD-1 was less than what was determined for F-76. According to MIL-DTL-16884M, the maximum limit for TAN is 0.3 mg KOH/g for new fuel. The DSH, HDCCD-1 and HDCCD-2 fuels fall well below this value. The dissolved metals were determined on new fuel and on fuel samples drawn from the flowing fuel test which contained all of the metallic coupon types. While MIL-DTL-16884M does not require dissolved metals testing, these metals were evaluated pre- and post-exposure to determine if any substantial increase in concentration occurred post exposure that would be reflective of calculated corrosion rates. The analysis showed that the new DSH fuel contained 2 parts per million (ppm) of iron and nickel with 1 ppm of aluminum and silicon. The used DSH only contained 1 ppm nickel. The new HDCCD-1 fuel contained 1 ppm of iron, nickel, aluminum and silicon and the used HDCCD-1 contained only 1 ppm nickel. The new HDCCD-2 fuel contained none of the metals analyzed for and the used fuel contained only 1 ppm silicon. The used flow test fuel containing all of the coupon types showed no appreciable increase in dissolved metals after exposure which is indicative of the very low corrosion rates determined for these fuels in the overall corrosion studies and validates the lack of corrosion found in the metallurgical findings presented below. The dissolved metals results should only be viewed as a gross comparison because the fuel to metallic materials volume ratio for a typical fuel system could not be accounted for with this test set-up, which would be required to determine more accurate values.

Metallurgical Findings

The full report of the metallurgical findings [10] can be found in Appendix F. Below provides a summary of the findings for each test condition.

Initial Examination of Corrosion Coupons

A visual and low magnification examination using a stereomicroscope with magnifications up to 50X was conducted on all of the coupons in the as-received condition. In addition, transverse metallographic cross sections were taken to further document the surface condition of the coupons prior to any tests being conducted.

Static Immersion Findings

Examination of all of the coupons exposed to the DSH, HDCCD-1 and HDCCD-2 fuels displayed similar results when compared with the previously evaluated F-76 fuel. There was no noticeable metallurgical change in the base materials, i.e. there was no evidence of corrosive attack of the base metals or indications of attack on coupon surfaces at crevice sites. Macroscopic examination disclosed no appreciable change in appearance from the initial examination with the exception of the 360 leaded brass coupons and the 1010 carbon steel coupons that were coated with electroplated zinc.

For the 360 leaded brass alloy, the DSH fuel caused the coupons to darken, having a gray-blue appearance, Figure 8. Surface analysis by Scanning Electron Microscopy (SEM)/Energy Dispersive Spectroscopy (EDS) provided semi-quantitative chemical composition as follows:

Major elements (wt. % >10%)-copper, zinc and lead.

Minor elements (wt. % of 1-10%)-lead, carbon, oxygen and silicon.

The copper, zinc and lead are all expected since they are part of the base chemistry of UNS C36000. The carbon, oxygen and silicon constituents would appear to be a component of the dark surface film. SEM and microscopic evaluation disclosed no evidence of any corrosive attack. A rerun of the leaded brass alloy in DSH again showed the blue color on the coupon surfaces; however, it was lighter in color, Figure 8. SEM/EDS analysis of the coupon surface provided the same results determined in the initial exposure.

For the 1010 carbon steel coupons that had the electroplated zinc exposed to F-76 fuel, there was discernible general pitting that was observed macroscopically with a stereomicroscope, with further analysis by SEM, Figure 11, and microscopically with an optical microscope to determine cross section pit depth. The depth of the pits was approximately 0.0009-in for the F-76 fuel; however, the pits did not penetrate the base metal. No pitting was observed on any of these coupons that were subjected to the DSH, HDCD-1 and HDCD-2 fuels.

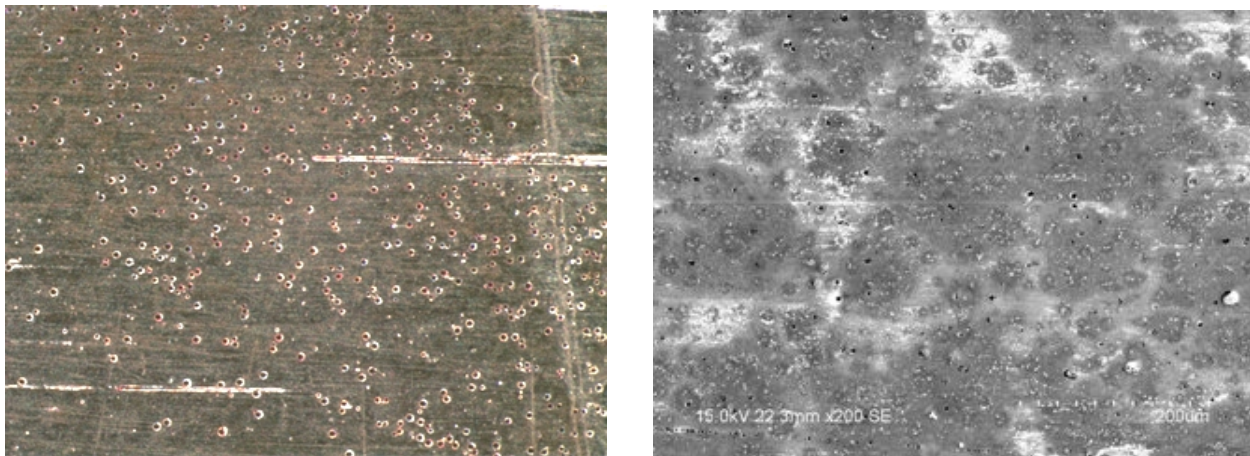


Figure 11. Macrophotograph (left, Mag.: 50X) and SEM photograph (right, Mag.: 200X) of carbon steel with electroplated zinc, static immersion, F-76 fuel. Fine pits were observed that did not penetrate to the base metal.

Table 7. Total Acid Number and Dissolved Metals-New and Used F-76 and DSH/HDCD-1 and 2 Flowing Fuels⁸

Sample	Total Acid Number, (mg KOH/gm)	Iron (ppm)	Copper (ppm)	Aluminum (ppm)	Nickel (ppm)	Zinc (ppm)	Lead (ppm)	Chromium (ppm)	Silicon (ppm)
F-76 New	0.26	nd	nd	0.14	nd	nd	nd	nd	1.03
F-76,Used Flowing	0.37	nd	nd	0.19	nd	nd	nd	nd	1.5
DSH Fuel, New	0.05	2	nd	1	2	nd	nd	nd	1
DSH Fuel, Used Flowing	0.10	nd	nd	nd	1	nd	nd	nd	nd
HDCD-1 Fuel, New	0.05	1	nd	1	1	nd	nd	nd	1
HDCD-1 Fuel, Used Flowing	0.11	nd	nd	nd	1	nd	nd	nd	nd
HDCD-2 Fuel, New	0.01	nd	nd	nd	nd	nd	nd	nd	nd
HDCD-2 Fuel, Used Flowing	0.01	nd	nd	nd	nd	nd	nd	nd	1

⁸ nd-Not Detected

Static Immersion Crevice Corrosion Findings

Evaluation of the crevice corrosion assemblies displayed similar results for the three fuels in comparison to the F-76 fuel. There was no evidence of any initiated crevice sites. For the four copper alloys; Cu-Ni 90/10 CDA 706, leaded brass CDA 360, silicon bronze alloy CDA 651 and electrolytic tough pitch CDA 110, the coupons showed evidence of discernible staining where the crevice washers and flat washers were in contact with the coupon surfaces, an example of which is shown in Figure 12.



Figure 12. Macrophotograph of Cu-Ni alloy CDA 706, after immersion testing in the DSH fuel as a crevice corrosion assembly. Note the stains that developed at the crevice washer (left) and flat washer (right) sites. Mag.: 10X

Metallographic cross sections taken through the stains revealed no indication of any attack. Significant stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76 and HD CD-2), 7075-T6 (F-76 and HD CD-1) and 5052-H32 (F-76),
- b) carbon steel coupons- plain (DSH), electroplated with silver (F-76) and electroplated with cadmium (F-76, DSH and HD CD-2)

In each case, higher magnification examination showed no crevice sites or indication of attack.

Flowing Test Findings

Examination of all of the coupons exposed to the DSH, HD CD-1 and HD CD-2, compared to the F-76 fuel, also displayed similar results to the static immersion testing. Once again, the majority of the coupons had no noticeable change with the exception of the carbon steel coupons that had the electroplated zinc exposed to the F-76 fuel where there was discernable pitting observed macroscopically, with SEM analysis and microscopically. The maximum depths of the pits were approximately 0.0005-in.; however, the pits did not penetrate the base metal.

Testing of the crevice corrosion assemblies, also exhibited similar results for all three fuels as the static immersion testing. The four copper alloy coupons again showed evidence of discernible staining at the washer locations. Further examination confirmed no evidence of any initiated crevice sites. Metallographic cross sections taken through the stains revealed no indication of any attack. Obvious stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76), 7075-T6 (F-76, HDCD-1 and HDCD-2) and 5052-H32 (F-76),
- b) carbon steel coupons- plain (F-76, DSH and HDCD-1), electroplated with silver (F-76, DSH, HDCD-1 and HDCD-2), electroplated with IVD Aluminum Class 3 and Class 10 (DSH and HDCD-1)

In each case, closer stereoscopic and microscopic examination showed no crevice sites or indication of attack.

Immersion Testing, Biological Effects in Fuel/Seawater and Fuel/Deionized Water

For this evaluation, carbon steel (C10100), stainless steel (S30403) and aluminum (A95052) were suspended in sealed glass jars (one coupon per jar) containing an equal volume of fuel/seawater or fuel/deionized water. One half of each coupon was in the fuel layer and the other half in the water layer.

Seawater Exposure. For the fuel/seawater exposures, on the 5052-H32 aluminum coupons, a pit was observed on one of the three coupons tested with the DSH fuel. The pit was present on the seawater side and extended to a depth of approximately 0.025-in. For the HDCD-1 fuel/seawater testing on the 5052-H32 aluminum coupons, pits were observed on two of the three tested coupons on the seawater immersed side. The pit depth was determined to be approximately 0.005-in.

For the HDCD-2 fuel/seawater testing on the 5052-H32 aluminum coupons, pits were observed on all three coupons. Two of the coupons showed pits present on the seawater side, with one of the pits extending to a depth of 0.030-in. These pits were located on the short end/side of the coupon immersed in the seawater. The pit on the second coupon appeared to be superficial. The third coupon had a pit at the fuel/seawater interface which extended inward a total of 0.032-in when measured from the edge of the coupon. The pit width (0.070-in) was widest at the fuel/seawater interface at the edge of the coupon. In addition, the pit penetrated the entire coupon cross sectional thickness (0.064-in).

For the prior F-76 fuel/seawater testing on the aluminum coupons, an individual pit was also observed on one of the three tested coupons. The pit was similarly on the seawater immersed side. The pit depth was determined to be approximately 0.012-in.

For the 304L stainless steel coupons, staining was observed on the seawater side of the samples, however, there was no evidence of any attack on the DSH, HDCD-1, HDCD-2 or F-76 fuel coupons.

Examination of the carbon steel coupons revealed evidence of oxidation as well as general overall corrosion on the seawater side for all four fuels – DSH, HDCD-1, HDCD-2 and the F-76. Pitting was observed with maximum depths of 0.0025-in measured for the DSH fuel sample, 0.003-in for the HDCD-1 fuel sample, 0.002-in for the HDCD-2 fuel and 0.004-in for the F-76 fuel.

Deionized Water Exposure. For the fuel/deionized water testing on the 5052-H32 aluminum coupons, staining was observed on the water side of the samples for the DSH, HDCD-1 and HDCD-2 as well as the previously tested F-76 fuel. Stereoscopic and metallographic examination revealed there was no evidence of any corrosive attack. For the 304L stainless steel coupons, slight staining was also exhibited on the deionized water side of the samples. There was no evidence of any attack for any of the fuels. Examination of the carbon steel coupons disclosed evidence of oxidation (rusting) as well as corrosion on the deionized water side for all four fuels which was not unexpected. Maximum pitting depth for the DSH fuel samples extended to 0.011-in., for the HDCD-1 fuel to 0.0015-in and for the HDCD-2 fuel to 0.013-in; interestingly the greatest pit depths were observed on the fuel side at the fuel water interface of the DSH and HDCD-1 fuels. Maximum pitting depths of 0.0055-in measured for the previously tested F-76 fuel sample.

A summary of the results of the Immersion Testing, biological effects in fuel/seawater and fuel/deionized water are presented in Tables 8 and 9.

Table 8. Results of the Fuel/Seawater Testing

Fuel/Seawater	5052H32 Aluminum	304L Stainless Steel	1010 Carbon Steel
DSH	Pits present on 1/3 coupons, Max Depth: 0.025-in	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons- Max. Depth: 0.0025-in.
HDCD-1	Pits present on 2/3 coupons, Max Depth: 0.005-in	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.003-in.
HDCD-2	Pits present on 3/3 coupons, 1: Superficial 1, Depth:0.030-in 1, Width : 0.070-in, Inward: 0.032-in and Through Coupon Cross Section: 0.064-in	Stains	Oxidation/Corrosion and Pits present on 1/3 coupons - Max. Depth: 0.002-in.
F-76	Pits present on 1/3 coupons, Max Depth: 0.012-in	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.004-in.

Table 9. Results of the Fuel/Deionized Water Testing

Fuel/Deionized Water	5052H32 Aluminum	304L Stainless Steel	1010 Carbon Steel
DSH	Stains	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.011-in.
HDCD-1	Stains	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.0015-in.
HDCD-2	Stains	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.013-in.
F-76	Stains	Stains	Oxidation/Corrosion and Pits present on 2/3 coupons - Max. Depth: 0.0055-in. One of three coupons did not show any oxidation. SEM confirmed 1010 steel composition.

DISCUSSION

Overall Corrosion

This evaluation was performed to determine if any detrimental corrosion of metallic materials commonly found in U.S. Navy and Coast Guard ship fuel systems occurred when exposed to alternative fuels consisting of 1) 50/50 blend of Direct Sugar to Hydrocarbon-76 (DSH-76) and F-76 petroleum based fuel and 2) a 20/80 ratio of Hydro-treated Depolymerized Cellulosic Diesel (HD CD) and F-76 fuel. It was also necessary to determine if the alternative fuel resulted in any more corrosion or metallurgical differences than determined previously for the currently used F-76 fuel.

From a corrosion perspective, this study showed that the majority of materials were not affected by the fuel types tested, i.e. no evidence of general or crevice corrosion was detected. The most significant corrosion was found on the zinc (electroplated and galvanized) and the electroplated cadmium coupons that had the plating applied to a 1010 carbon steel substrate for all fuel types, whether static or flowing conditions. In the flowing HD CD-2, the electroplated silver on 1010 carbon steel also showed more corrosion compared to F-76 (0.01 mpy in HD CD-2, 0.001 mpy in F-76). Corrosion rate data for the carbon steel coupons with the various plating materials is provided for guidance only because these coupons were not composed entirely of the plating material. Where plating corrosion did occur, it was limited to the plating only because there was no detectable corrosion of the 1010 carbon steel coupons in any of the fuels. The electroplated zinc corrosion included surface pitting whereas the cadmium plating showed no evidence of pitting.

Crevice corrosion was not evident for any of the metallic materials. The only other notable finding was the weight gain determined for the aluminum based materials and 304L stainless steel associated with all fuel types. This may be attributed to oxidation of the surface or some other phenomenon that was not investigated as part of this study. This weight increase was also documented for 304L stainless steel in the prior NAVSSES 1985 F-76 fuel corrosion study. Aluminum materials were not evaluated in the 1985 study. It was also noted during this current evaluation that as the testing progressed, the fuels darkened somewhat compared to the new unused fuel. Darkening of the F-76 fuel was also noted in the NAVSSES 1985 report. Any detected corrosion rates for this study had a magnitude of 10^{-3} mpy for both fuel types which were consistent with the NAVSSES 1985 findings for any of the similar materials tested.

The limited biological immersion testing did not produce any visually observed biological film at the interface between the fuels and the water (deionized or seawater) or anywhere else on the coupon surface. The carbon steel half of the coupons exposed to the water layers oxidized (rust) with pitting, as expected. The 304L stainless steel was unaffected, except for some surface staining. The 5052-H32 aluminum showed some degree of random pit formation on the ends of the coupons exposed to the seawater for each fuel type.

Metallurgical Corrosion

The static immersion and flow testing conducted on the alternative fuels DSH, HD CD-1, and HD CD-2, when compared with the previously tested F-76 fuel, indicate similar results for all of the metals when evaluated macroscopically, microscopically and metallurgically. There was no observed metallurgical change in the metallic materials, i.e. there was no evidence of corrosive attack of the base metals or indications of attack on coupon surfaces at crevice sites.

In the static immersion tests, the majority of the coupons displayed no appreciable change with the exception of the 360 leaded brass coupons and 1010 carbon steel coupons coated with electroplated zinc. While there was some discoloration of the leaded brass coupons in all four fuels, there was no evidence of any corrosive attack. The DSH fuel formed a thick black tacky coating on the leaded brass coupons, the surfaces showing a gray-blue colored appearance when the film was removed by cleaning post exposure. Retesting of three additional coupons in the DSH fuel again resulted in the coupons darkening considerably; however, the tacky coating did not form. Coupon cleaning resulted in the surfaces having a lighter blue appearance. SEM and metallographic evaluation disclosed no evidence of any corrosive attack. The presence of the bluish coloration is thought to be due to an oxidative process and is currently being investigated by NAVAIR Code 4.4.5. For the carbon steel coupons with the electroplated zinc, there was general pitting that was observed macroscopically, with SEM analysis, as well as microscopically in F-76 fuel samples. The depth of the pits was approximately 0.0009-in for the F-76 fuel; however, the pits did not penetrate the base metal. Only the plating was attacked. No pitting was observed in the carbon steel coupons with the electroplated zinc that were exposed to the DSH, HD CD-1 and HD CD-2 fuels.

Static immersion testing of the crevice corrosion assemblies also exhibited similar results for the DSH, HD CD-1 and HD CD-2 fuels when compared with the F-76 fuel. While some of the coupons showed evidence of staining at the washer locations, particularly the four copper alloy coupons in all of the fuels, there was no evidence of any initiated crevice sites. Metallographic cross sections taken through the stains confirmed no indication of any attack. Significant stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76 and HD CD-2), 7075-T6 (F-76 and HD CD-1) and 5052-H32 (F-76),
- b) carbon steel coupons- plain (DSH), electroplated with silver (F-76) and electroplated with cadmium (F-76, DSH and HD CD-2)

In each case, higher magnification examination, coupled with the metallographic evaluation, showed no crevice sites or indication of attack.

For the flowing fuel tests, examination of all of the coupons exposed to alternative fuels DSH, HD CD-1 and HD CD-2, as well as the F-76 fuel also displayed similar results. The majority of the coupons had no noticeable change with the exception of the carbon steel coupons that were finished with the electroplated zinc. Pitting was observed macroscopically, with SEM analysis and microscopically for the coupons exposed to the F-76 fuel with the maximum pit depth measured to be approximately 0.0005-in; however, the pitting again did not penetrate the

base metal. No pitting was observed in the carbon steel coupons with the electroplated zinc that were exposed to the DSH, HDCD-1 and HDCD-2 fuels.

Testing of the crevice corrosion assemblies, also exhibited similar results for all four fuels. The four copper alloy coupons showed evidence of staining at the washer locations. Obvious stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76), 7075-T6 (F-76, HDCD-1 and HDCD-2) and 5052-H32 (F-76),
- b) carbon steel coupons- plain (F-76, DSH and HDCD-1), electroplated with silver (F-76, DSH, HDCD-1 and HDCD-2), electroplated with IVD Aluminum Class 3 and Class 10 (DSH and HDCD-1)

Visual, low and high magnification examination revealed no evidence of any crevice initiation. Metallographic cross sections taken through the stains confirmed no indication of attack.

Evaluation of the biological effects, in mixtures of each of the fuels and seawater as well as each fuel and deionized water, were also conducted via immersion testing and compared with the prior F-76 fuel results. Here, coupons of 5052-H32 aluminum, 304L stainless steel, and 1010 carbon steel were tested. For the fuel/seawater testing, on the 5052-H32 aluminum samples, pitting was observed on one of the three coupons in the DSH fuel. The pit was present on the seawater side and extended to a depth of approximately 0.025-in. For the HDCD-1 fuel/seawater testing on the 5052-H32 aluminum samples, pits were observed on two of the three tested coupons on the seawater immersed side. The maximum pit depth was determined to be approximately 0.005-in. The HDCD-2 fuel/seawater testing disclosed some degree of pitting on all three of the 5052-H32 aluminum samples. Two of the three coupons displayed pits on the seawater immersed side, one of which was located on the end of the coupon that had a depth of 0.030-in. The second coupon had one pit that was characterized to be superficial. The third coupon had a pit at the fuel/seawater interface which extended inward 0.032-in when measured from the edge of the coupon. The pit width (0.070-in) was largest at the fuel/seawater interface at the edge of the coupon. In addition, the pit penetrated the entire coupon cross sectional thickness (0.064-in). For the F-76 fuel/seawater testing on the 5052-H32 aluminum samples, an individual pit was observed on one of the three tested coupons. The pit was located on the seawater immersed side with the maximum pit depth determined to be approximately 0.012-in. The 304L stainless steel coupons tested in the fuel/seawater mixtures only displayed staining from each of the four fuels; there was no evidence of corrosive attack. For the carbon steel coupons, there was general attack in the seawater immersed side as well as pitting observed near the fuel/seawater interface. Maximum pit depths were measured for each of the fuels with the results as follows: DSH (0.0025-in.), HDCD-1 (0.003-in.), HDCD-2 (0.002-in.) and F-76 (0.004-in.).

Some staining was noted on the 5052-H32 aluminum coupons that were subjected to the fuel/deionized water mixture: all four fuels caused some discoloration but no evidence of any attack. Slight staining was also observed on the deionized water side of the 304L stainless steel coupons, with no indication of attack in any of the fuels – DSH, HDCD-1, HDCD-2 and F-76. Examination of the carbon steel coupons revealed evidence of oxidation and corrosion on the deionized water side of the DSH, HDCD-1, HDCD-2 and the F-76 fuel samples. Pitting also was

observed in close proximity to the fuel/deionized water interface, with maximum depths of 0.011-in measured for the DSH fuel and 0.0015-in for the HDCD-1. For the HDCD-2 fuel coupons, the maximum pit depth was determined to be 0.013-in, which was in the deionized water immersed side. Lastly, a maximum pit depth of 0.0055-in was measured for the previously tested F-76 fuel/deionized water coupons, which was close to the fuel/deionized water interface.

CONCLUSIONS/RECOMMENDATIONS

Per the test protocol [2], acceptance criteria for this evaluation were that the metallic materials immersed in the alternative fuel blend would be no worse than the F-76 fuel from a corrosion perspective. Based on the results of this evaluation, it is concluded that there will be no negative effects from using the DSH, the HDCD-1 or the HDCD-2 alternative fuel blends as a replacement for the petroleum based F-76 fuel. Any determined corrosion rate for any of the materials was extremely low to non-existent for the DSH, HDCD-1 and HDCD-2 fuels. While the electroplated zinc and cadmium on 1010 carbon steel coupons did exhibit some minor corrosion, the effects were similar to F-76 for these fuels, except the alternative fuels had lower corrosion rates. One issue still under investigation by NAVAIR Code 4.4.5 Fuel and Fuel Systems group is the cause of the formation of the black tacky film on the leaded brass coupons exposed to DSH and the gray-blue surface under the film. While the tacky film did not form on a rerun of the test, the coupons did turn dark brown and a lighter blue surface color was present when the brown film was removed with coupon cleaning post exposure. An assessment from the fuel system in-service engineering agent (ISEA) should be conducted to determine if a developed surface film on the leaded brass will be detrimental at locations used in the fuel system. The highest corrosion rate for any of the materials/fuel combinations was associated with the electroplated cadmium on 1010 carbon steel coupons; 0.136 mpy in static F-76, 0.064 mpy in static DSH, 0.116 mpy in static HDCD-1 and 0.021 mpy in static HDCD-2. Flowing conditions showed lower corrosion rates for the electroplated cadmium and zinc on the 1010 carbon steel coupons.

The metallurgical analysis conducted on the DSH, HDCD-1 and HDCD-2 alternative fuels, exhibited similar results in the static immersion and flow testing when compared with the previously evaluated F-76 fuel. There was no observed metallurgical change in the metallic materials, i.e. there was no evidence of corrosive attack of the base metals or indications of attack on coupon surfaces at crevice sites. The previously evaluated F-76 fuel exhibited indications of general pitting on the carbon steel coupons with electroplated zinc; however, the pitting was only evident in the plating and not the base metal. In this study, the DSH, HDCD-1, and HDCD-2 fuels did not exhibit any evidence of pitting of the zinc plating. From a metallurgical perspective, these fuels pose a risk no worse than the currently used F-76 fuel. As discussed at the Alternative Fuels program review [11], based on the metallic materials corrosion findings reported from this study and previously reported results [1], consideration should be given to testing only those metallic materials that had reportable corrosion in future alternative fuels with similar chemistries as those evaluated to this point.

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- [2] Alion Science & Technology/NSWCCD Test Protocol-U.S. Navy Alternative Fuels Program Materials Immersion Test Protocol, Revision 2 of 06 Aug 2010
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- [9] Institute of Petroleum, Method IP-501-Determination of Aluminum, Silicon, Vanadium, Nickel, Iron, Sodium, Calcium, Zinc and Phosphorous in Residual Fuel Oil by Ashing, Fusion and Inductively Coupled Plasma Emission Spectrometry
- [10] NSWCCD Memorandum 10310, Ser 612/14-262 of 08 Sept 2014
- [11] Alternative Fuels Program Review at NSWCCD of 30 October 2014

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APPENDIX A



U.S. Navy Alternative Fuels Program Materials Immersion Test Protocol



Contract Number:

Approvals	Activity	Date
Author: B. J. Rampolla	Alion Science & Technology	8/6/10
SME:		
S. Murray – Corrosion	NSWCCD 614	
S. Lutgen – Non-Metallics	NSWCCD 617	
E. Hakun - Metals	NSWCCD 615	
TWH:		
J. Blackburn – Ferrous Metals	NAVSEA 05	
C. Wong – Non-Ferrous Metals	NAVSEA 05	
M. Lattner – Non-Metallic Materials	NAVSEA 05	
M. Ingle – Corrosion	NAVSEA 05	
Navy POC: R. Kamin	CNO N430F	

IMMERSION TESTING OF METALLIC AND NON- METALLIC MATERIALS

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REVISION HISTORY

<u>DATE</u>	<u>REVISION</u>	<u>DESCRIPTION</u>
11/24/09	N/A	INITIAL ISSUE
04/16/10	Rev 1	Updated Immersion Tests, Table 1 Materials, Appendix B, Typo Fixes
8/6/10	Rev. 2	Added reference to algae fuels in Section 2 Added App. C covering metallic material specifications Added App. D covering metallic material plating requirements Added App. E listing additional metallic materials being considering for addition to the test matrix

U.S. Navy Alternate Fuels Program “Immersion Testing of Metallic and Non-Metallic Materials”

1 Introduction

Potential alternative (non-petroleum based) fuels must meet diesel F-76 specification requirements per MIL-F-16884 (current Rev. L, 10/23/06) **PLUS** additional fitness-for-purpose (FFP) properties. The overall alternative fuel testing protocol will also include component-rig bench tests, engine tests, platform trials, and field trials.

Under the Materials FFP evaluation, samples of representative metallic and non-metallic materials exposed to the liquid fuel (i.e., fuel-wetted parts) in shipboard systems (i.e., fuel transfer piping and components, diesel engines, gas turbines, boilers) will be subject to immersion in fuel samples to determine fuel effects compared to baseline F-76 exposure. Immersion testing shall be performed in accordance with this protocol.

Notes

- Prior to initiation of any material testing in a proposed alternative fuel, the fuel suppliers will be requested to provide their own material test data, if any, and the Navy will conduct literature searches for additional material test data in the proposed fuels. The intent will be to eliminate unnecessary material tests if acceptable data already exist.
- To further eliminate unnecessary material tests, the FFP fuel chemistry related tests will be performed prior to materials testing and the results will be combined with those from the F-76 specification tests to determine if the fuel key chemical constituents or characteristics justify eliminating some of the material tests (and possibly some of the component rig performance tests). That is, review of the fuel properties affecting material degradation may show sufficient similarity to F-76, which would justify reducing or eliminating some of the materials tests.
- The initial materials for testing are considered representative of larger materials ‘families’, and the initial testing is considered ‘screening’ because additional testing of other materials from certain ‘families’ may be necessary based on the initial results.
- The proposed static, immersion test duration will be 180 days (2,160 hrs) at a constant temperature of 120 degrees F which is the maximum fuel use temperature aboard ship. Previous (1987) NAVSSES tests (see [Appendix A](#)) in F-76 fuel were conducted for longer times (5472 hrs static, 700 hrs dynamic), but at lower (room) temperature. The reduced exposure time is because the alternate fuel must meet the diesel F-76 specification requirements per MIL-DTL-16884L. If the alternate fuel chemistry is the same as F-76 diesel fuel, and these materials passed the 1987 testing, a shorter exposure time is justified. For comparison purposes, the metallic and non-metallic samples will be immersed in both the alternate fuel and diesel F-76 for comparison purposes during the evaluation phase.

- The FFP evaluations will also include material exposure to combusted fuel via laboratory burner rig tests. This testing is addressed separately.
- In addition, component-rig bench tests, as noted above, are being evaluated to address such issues as fuel combustion effects on actual components including gas turbine combustors and diesel cylinders/liners, and fuel erosion effects on fuel nozzles and injectors. This testing is addressed separately.
- Primary supporting references for development of this protocol are:
 - [1] 6/10/08 draft revision of ASTM D4054, Standard Practice for Evaluating the Compatibility of Additives with Aviation-Turbine Fuels and Aircraft Fuel System Materials (current revision 1993, reapproved 2003)
 - [2] MIL-HDBK-510-1, 11/13/08, Aerospace Fuels Certification
 - [3] F-FA-FP-87-00629, 8/27/87, Alternate Fuels Program Static and Modified Loop Testing of Metallic and Nonmetallic Samples, Report PM-507
 - [4] Alion Report 490-07-053, 12/31/07, Alternative Fuel Certification and Approval Protocol Development for Fleet Use, Final Report
 - [5] Material Compatibility of F-T Fuels, 8/17/06, A. Fletcher, Materials & Manufacturing Directorate, Air Force Research Laboratory
 - [6] Auxiliary Fuel System Materials, NSWCCD, July 2008.
 - [7] NAVSEA letters 9221 Ser 922/026, 027, 029 to Alstom-Powere, Foster-Wheeler, Babcock & Wilcox, Boiler Fuel Wetted Parts, Sept 2007.

2 Anticipated Alternative Fuels

The alternative fuels will be refined, 2nd generation, liquid, hydrocarbon from non-petroleum sources. The first fuel to be tested will be algae derived.

Notes

- First generation biodiesel fuels (fuels based on ester and produced from bio-oil and an alcohol) are considered unacceptable for Navy applications, so will not be included in the alternative fuel testing program.
- Gasoline and gasoline substitutes such as ethanol are also not included.

3 Alternative Fuels Materials Issues

3.1 Metallic

The only reported problems have been in *ethanol* fuels for gasoline powered engines (not part of this program) because of their corrosive nature. See Appendix A for results of previous (1987) NAVSSES testing to establish baseline in F-76 fuel. In summary:

- Tested materials: ductile iron, 1010 carbon steel, 4130 alloy steel, 304L stainless, copper-silicon alloy 655, leaded brass alloy 353, phosphor bronze alloy 510.
- 5472 hrs static immersion and 700 hrs dynamic (in flowing fuel) – room temperature.
- Maximum corrosion rate under dynamic conditions of 5×10^{-2} mpy (mils per year) for copper silicon alloy 655 and leaded brass alloy 353

From the reference [5] Air Force report for testing in Fischer-Tropsch neat and at 50/50 blend with JP-8, no issues with corrosion of metallic materials based on light optical and microstructure evaluations. Evaluation of pitting per ASTM G46 is still in progress at the time of this report.

Note

- The primary conclusion from the above information is that diesel fuel is not an aggressive environment for metallic materials. As such, immersion testing of a limited number of representative materials is justified, as discussed in Section 4.1.

3.2 Non-metallic

Primary problems have been reduced swelling and leaking of Buna-N seals in ultra-low-sulfur (ULS) diesel as result of removal of aromatic compounds from processing to achieve the low sulfur levels, and embrittlement and damage from various fuel compounds. See [Appendix A](#) for results of previous NSWCCD testing to establish baseline in F-76 fuel, which showed greater degradation of Buna-N vs Viton, and asbestos vs packing. Results from the reference [5] Air Force report for testing in Fischer-Tropsch neat and at 50/50 blend with JP-8 are summarized as follows:

- Decreased nitrile swelling vs. JP-8
- Reduced lap shear strength of epoxy adhesive (still OK for non-structural use)
- Detrimental effect on polyethylene wire insulation

4 Proposed Materials Test Program

4.1 Metallic Materials

Table 1 lists the recommended metallic materials for immersion testing based on the detailed justifications provided in Table 1-1, which shows the complete list of fuel wetted gas turbine, fuel transfer system, and boiler materials as provided by NSWC subject matter experts (SME), the materials previously tested by NAVSSES (see 3.1 and [Appendix A](#)), and provides justifications for the Table 1 reduced set of representative materials for testing.

Table 1-1 does not specifically list diesel engine fuel wetted materials, but we believe at this time that the diesel materials are indeed covered based on the following interactions with diesel OEM's:

- In July 07 the NSW diesel engine SME's issued requests to the primary diesel engine OEM's for lists of fuel wetted materials for their engines. The general response was that the specific materials were considered proprietary, but they would review our proposed lists and suggest additional materials as needed.
- In October 2007 NAVAIR/Alion sponsored a 'Navy Diesel Engine Fuel Summit' at which the draft, overall alternative fuel testing protocol was discussed. Diesel engine OEM attendees were: Caterpillar, Cummins, MTU/DDC, Fairbanks Morse/ALCO/Colt/Pielstick, Volvo Penta, IF/FDGM, EMD, Yanmar.
- From April 09 through June 09, NAVAIR/Alion also presented 'WEBEX' sessions to diesel engine OEM's Caterpillar, Cummins, and Fairbanks Morse (and gas turbine OEM's Rolls Royce, General Electric, Hamilton Sundstrand, and Vericor). The 'WEBEX' slides have included the same list of fuel wetted materials as showing in Table 1.
- The net result from the above contacts is that only Cummins thus far has identified the following specific metallic materials they feel should be included: tool steels (no specific grades), and alloy steels 8620, 9310, 4140, 4340, HSLA, and nitriding grades. As noted in Table 1-1, we feel these steels will be adequately represented by the plain carbon 1010 steel.

For information, [Table 1-2](#) lists the ASTM D4054/MIL-HDBK-510 metallic materials (which are the same), and [Table 1-3](#) compares the ASTM/MIL and Navy material lists.

Table 1 – Representative Metallic Materials for Navy Immersion Tests

GENERIC DESIGNATION	SPECIFIC MATERIAL See Appendix C for Base Metal Specifications See Appendix D for Plating Requirements See Appendix E for Additional Materials Being Considered	SOAK TEMPERATURE PER SHIPBOARD MAXIMUM USE TEMPERATURE All 180 day soak time See testing requirements below
Aluminum & Alloys	• 356-T6, uncoated • 2024-T3, uncoated • 7075-T6, uncoated • 7075-T6, anodized (chromic acid) • 7075-T6, anodized (sulfuric acid) • 7075-T6, chromate conversion coated • 5052, uncoated, UNS A95052	120
Copper & Alloys	• Silicon bronze alloy C65100, or equivalent • Leaded brass alloy C36000, or equivalent. • Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000, uncoated • CuNi 90-10	120
Steel (Carbon, Alloy)	• 1010 carbon steel, uncoated • 1010 carbon steel, with Ion Vapor Deposition (IVD) aluminum plating	120

GENERIC DESIGNATION	SPECIFIC MATERIAL See Appendix C for Base Metal Specifications See Appendix D for Plating Requirements See Appendix E for Additional Materials Being Considered	SOAK TEMPERATURE PER SHIPBOARD MAXIMUM USE TEMPERATURE All 180 day soak time See testing requirements below
	• 1010 carbon steel, with Ion Vapor Deposition (IVD) tin plating • 1010 carbon steel, with Ion Vapor Deposition (IVD) silver plating • 1010 carbon steel, with Ion Vapor Deposition (IVD) cadmium plating • 1010 carbon steel, with Ion Vapor Deposition (IVD) nickel plating • 1010 carbon steel, with Ion Vapor Deposition (IVD) zinc plating	
Stainless Steel	• 440C, heat treated • 304, UNS S30403	120
Nickel & Alloys	• IN 200, uncoated	120
Titanium & Alloys	• 6Al-4V	120
Solder	• 60-Sn – 40 Pb	120

Testing requirements are as follows:

• **Immersion Testing**—180 day immersion test in fuel samples at 120 degrees F using a constant temperature water bath to maintain temperature. For the general corrosion study, three cleaned and weighed metallic coupons of each material type listed in Table 1 will be suspended in 475 milliliter (16 oz) wide-mouth sealed glass jars filled with the respective fuel oil. For the crevice corrosion study, two cleaned and weighed metallic coupons of each material listed in Table 1 will be sandwiched together, separated by Teflon® crevice washers. Each coupon assembly will be held together by nylon bolts/nuts to preclude any galvanic interaction. Each crevice corrosion coupon assembly will be suspended in a 475 milliliter (16 oz.) wide-mouth sealed glass jar filled with the respective fuel oil.

• Both the alternate fuel and original F-76 fuel will be evaluated for comparison purposes.

Prior to the start of the immersion test, a sample of the alternate fuel and the F-76 fuel will be taken and analyze for trace levels of iron, copper, aluminum and zinc, and any other elements of interest representative of the metallic materials being tested. A post immersion test sample of each fuel will be retained for comparison purposes to determine if any increase in constituents has occurred that would suggest a corrosion problem. Post exposure evaluation of the coupons will be conducted as discussed below. Appendix B provides a more detailed overview of the test procedure.

• **Immersion Testing, biological effects in fuel/seawater and fuel/distilled water**—180 day static immersion test in F-76 fuel/water mixture and alternate fuel/water mixture at 120 degrees F using a constant temperature water bath to maintain temperature. The waters to be used are natural seawater from the New Jersey shore and de-ionized water. Cleaned and weighed metallic coupons (3 each) of carbon steel per Unified Number System (UNS) C10100, stainless steel per UNS S30403 and aluminum per UNS A95052 will be suspended in 240 milliliter (8 oz.) sealed glass jars (one coupon per jar) containing an equal volume of fuel/seawater and fuel/distilled water. One half of each coupon will be in the fuel layer and the other half in the water layer under static conditions. There will be no attempt to replenish the fuel or water during the test period. Any deposits or growth will be documented and photographed, but will be removed with no further analysis. The extent of corrosion will be assessed by visual inspection, weight loss and if necessary SEM examination (metallographic sectioning for microstructure analysis) as discussed below. Appendix B provides a more detailed overview of the test procedure.

• **Flowing Fuel Testing**—The original 1987 NAVSSES F-76 fuel testing included a modified loop test that subjected all of the metallic coupon materials simultaneously to flowing F-76 fuel in order to assess corrosion and erosion effects. Because the alternate fuel must be identical to F-76 (MIL-DTL-16884L), and the corrosion rates in the original F-76 flowing fuel test were extremely low, the need for a complicated flow loop corrosion test is not warranted. To ensure there is no drastic change in findings, a moving fuel test will be performed. Three cleaned and weighed metallic coupons of each material listed in Table 1 in addition to two coupons of each material assembled for crevice evaluation using Teflon® crevice washers will be suspended in a circulating bath of each fuel oil heated to 120 degrees F for the 180 day period. All coupon types will be exposed at one time. Post exposure evaluation of the coupons will be conducted as discussed below. Appendix B provides a more detailed overview of the test procedure.

• Prior to immersion or flow testing, the metallic coupons will be measured for surface area, cleaned per ASTM G1-03 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens* and weighed to the nearest 0.00000 grams in order to determine the corrosion rate following exposure. The coupons will undergo evaluation as follows:

- **Surface Evaluation:** Visual inspection and at approx. 50X for to get an initial surface condition prior to exposure in the fuel. Photo documentation.
- **Scanning-electron microscope (SEM) evaluation:** Examination at 100X of the unexposed surfaces to compare with post exposure surfaces. Photo documentation.

• Post exposure cleaning and weighing will be performed to determine any subsequent weight loss due to corrosion. A corrosion rate in mils per year (mpy) or other units as required will be provided. While the total exposure time is 180 days, samples of each metal coupon will be pulled at 60 day intervals up to 180 days from the alternate fuel and F-76 fuel and evaluated visually and at 50X for evidence of surface staining, deposit formation and gross corrosion. If there is no noticeable change at the end of the 180 day time frame, the testing will be stopped and coupon evaluation will be performed as described below.

- Post exposure evaluation methods as follows: :
 - **Corrosion rate calculations:** Clean the coupons per ASTM G1-03, *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*. Weigh the coupons to the nearest 0.00000 grams and record data.
 - **Surface Evaluation:** Visual inspection and at approx. 50X for evidence of staining, deposits, and gross corrosion. Photo documentation.
 - **Scanning-electron microscope (SEM) evaluation:** Examination at 100X of worst case coupon for each material for evidence of pitting per ASTM G46, stress cracking conditions and crevice corrosion for the crevice prepared coupon sets, etc. Photo documentation.
 - **Microstructure Evaluation:** Cross section, mount and polish using standard techniques for materials being examined. Examine at 100-1000X for evidence of microstructure changes, corrosion or other effects. Based on findings, conduct further evaluation via scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDXA) to analyze corrosion products. Photo documentation.
 - **Trace Metal Analysis:** Conduct trace metal analysis of the fuel post exposure for iron, copper, aluminum and zinc to determine if leaching of these constituents from the metals has occurred. This would signal some level of corrosion of the base metals.
- Acceptance criteria for the metallic materials immersed in the tested alternative fuel will be results from the above evaluations no worse than in F-76 fuel.

***NOTE** If Fitness for Purpose (FFP) testing of an alternative fuel shows microbial growth in excess of that in F-76, this protocol shall be modified to include exposure of the metallic test materials to the fuel in the presence of the growth organisms to determine their effects. The modifications shall include reduced temperature and extended duration as appropriate, and shall be approved by NAVAIR.*

4.2 Non-Metallic Materials

• Table 2 lists the recommended non-metallic materials for immersion testing based on the list of Navy fuel wetted non-metallic materials in Table 2-1, which shows the complete list of fuel wetted gas turbine, fuel transfer system, and boiler non-metallic materials as provided by NSWC subject matter experts (SME), and the non-metallic materials previously tested by NAVSSES (see 3.2 and Appendix A). The proposed materials for testing are based on the ASTM D4054 requirements, as shown. The non-metallic materials testing will be conducted in accordance with ASTM D471 *Standard Test Method for Rubber Property—Effect of Liquids*. The same Section 4.1 comments regarding diesel engine metallic materials also applies for the non-metallic materials.

- [Table 2-2](#) lists the ASTM D4054/MIL-HDBK-510 non-metallic materials (which are the same), and [Table 2-3](#) lists D4054/MIL-HDBK non-metallic test regiments and acceptance criteria, which will be followed for the subject alternative fuel protocol.

- For Non-metallic samples-Sample immersion for 180 days at 120 degrees F. For the first month at 7 day intervals, samples of each non-metallic material will be pulled from the immersion tank and evaluated for fuel absorption (volume swell) and weight gain per ASTM D471. Frequency of subsequent checks can be adjusted as needed based on the initial results. Once swell and weight gain measurements plateau for each material, which could occur well short of the 180 day exposure period, the immersion test will be terminated and the samples evaluated per the Table 2-3 test procedures and acceptance criteria.

Table 2 – Representative Non-Metallic Materials for Navy Immersion Tests

NON-METALLIC MATERIALS See Table 2-1 for specification details	PROPOSED TEST(S) • Evaluation Method and Test Criteria shown in Table 2-3 • May change depending on specific form tested
Nitrile (O-ring, sheet) Fluorocarbon (O-ring, sheet) Fluorosilicone (O-ring, sheet) Chloroprene (O-ring, sheet) Polyurethane (form TBD) Polytetrafluoroethylene (PTFE) (hose) Polyimide (diaphragm) Polyester (form TBD) Misc. plastics (form TBD) Fiberglass (pipe) Epichlorohydrin fuel hose	Tensile Strength, Hardness, Elongation, Volume Swell
Adhesives	
Sealants	
Asbestos (gasket)	
Other gaskets: • Cork and rubber gasket sheet • Hard gray fiber • Metallic-graphite, spiral wound	
	Lap Shear, Static Shear
	Peel Strength, Hardness Shore A, Tensile Strength, Elongation, Volume Swell
	Tensile Strength
	Hardness – Shore M, Tensile Strength, Elongation Compression Set, Volume Swell

NON-METALLIC MATERIALS See Table 2-1 for specification details	PROPOSED TEST(S) • Evaluation Method and Test Criteria shown in Table 2-3 • May change depending on specific form tested
• Non-asbestos • Metallic/rubber • Garlock style 9900 or equivalent	
Packing	Tensile Strength, Volume Swell
Coating - Epoxy-polyamide (MIL-DTL-24441) Coating-Ultra-high solids epoxy (MIL-PRF-23236, TY-VII, Class 5)	Hardness (pencil), Tape Adhesion
Carbon seal material	Hardness, Weight Loss

TABLE 1-1 – Metallic Materials for Testing in Alternative Fuels (see Table 2-1 for non-metallic materials)

Summary

- This table lists the gas turbine, fuel transfer system, and boiler fuel wetted metallic materials, the materials tested by NAVSSES in 1987, and proposed representative materials for testing in alternative fuels.
- SMNI = Specific Material Not Identified, e.g., material only identified as ‘aluminum’, ‘stainless steel’, etc.
- See Appendix E for additional materials being considered.

GENERIC DESIGNATION	FUEL WETTED METALLIC MATERIALS									MATERIALS TESTED BY NAVSSES (see Appendix A)	PROPOSED REPRESENTATIVE MATERIALS FOR NAVY TESTS	
	GAS TURBINES							FUEL TRANSFER SYSTEM	BOILERS		MATERIAL	MATERIAL SELECTION JUSTIFICATION
	501-K17	501-K34	250-KS4	TF40B	ETF40B	T-62	Solar					
Aluminum & Alloys	SMNI 2014-T6, T651, T851 2024-T4, T351 (1) 3003-H14 6061-0 (1), T651 356-T6 cast (2) (1) Anodize MIL-A-8625 Type II, Class 1 (2) Anodize MIL-A-8625 Type II, Class 2	SMNI 2014-T6, T651 2024-T4, T351 3003-H14 6061-0, T651 356-T6 cast	SMNI 7075-T651 356-T6 cast	SMNI	SMNI, anodized (no coating specifics)	SMNI	SMNI	3000 Series 6061 T-6	X	X	356-T6, uncoated 2024-T3, uncoated 7075-T6, uncoated 7075-T6, anodized (chromic acid, sulfuric acid), chromate conversion coated	The selected alloys are considered to have similar corrosion resistance as the other identified aluminum alloys. The performance of the anodized and chromate coatings on the 7075 material will be representative of coating performance on other aluminum alloys.
Copper & Alloys	Brass (SMNI), silver plated (no coating specifics) Bronze (lead ed) Beryllium copper (SMNI), unplated and silver plated (no coating specifics) Copper gasket washer (SMNI)	Brass (SMNI), silver plated (no coating specifics) Bronze (lead ed) Beryllium copper (SMNI), unplated and silver plated (no coating specifics) Copper gasket washer (SMNI)	Bronze (lead ed) Beryllium copper (SMNI), unplated and silver plated (no coating specifics)	CuZn (SMNI) Bronze, SAE 52100	CuZn (SMNI) Bronze, SAE 52100	X	X	Monel 400, K-500, Cast Monel Grade M30C, M30H Alloy C122, 464, 642, 272 Be-Cu 70-30, 90-10 CuNi Aluminum bronze C95800, C64200, C95200, C63200 Ni-Al bronze C95800 Tin bronze C90300, C905000 Leaded tin bronze C93700, C92200 Phosphor bronze C51000 Silicon bronze C65100 Leaded brass C36000 Naval brass C46400 70-30 brass C26000 Red brass C23000 Leaded red brass C83600	Soft copper gasket (SMNI) Brass QQ-B-626 – lead ed/unlead ed Leaded bronze QQ-B-691 SAE 660 (C93200) Cast bronze (SMNI) Brass (SMNI) Steel (SMNI)	Alloy 655 CuSi Alloy 353 lead ed brass 510 phosphor bronze	Silicon bronze alloy C65100, or equivalent Leaded brass alloy C36000, or equivalent. Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000 Uncoated CuNi 90-10	The selected bronze and brass alloys are similar to those showing the highest corrosion rates in the NAVSSES 1987 test in F-76. Results for unalloyed copper will be compared to those from the standard ASTM D130 copper strip corrosion test as required in the F-76 specification (and most diesel fuel specifications), which is performed at 212F, but for only about 3 hrs.
Cast Iron Steel (Carbon, Alloy)	SMNI, tin plated, silver plated, cadmium plated (no coating specifics)	SMNI, tin plated, silver plated, cadmium plated (no coating specifics) Spring steel SAE 1060 MS 16624 retaining ring	SMNI, zinc plated (no coating specifics)	SMNI	SMNI, nickel plated (no coating specifics)	X	X	Gray Iron Ductile Iron Ni-Resist AISI 1059, 4150, 1065 thru 1090 ASTM A36, A53, A105, A106, A108, A214, A519, A216, A487 QQ-S-691, MIL-T-20157, MIL-P-10971 Nitrided 4130	Cast steel (SMNI) AISI C12L14 MIL-S-15083 Cl 70-36 Cast iron MIL-T-6736 – 4130/8630 AISI 1117 Carbon steel (SMNI)	1010 carbon steel 4130 alloy steel	Plain carbon, type 1010 or similar, uncoated and IVD aluminum, cadmium, zinc, nickel, silver, tin plated.	No significant difference in corrosion performance is expected among carbon and alloy steels in fuel, therefore the plain carbon steel will be representative. The various coatings on carbon steel will also be representative of the same coatings on other materials

GENERIC DESIGNATION	FUEL WETTED METALLIC MATERIALS									MATERIALS TESTED BY NAVSSES (see Appendix A)	PROPOSED REPRESENTATIVE MATERIALS FOR NAVY TESTS	
	GAS TURBINES							FUEL TRANSFER SYSTEM	BOILERS		MATERIAL	MATERIAL SELECTION JUSTIFICATION
	501-K17	501-K34	250-KS4	TF40B	ETF40B	T-62	Solar					
Stainless Steel	SMNI 440C	SMNI 440C CRES Ni plated	SMNI	SMNI 304, 316 – MIL-S-5059 321 – AMS 5510 347 – AMS 5512 A286 – AMS 5734	SMNI 304, 316 – MIL-S-5059 321 – AMS 5510 347 – AMS 5512 A286 – AMS 5734 440	SMNI 440C – AMS 5630, AMS 5880	SMNI	302, 303, 304, 304L, 316, 316L, 410, 416, 431, 440 CF3, CF3M, CF-8M (UNS J92900) ASTM A240 XM-19 (Nitronic 50), Duplex Gr 2205, Alloy 20 17-4PH, 17-7 PH, 15-7 PH	CRES 440C, 410, 303, 304, 302, 316 MIL-R-21248 AMS 5520 15-7PH	304	Type 440C, heat treated	The seawater pitting resistance of stainless steels is ranked via the pitting-resistance-equivalent (PRE). The PRE values for the Navy identified stainless steels range from 17 (440C) to 25 (316).
Nickel & Alloys Cobalt Alloys	SMNI	SMNI Ni bronze	SMNI	x	x	x	x	600, 625, Hastelloy B Haynes 25 (cobalt base)	x	x	Pure, IN 200, uncoated	The other nickel base alloys in ASTM D4054 have high corrosion resistance. IN 200 will be conservative.
Titanium \$ Alloys	x	x	x	x	x	x	x	6Al-4V	x	x	6Al-4V	Representative of all titanium
Solder	x	x	x	x	x	x	x	x	x	x	60 Sn – 40 Pb	Used in Air force tests

TABLE 1-2 – ASTM D4054/MIL-HDBK-510 Metallic Materials

GENERIC DESIGNATION	Same for ASTM D4054, 6/10/08 Draft, and MIL-HDBK-510-1, 11/13/08	
	MATERIALS TO BE TESTED	
	Soak time 28 days – see below evaluation criteria	SOAK TEMP (oF)
Aluminum & Alloys	• 2024-T3, Uncoated • 5052-H34, Uncoated • 6061-T6, Uncoated • 7050-T74, Uncoated • 7075-T6, Anodized, Chromic Acid, MIL-A-8625, Type I • 7075-T6, Anodized, Sulfuric Acid, MIL-A-8625, Type IIB • 7075-T6, Chromate conversion, MIL-DTL-5541, Class 1A	200
Copper & Alloys	• Brass, Alloy 268, hot rolled, uncoated • CuNi. 90-10. annealed. uncoated	200
Steel (Carbon, Alloy)	• 4130 alloy, annealed or normalized, aluminum ion-vapor-deposited (IVD), AMS 2427 • 4340, annealed or normalized, cadmium plated, SAE-AMS-QQ-P-416 • Nitralloy 135, nitrided • Tool steel, A11 (CPM 10V), uncoated	325
Stainless Steel	• A286, solution treated, silver plated, SAE-AMS-2410 • 440, ASTM A240, uncoated • 304, ASTM A240, uncoated • 17-4PH, H900, uncoated	325
Nickel & Alloys	• Pure, IN 200, uncoated • Monel 400, uncoated • Inconel 625, uncoated • Inconel 718, uncoated • Waspalloy, uncoated	325
Titanium & Alloys	• CP70, uncoated • 3Al-2.5V, uncoated • 8Al-1V-1Mo, uncoated	325
Magnesium & Alloys	• Cast AZ91-T6, uncoated	200
Lead	• Pure, SAE-AMS-4751, uncoated	325
Solder	• Sn 60 – Pb 40	325
Misc	• TAP MS 285 • Mag Wire Type I	325

Metallic Specimen Evaluation Criteria

ASTM D4054

Surface Evaluation: Visual examination at low power (<50X) – inspect for evidence of staining, deposits, or gross corrosion

Microstructural Evaluation: Cross section, mount and polish using standard techniques for materials being examined – examine at 100X to 1000X for evidence of microstructural changes, corrosion, or other effects – if evidence of corrosion conduct further evaluation via scanning electron microscopy (SEM) and energy dispersive X- ray analysis (EDAX) to analyze corrosion products.

MIL-HDBK-510

Same as ASTM with addition of pitting evaluation per ASTM G46, and weight loss/gain measurements during testing.

TABLE 1-3 – ASTM D4054/MIL-HDBK-510 vs. Navy Metallic Material Lists

GENERIC DESIGNATION	ASTM/MIL <i>Specific materials also in Navy list are bolded and italicized</i>	NAVY
Aluminum & Alloys	• 2024-T3, Uncoated • 5052-H34, Uncoated • 6061-T6, Uncoated • 7050-T74, Uncoated • 7075-T6, Anodized, Chromic Acid, MIL-A-8625, Type I • 7075-T6, Anodized, Sulfuric Acid, MIL-A-8625, Type IIB • 7075-T6, Chromate conversion, MIL-DTL-5541, Class 1A • Cast 356-T6, uncoated	• Cast 356-T6, uncoated • 2024-T3, uncoated • 7075-T6, uncoated • 7075-T6, anodized (chromic acid, sulfuric acid), chromate conversion coated
Copper & Alloys	• Brass, Alloy 268, hot rolled, uncoated • CuNi, 90-10, annealed, uncoated	• Silicon bronze alloy C65100 or equivalent • Leaded brass alloy C36000, or equivalent. • Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000 , uncoated • CuNi 90-10
Steel (Carbon, Alloy)	• 4130 alloy, annealed or normalized, aluminum ion-vapor- deposited (IVD), AMS 2427 • 4340, annealed or normalized, cadmium plated, SAE-AMS- QQ-P-416 • Nitralloy 135, nitrided • Tool steel, A11 (CPM 10V), uncoated	• 1010 carbon steel, uncoated and with IVD aluminum, tin, silver, cadmium, nickel, and zinc platings
Stainless Steel	• A286, solution treated, silver plated, SAE-AMS-2410 • 440, ASTM A240, uncoated • 304, ASTM A240, uncoated • 17-4PH, H900, uncoated	• 440C, heat treated
Nickel & Alloys	• Pure, IN 200, uncoated • Monel 400, uncoated • Inconel 625, uncoated • Inconel 718, uncoated • Waspalloy, uncoated	• IN 200, uncoated
Titanium & Alloys	• CP70, uncoated • 3Al-2.5V, uncoated • 8Al-1V-1Mo, uncoated	• 6Al-4V
Magnesium & Alloys	• Cast AZ91-T6, uncoated	N/A
Lead	• Pure, SAE-AMS-4751, uncoated	N/A
Solder	• Sn 60 – Pb 40	• Sn 60 – Pb 40
Misc	• TAP MS 285 • Mag Wire Type I	N/A

TABLE 2-1 – Non-Metallic Materials for Testing in Alternative Fuels (see Table 1-1 for metallic materials)

Summary

- This table lists the gas turbine, fuel transfer system, and boiler fuel wetted non-metallic materials, the non-metallic materials tested by NAVSSES in 1987, and proposed representative materials for testing in alternative fuels.
- SMNI = Specific Material Not Identified, e.g., material only identified as ‘aluminum’, ‘stainless steel’, etc

GENERIC DESIGNATION	FUEL WETTED NON-METALLIC MATERIALS See Note 1 for Boiler Non-Metallic Materials							FUEL WETTED MATERIALS IDENTIFIED IN FUEL TRANSFER SYSTEM	SPEC SUMMARY Type, Class, and Grade information are provided if part of spec	MATERIALS TESTED BY NAVSSES (see Appendix A)	PROPOSED REPRESENTATIVE MATERIALS FOR NAVY TESTS
	GAS TURBIN ES										
	501-K17	501-K34	250-KS4	TF40B	ETF40B	T-62	Solar				
Synthetic Rubber	SMNI	SMNI	SMNI	SMNI	SMNI	X	X	MIL-P-83461 (replaced)	MIL-P-83461 • Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275F (135C), for use in Boss Fittings • Rev. B, 2/25/80 cancelled via Notice 3, 10/1/03 - replaced w/ SAE-AMS-P-83461 • Covers O-ring packing • Originally required specific formulation given in the spec., but no longer needed. • QPL-83461-6, 3/15/93 lists one approved material as Parker N756-75, which is nitrile	X	MIL-P-83461 covers nitrile material See below
Nitrile (butadiene)	• MIL-P-5315 N602-70 – O-ring – Buna-N	• MIL-P-5315 (replaced)	X	X	X	X	Buna-N	-----	MIL-P-5315 • Packing, Preformed, Hydrocarbon Fuel Resistant • Rev. B, 12/2/64 cancelled via Notice 4, 2/28/02 - replaced w/ SAE-AMS-P-5315, Butadiene – Acrylonitrile (NBR) Rubber for Fuel-Resistant Seals 60-70.	MIL-R-6855 Rubber, Synthetic, Sheets, strips, Molded or Extruded Shapes Rev. E, Notice 2, 6/15/01	Use SAE-AMS-P-5315 for O-ring form Use SAE-AMS-P-83461 for packing Use MIL-PRF-2765 or MIL-R-6885 for sheet
	X	X	X	X	X	X	X	MIL-P-83461/1	MIL-P-83461/1 • Covers O-ring sizes and tolerances • /2 covers O-ring sizes and tolerances specifically for use in straight thread tube boss fittings		
	X	X	X	X	X	X	X	MIL-P-25732 (cancelled)	MIL-P-25732 • Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Limited Service at 275F (135C) • Rev. C, 2/25/80 cancelled via Notice 1, 11/15/89 – future designs should use MIL-P-83461 • Reactivated via Notice 2, 8/7/03 to maintain existing equipment • Material is copolymer of butadiene/acrylonitrile (nitrile)		
	X	X	X	X	X	X	X	SAE-AMS-P-5516 (withdrawn)	SAE-AMS-P-5516 • Packing, Preformed, Petroleum Hydraulic Fluid Resistant, 160F (71C) • V rings per AN6225 • Class A – low flexibility • Class B – high flexibility – withdrawn – use MIL-P-25732 • SAE document withdrawn 7/22/08 – use MIL-DTL-5516 (Rev. D, 5/15/08) • Per QPL-5516, acceptable material is Acushnet compound P-JS-103-1 Class NBR (nitrile)		
	X	X	X	X	X	X	X	MIL-R-2765 (replaced)	MIL-R-2765 • Rubber Sheet, Strip, Extruded, and Molded Shapes, Synthetic, Oil Resistant • Rev. D, 9/24/86 replaced w/ MIL-PRF-2765E, 9/27/04 • Intended as gasket material • Most sources identify material as nitrile		
Fluorocarbon	SMNI	SMNI	SMNI	SMNI	SMNI	SMNI	SMNI	MIL-R-83248 (cancelled)	MIL-R-83248 • Rubber, Fluorocarbon Elastomer, High Temperature, Fluid and Compression Set Resistant	MIL-R-83248	Use AMS 7276, AMS 7259, AMS 3216, AMS 3218 covering O-ring and sheet form in two hardness

									• Types: I – O-rings etc; II – Molded parts other than I plus sheet, strip, extruded shapes • Classes: 1 – 75 +/- 5 hardness; 2 – 90 +/- 5 hardness • Rev. C, 6/28/94 cancelled via Notice 2, 6/21/01 – replacements: Type I, Class 1: AMS 7276 Type I, Class 2: AMS 7259 Type II, Class 1: AMS 3216 Type II, Class 2: AMS 3218 • All above AMS materials are fluorocarbon (FKM)		ranges <u>Additional materials for consideration:</u> SAE-AMS-R-83485 Type 1 (low temperature fluorocarbon)
Fluorosilicone	Silicone rubber (SMNI)	Silicone rubber (SMNI)	x	x	x	x	x	MIL-R-25988 (replaced)	MIL-R-25988 • Rubber, Fluorosilicone Elastomer, Oil and Fuel Resistant, Sheets, Strips, Molded Parts, and Extruded Shapes • Rev. B, 7/12/83 replaced w/ MIL-DTL-25988C, 8/11/06 • Types: I – O-rings etc; II – Molded parts other than I plus sheet, strip, extruded shapes • Classes: 1 – General purpose; 2 – High-strength, general purpose, Type II only; 3 – high modulus, increased temp resistance, Type I and II	X	Use MIL-DTL-25988
Chloropene	SMNI	SMNI	x	x	x	x	x	SMNI	----	X	<u>Material designations:</u> ASTM D2000 Type BC, BE ASTM D1418 Class CR <u>Product form:</u> TBD <u>Product specification:</u> TBD
Polyurethane (polyester urethane, polyether urethane)	x	x	x	x	x	x	x	SMNI	----	X	<u>Material designations:</u> ASTM D2000 Type BG ASTM D1418 Class Au/EU <u>Product form:</u> TBD <u>Product specification:</u> TBD
Polytetrafluorethylene (PTFE)	SMNI (hose)	SMNI	SMNI	x	x	x	SMNI	SMNI (including glass filled PTFE)	----	X	<u>Material designations:</u> Teflon, Delrin <u>Product form:</u> Hose <u>Product specification:</u> TBD
Polyimide diaphragm	SMNI	SMNI	x	x	x	x	x	Polyamide Nylon	----	X	<u>Material designations:</u> Vespel <u>Product form:</u> Diaphragm <u>Product specification:</u> TBD
Polyester	SMNI	SMNI	x	x	x	x	x	x	----	X	<u>Material designations:</u> ASTM D1201 <u>Product form:</u> TBD <u>Product specification:</u> TBD
Other plastics	x	x	x	x	x	x	x	Phenolic - asbestos paper filler Oxymethylene Acrylic Polycarbonate Vinyl Polypropylene	----	Nylatron	Nylatron Fluorosint material used in Combustion Engineering boiler control blocks Other materials TBD
Fiberglass	SMNI	SMNI	x	x	x	x	x	x	----	X	<u>Material designations:</u> ASTM D5677 <u>Product form:</u> Pipe <u>Product specification:</u> TBD

Adhesives & Sealants	• Plastisol epoxy • Uniset A-304-29 epoxy	• Plastisol epoxy • Uniset A-304-29 epoxy	x	x	x	x	x	x		<u>Material designations:</u> TBD <u>Product form:</u> Adhesive <u>Product specification:</u> TBD <u>Additional adhesives for consideration:</u> Vinyl phenolic – MMM-A-132 Type 1, class 3 Epoxy resin Nitrile phenolic – MMM-A-132 Type 1, Class 2 Methacrylate – ASTM D5363 Group 4, Class 1, Gr 1 Cyanoacrylate – A-A-3097 Type II, Class 1 <u>Additional sealants for consideration:</u> Polysulfide dichromate cured – SAE-AMS-S-8802 Type I, Class B-2 Polysulfide manganese cured – SAE-AMS-S-8802 Type II, Class B-2 Fluorosilicone – SAE-AMS-3375 Polyurethane – SAE-AMS-3279 Polythioether – SAE-AMS-3277 Class B-2 Polysulfide lightweight – SAE-AMS-3281 Polysulfide – SAE-AMS-3283 (groove injection) Fluorosilicone – MIL-S-85334 (groove injection) Epoxy paste – MMM-A-132 Type 1, Class 3 Nitrile epoxy film – MMM-A-132 Type 1, Class 2
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GENERIC DESIGNATION	FUEL WETTED NON-METALLIC MATERIALS								SPEC SUMMARY Type, Class, and Grade information are provided if part of spec	MATERIALS TESTED BY NAVSSES (see Appendix A)	PROPOSED REPRESENTATIVE MATERIALS FOR NAVY TESTS
	See Note 1 for Boiler Non-Metallic Materials										
	GAS TURBINES							FUEL WETTED MATERIALS IDENTIFIED IN FUEL TRANSFER SYSTEM			
501-K17	501-K34	250-KS4	TF40B	ETF40B	T-62	Solar					
Asbestos	x	x	x	SMNI	SMNI	x	x	x	----	Asbestos gasket HH-P-46 Class 1	Use HH-P-46 Class 1
Resin Impregnated Cellulose	x	x	x	x	x	SMNI	x	x	----	X	Material designations: TBD Product form: Fuel filter media Product specification: TBD
Cork and rubber gasket sheet	SAE-AMS-C-6183 Type 1, Class 1, Gr. B	SAE-AMS-C-6183 Type 1, Class 1, Gr. B	x	x	x	x	x	SAE-AMS-C-6183	SAE-AMS-C-6183 • Cork and Rubber Composition Sheet, for Aromatic Fuel and Oil Resistant Gaskets • Replaces Rev. B of MIL-C-6183, 2/13/81 via Notice 1, 12/18/98 • Types: I – Molded; II – Continuous roll • Classes: 1 – Aromatic fuel; 2 – Oil resistant • Grades: A – Soft; B – Medium; C - Firm	X	Use SAE-AMS-C-6183 Type 1, Class 1, Grade B
Hard gray fiber gasket for use with aromatic fuels	SMNI	SMNI	x	x	x	x	x	x	-----	X	Material specifications: ASTM D710, MIL-F-1148, MIL-F-10336, MIL-F-13526 Product form: Gasket

GENERIC DESIGNATION	FUEL WETTED NON-METALLIC MATERIALS								SPEC SUMMARY Type, Class, and Grade information are provided if part of spec	MATERIALS TESTED BY NAVSSES (see Appendix A)	PROPOSED REPRESENTATIVE MATERIALS FOR NAVY TESTS
	See Note 1 for Boiler Non-Metallic Materials										
	GAS TURBINES							FUEL WETTED MATERIALS IDENTIFIED IN FUEL TRANSFER SYSTEM			
501-K17	501-K34	250-KS4	TF40B	ETF40B	T-62	Solar					
Other gaskets	X	X	X	X	X	X	X	MIL-G-24716	<u>MIL-G-24716</u> - Gaskets, Metallic-Flexible Graphite, Spiral Wound - Rev. A, 4/5/93 - Types: I – For applications other than pipeline flange joints; II – For ANSI B16.5 flange joints with metal outer rings - Classes: A – Corrosion resistant steel for 1050F max; B – Nickel- chromium-iron for 900F; C – Nickel-copper for 700F max where seawater contact is possible	X	Use MIL-G-24716 MIL-DTL-24669 MIL-G-24748 Type A, B Navy spec STR 508 (Garlock style 990 or equivalent)
								MIL-G-24696 (replaced)	<u>MIL-G-24696</u> - Gasket, Sheet, Non-Asbestos - Rev. B, 5/25/95 replaced by MIL-DTL-24696C, 9/5/08 - Types: I – Exposed to saturated steam to 366F/150 psig; II – For water service to 300F/1800 psig, lube oil service to 250F/150 psig, hydraulic oil service to 180F/600 psig		
								MIL-G-24748, Type A, Type B	<u>MIL-G-24748</u> - Gaskets, Metallic and Rubber, For Use in Union Pipe Fittings ¼ to 2-Inch NPS with Various Fluids From -30F (-34C) to 400F (204C) - Rev. A, 1/12/94 - Types: A - -30F to 250F; B - -30F to 300F		
								Navy spec STR 508	<u>No spec details available</u> - Garlock states that their Style 9900, graphite fibers with nitrile binder, meets STR 508 not be controlled beyond normal limits; 2 – Where detrimental material content must be controlled - Grades: I – Treated with corrosion inhibitor; N – No corrosion inhibitor		

GENERIC DESIGNATION	FUEL WETTED NON-METALLIC MATERIALS							FUEL WETTED MATERIALS IDENTIFIED IN FUEL TRANSFER SYSTEM	SPEC SUMMARY Type, Class, and Grade information are provided if part of spec	MATERIALS TESTED BY NAVSSES (see Appendix A)	PROPOSED REPRESENTATIVE MATERIALS FOR NAVY TESTS																																
	See Note 1 for Boiler Non-Metallic Materials																																										
	GAS TURBINES																																										
501-K17	501-K34	250-KS4	TF40B	ETF40B	T-62	Solar																																					
								MIL-P-24583	<u>MIL-P-24583</u> • Packing Material, Graphitic or Carbon Braided Yarn • Rev. B, 8/22/91 • Types: I – Continuous filament graphitic or carbon yarn; II – Staple graphitic or carbon yarn • Classes: 1 – Where detrimental material and lubricant content of packing need not be controlled beyond normal limits; 2 – Where detrimental material content must be controlled; 3 – Same as 1 with max 260C (500F) stuffing box temp • Grades: I – Treated with corrosion inhibitor; N – No corrosion inhibitor																																		
								MIL-P-17303 (cancelled)	<u>MIL-P-17303</u> • Packing Materials, Plastic Metallic and Plastic Nonmetallic • Class I – Plastic metallic, lead base: Type B – continuous strip, w/ or w/o cotton jacket, symbol 1433 Type C – continuous strip, metal foil jacket, symbol 1434 Type D – continuous strip, braided metal jacket, symbol 1432 Type E – continuous strip, w/ or w/o cotton jacket, symbol 1437 • Class II – Plastic nonmetallic Type C – continuous strip, braided asbestos yarn w/ NiCu wire insert jacket, symbol 1108 Type D – continuous strip, w/ or w/o cotton jacket, symbol 1109 Type E - continuous strip, braided asbestos yarn w/ NiCrFe alloy wire jacket, symbol 1111 Type F - continuous strip, braided metal jacket, symbol 1112 • Rev. D, 1/4/84 cancelled via Notice 1, 12/4/08 – replaced as follows: <table><tr><th>Class</th><th>Type</th><th>Symbol</th><th>Replacement</th></tr><tr><td>I</td><td>B</td><td>1433</td><td>MIL-PRF-24790 Type</td></tr><tr><td>I I</td><td>C</td><td>1434</td><td>MIL-PRF-24790 Type I</td></tr><tr><td>I</td><td>D</td><td>1432</td><td>MIL-PRF-24790 Type II</td></tr><tr><td>II</td><td>C</td><td>1108</td><td>MIL-P-24503/MIL-P-24583 combination</td></tr><tr><td>II</td><td>D</td><td>1109</td><td>MIL-PRF-24790 Type I (fresh water) or MIL- P-17416f (petroleum based fluid)</td></tr><tr><td>II</td><td>E</td><td>1111</td><td>MIL-P-24503/MIL-P-24583 combination</td></tr><tr><td>II</td><td>F</td><td>1112</td><td>MIL-PRF-24790 Type I (fresh water) or MIL- P-17416f (petroleum based fluid)</td></tr></table>	Class	Type	Symbol	Replacement	I	B	1433	MIL-PRF-24790 Type	I I	C	1434	MIL-PRF-24790 Type I	I	D	1432	MIL-PRF-24790 Type II	II	C	1108	MIL-P-24503/MIL-P-24583 combination	II	D	1109	MIL-PRF-24790 Type I (fresh water) or MIL- P-17416f (petroleum based fluid)	II	E	1111	MIL-P-24503/MIL-P-24583 combination	II	F	1112	MIL-PRF-24790 Type I (fresh water) or MIL- P-17416f (petroleum based fluid)		
Class	Type	Symbol	Replacement																																								
I	B	1433	MIL-PRF-24790 Type																																								
I I	C	1434	MIL-PRF-24790 Type I																																								
I	D	1432	MIL-PRF-24790 Type II																																								
II	C	1108	MIL-P-24503/MIL-P-24583 combination																																								
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II	E	1111	MIL-P-24503/MIL-P-24583 combination																																								
II	F	1112	MIL-PRF-24790 Type I (fresh water) or MIL- P-17416f (petroleum based fluid)																																								
								MIL-P-24790 (replaced)	<u>MIL-P-24790</u> • Packing Material, Braided, Non-Asbestos • Rev. -, 7/1/94 replaced by MIL-PRF-24790A, 11/23/98 and Amendment 1, 2/6/03 • Types: I – Rotary and centrifugal pump applications; II – Reciprocating pumps • Classes: A Type I: Freshwater, seawater, boiler feed; A Type II – Saturated steam																																		
								MIL-P-24752 CLASS 1	<u>MIL-P-24752</u> • Packing Material, Flax or Hemp • Rev. -, 10/1/90 • Classes: I – Flax; 2 – Hemp; 3 Flax and hemp																																		

								HH-P-151 CL2	HH-P-151 • Packing, Rubber-Sheet, Cloth-Insert • Rev. F, 7/19/85 • Classes: 1 – Commercial; 2 – Polychloroprene rubber; 3 – Styrene- butadiene rubber; 4 – Acrylonitrile-butadiene rubber		
Coatings	X	X	X	X	X	X	X	Three coats: Formulas 150, 151 and 152	-----	X	Epoxy-polyamide – MIL-DTL-24441: Three coats
Mechanical Seals	X	X	X	X	X	X	X	Carbon	-----	Crane No. 7250	Use Crane No. 7250 or equivalent

Notes

1. Boiler non-metallic materials:

- Fluorocarbon

Polytetra-fluorethylene (PTFE)

Adhesives & Sealants

Hard gray fiber gasket for use with aromatic fuels

Other gaskets

Packing
- O-ring – SMNI

Teflon tape thread sealant

John Crane Plastic Lead Seal #2

Fiber - SMNI

Flexitallic Flexite (CRES)

Goretex 100% PTFE Fluorocarbon, Polypenco Fluorsint 500

TABLE 2-2 – ASTM D4054/MIL-HDBK-510 Non-Metallic Materials

GENERIC DESIGNATION	Same for ASTM D4054, 6/10/08 Draft, and MIL-HDBK-510-1, 11/13/08 (except cyanoacrylate adhesive not listed in MIL-HDBK-510)		
	MATERIALS TO BE TESTED Soak time 28 days unless otherwise indicated	SOAK TEMP (oF)	TEST REGIMENT See Table 2-3
Fluorocarbon	- Gasket, O-Ring SAE-AMS-7276 (FKM) - Gasket, O-Ring - low temperature fluorocarbon – SAE-AMS-R-83485 Type 1	325	Gasket, O-ring
Nitrile (Also under Adhesives, Coatings)	• Gasket, O-Ring SAE-AMS-P-5315	160	Gasket, O-ring
	• Bladder (inner liner) (specification not identified)	160	Bladder
	• Bladder (self sealing) – MIL-T-5578 (30 minute soak)	RT	Bladder – volume swell only
	• Hose – aerial refueling - acrylic nitrile – MIL-H-4495	160	Hose
Fluorosilicone (Also under Sealants)	• Gasket, O-Ring SAE-AMS-R-25988, Type I, Class 1, Grade 70	225	Gasket, O-ring
Polyurethane (Also under Coatings, Sealants, Foam)	Bladder (inner liner) (specification not identified)	200	Bladder
Epichlorohydrin	• Hose – ground refueling - MIL-DTL-26521	160	Hose
Adhesives	- Vinyl Phenolic – MMM-A-132 Type 1, Class 3 - Epoxy Resin (specification not identified) - Nitrile Phenolic - MMM-A-132 Type 1, Class 2 - Epoxy Paste - MMM-A-132 Type 1, Class 3 - Nitrile Epoxy Film - MMM-A-132 Type 1, Class 2 - Methacrylate – ASTM D5363 Group 4, Class 1, Gr1 - Cyanoacrylate – A-A-3097 Type II, Class 1 (<i>not in MIL-HDBK-510</i>)	200	Adhesive Static Shear for methacrylate and cyanoacrylate Adhesive Lap Shear for remainder
Coatings	- Nitrile – SAE-AMS-S-4383 - Polyurethane – SAE-AMS-C-27725 Type II - Epoxy – BMS 10-20, 10-39 - Epoxy Polyamide – MIL-DTL-24441	120 for epoxy-polyamide 200 for remainder	Coating
Sealants (standard)	- Polysulfide Dichromate Cured – SAE-AMS-S-8802 Type I, Class B-2 - Polysulfide Manganese Cured - SAE-AMS-S-8802 Type II, Class B-2 - Fluorosilicone – SAE-AMS-3375 - Polyurethane – SAE-AMS-3279 - Polythioether – SAE-AMS-3277 Class B-2 - Polysulfide Lightweight – SAE-AMS-3281	200	Sealant - Standard
Sealants (groove injection)	- Polysulfide - SAE-AMS-3283 - Fluorosilicone – MIL-S-85334	160	Sealant – Groove Injection (volume swell only)
Composite	- Epoxy Graphite: AS4/3501-6, IM7/977-3, IM7/8552 - Graphite Bismaleimide – IM7/5250-4 (specifications not identified)	200	Composite
Foam	• Polyurethane – MIL-PRF-87260	200	Foam
Film	- Teflon (specification not identified) - Nylon (specification not identified) - Polyethylene (specification not identified) - Kapton (specification not identified)	200 for Kapton 160 for remainder	Film
Potting Compound	• Polysulfide – MIL-PRF-8516, Cure B	160	Potting compound

Table 2-3 – ASTM D4054 Non-Metallic Test Regiments and Acceptance Criteria

MATERIAL FORM	TEST	PROCEDURE	TEST REQUIREMENTS	ALLOWABLE VARIATION FROM BASELINE
Adhesive	Lap Shear	ASTM D1002	> 1500 psi	250 psi decrease
	Static Shear	MIL-R-46082, Method A	> 1200 psi	250 psi decrease
Bladder	Tensile Strength	ASTM D412	> 1500 psi	200 psi decrease
	Elongation	ASTM D412	> 300%	40% decrease
	Volume Swell	ASTM D471	< 25%	+/- 5%
Coating	Hardness (pencil)	ASTM D3363-05	>/- unaged	1 % decrease
	Tape Adhesion	FED-STD-141	Pass	-----
Sealant (standard)	Peel Strength	SAE AS5127/1	> 20 lb/in/100% cohes. (>10% for fluorosilicone)	8 lb/in decrease
	Hardness, Shore A	ASTM D2240	> 35 pts	+/- 5 pts
	Tensile Strength	ASTM D412	> 200 psi	35 psi decrease
	Elongation	ASTM D412	> 150 pts	25% decrease
	Volume Swell	ASTM D471	0-20% (0-30% for polyurethane) (0-25% for polythioether)	5% increase
Sealant (groove injection)	Volume Swell	ASTM D471	1-12%	+/- 5%
Composite (epoxy graphite, graphite bismaleimide)	Laminar Shear	ASTM D790	> 5000 psi	500 psi decrease
Foam	Tensile Strength	ASTM D412	> 10 psi	5 psi decrease
	Elongation	ASTM D412	> 100%	15% decrease
	Resistivity	ASTM D257	< 1.0 x 10 ¹² Ohm-cm	-----
Gasket, O-Ring	Hardness, Shore M	ASTM D2240	+/- 5 pts from unaged (-20 pts for fluorosilicone)	+/- 5 pts
	Tensile Strength	ASTM D1414	> 1000 psi	125 psi decrease
	Elongation	ASTM D1414	> 200% - nitrile > 125% - fluorosilicone > 150% - fluorocarbons	35% decrease
	Compression Set	ASTM D395	< 50% - nitrile < 65% - fluorosilicone < 60% - fluorocarbons	5% increase
	Volume Swell	ASTM D471	0-25% - nitrile & fluorsilicone 0-10% - fluorocarbons	+/- 10%
Hose	Tensile Strength	ASTM D412	> 1200 psi - nitrile > 1500 psi - epichlorohydrin	125 psi decrease
	Elongation	ASTM D412	> 150% - nitrile > 300% - epichlorohydrin	25% decrease
	Hardness, Shore A	ASTM D2240	+/- 5 pts from unaged	+/- 5 pts
	Volume Swell	ASTM D471	< 8%	+/- 5%
Film	Tensile Strength	ASTM D412	> 500 psi	TBD
	Elongation	ASTM D412	> 25%	TBD
Potting Compound	Hardness, Shore A	ASTM D2240	> 20 pts	+/- 5 pts
	Tensile Strength	ASTM D1414	> 100 psi	35 psi decrease
	Elongation	ASTM D1414	> 150%	25% decrease
	Peel Strength	SAE AS5127/1	> 10 lb/in/100% cohes.	8 lb/in decrease
	Volume Swell	ASTM D471	> - 20%	+/- 10%

APPENDIX A - NSWCCD MATERIAL TESTS

Ref: F-FA-FP-87-00629, Alternate Fuels Program Static and Modified Loop Testing of Metallic and Nonmetallic Samples, 8/27/87

MATERIALS	TEST All in F-76 Fuel at RT	EVALUATION METHOD	RESULTS CONCLUSIONS
<u>Metallic</u> • 1010 carbon steel • 4130 alloy steel • 304 stainless • 655 CuSi • 353 leaded brass • 510 phosphor bronze	• <u>Static immersion</u> 5472 hrs • <u>Modified loop</u> Includes static exposure and direct impingement exposure – 60 gpm – 1725 hrs (including 700 with fluid flowing)	• Weight loss • 100X SEM examination	• No significant corrosion of any materials • Based on weight loss: – Static – Immersion/loop: 0.1×10^{-3} mil per yr (mpy) to 3×10^{-2} mpy – dynamic loop: 8×10^{-3} mpy to 5×10^{-2} mpy • Highest rates are for leaded brass and copper silicon alloys • Loop testing produces essentially same results as static in 1/3 time
<u>Non-metallic</u> • BUNA-N (MIL-R-6855) • Viton (MIL-R-83248) • Asbestos gasket (HH-P-46 Class 1) • Packing (MIL-P-17303) • Nylatron • Carbon seal material (Crane No. 7250)	• <u>Static immersion</u> 5472 hrs	<u>BUNA-N and Viton</u> • Tensile test • Hardness test • Dimensional change <u>Asbestos and packing</u> • Tensile test <u>Nylatron and carbon</u> • Weight loss	<u>BUNA-N and Viton</u> • BUNA-N more affected – see detailed results below <u>Asbestos and packing</u> • Asbestos more affected – see detailed results below <u>Nylatron and carbon</u> • Neither material affected

Detailed Results

MATERIAL	% DECREASE IN TENSILE STRENGTH	% DECREASE IN ELONGATION	CHANGE IN HARDNESS	% DIMENSIONAL EXPANSION AFTER IMMERSION
BUNA-N	17.89	20.8	Not significant	Thickness: + 6.67% Width: + 3.8%
Viton	9.06	11.1	Not significant	Thickness: - 3.22 to + 3.33% Width: - 0.1 to + 0.1%
Asbestos	24.23	N/A	N/A	N/A
Packing	4.87	N/A	N/A	N/A

APPENDIX B**METALLIC SPECIMENS PREPARATION PROCEDURE**

Ref: F-FA-FP-87-00629, Alternate Fuels Program Static and Modified Loop Testing of Metallic and Nonmetallic Samples, 8/27/87 (results are summarized in Appendix A)

STEP	DESCRIPTION
	NOTE: Below provides general guidelines for corrosion testing of metallic materials at 120 degrees F.
1	Obtain a sample of unused alternate fuel and F-76 fuels for spectrographic chemical analysis. Analyze the fuels for iron, copper, aluminum and zinc (for comparison to post test analysis).
2	24 coupons of each material (½" wide x 3" long x 1/16" thick) will be obtained with either double disc (fine finish) or glass bead finish (to be specified) or the applied coating, as specified.
3	Measure all coupons for surface area, record results associated with the coupon designation.
4	Clean coupons per ASTM G1-03 depending on alloy type. Store in a desiccator to keep dry until weighed. Do not touch coupons at any time with bare fingers. Handle only with stainless steel forceps.
5	Assemble the coupon units for crevice corrosion testing. Sandwich two coupons together using Teflon® crevice washers as spacers. Bolt together using nylon bolts/nuts.
6	Weigh all coupons (except crevice corrosion specimens) to the nearest 0.00000 grams and return to the desiccator until fuel exposure begins. Tabulate sample numbers and coupon designations for data tracking purposes.
7	Immersion Testing: Conduct static immersion testing in accordance with practices noted in ASTM G31, <i>Standard Practice for Laboratory Immersion Corrosion Testing of Metals</i> . Since temperatures will be well below the flash point of the fuel, the immersion setup will employ the metal coupons suspended in each fuel type on a Teflon coated wire attached to the lid of a 475 milliliter (16 oz.) wide-mouth glass jar. There will be three coupons of the same material type per jar and one crevice corrosion assembly per jar. The jars will be filled with a known volume of the fuel in order to completely cover the coupons. The lid with the coupons attached will be screwed onto the jar. All jars will be placed into a water temperature controlled bath and heated to 120 degrees F for the 180 day period. At 60 day intervals, a coupon of each material (except for crevice corrosion) will be removed for examination visually and at 50X to determine if any gross corrosion appears to be occurring. Data will be recorded and the coupon returned to the jar for continued exposure. Post exposure evaluation of the coupons will be conducted as discussed in section 4.1 of this test protocol.
8	Immersion Testing, biological effects in fuel/seawater and fuel/distilled water: 180 day static immersion test in fuel/water mixtures at 120 degrees F using a constant temperature water bath to maintain temperature. Both the alternate fuel and original F-76 fuel will be evaluated for comparison purposes. The waters to be used are natural seawater from the New Jersey shore and de-ionized water. Cleaned and weighed metallic coupons (3 each) of carbon steel per Unified Number System (UNS) C10100, stainless steel per UNS S30403 and aluminum per UNS A95052 will be suspended in 240 milliliter (8 oz.) sealed glass jars (one coupon per jar) containing an equal volume of fuel/seawater and fuel/distilled water. One half of each coupon will be in the fuel layer and the other half in the water layer under static conditions. There will be no attempt to replenish the fuel or water during the test period. Any deposits or growth will be documented and photographed, but will be removed with no further analysis. The extent of corrosion will be assessed by visual inspection, weight loss and if necessary, SEM examination (metallographic sectioning for microstructure analysis). Coupons will be retained for further analysis by another activity, if desired.

METALLIC SPECIMENS PREPARATION PROCEDURE (Con't)

9	Flow Testing: Conduct flow testing in accordance with practices noted in ASTM G31, <i>Standard Practice for Laboratory Immersion Corrosion Testing of Metals</i> . Since temperatures will be well below the flash point of the fuel, a moving fuel test will be performed where the corrosion coupon materials will be mounted on racks and immersed in a circulating bath of the F-76 and Alternate Fuel heated to 120 degrees F. Three cleaned and weighed metallic coupons of each material listed in Table 1 in addition to two coupons of each material assembled for crevice evaluation using Teflon® crevice washers and nylon bolts/nuts will be tested. All coupon types will be exposed at one time. Post exposure evaluation of the coupons will be conducted as discussed in section 4.1 of this test protocol.
10	At the end of the 180 day exposure period, all coupons will be removed, rinsed with solvent to remove any residual fuel, cleaned, dried and reweighed, repeating steps 4 and 6.
11	Obtain a sample of the post immersion fuel used for the flow tests. Conduct spectrographic analysis for iron, copper, aluminum and zinc. Compare with initial results as an indicator of specific metal type corrosion in the fuel. If any constituents have increased, sample and test fuel samples from the metallic materials that contain these constituents for additional comparison purposes.
12	Conduct the metallurgical analysis and corrosion rate calculations as denoted in Section 4.1 of this test protocol. Generate report of findings.

APPENDIX C**METALLIC MATERIALS SPECIFICATIONS**

See Appendix D for coating requirements

GENERIC DESIGNATION	SPECIFIC MATERIAL	Material Specification (or equivalent)	Heat Treating Specification (or equivalent)
Aluminum & Alloys	356-T6, uncoated	ASTM B26	As referenced in B26
	5052, uncoated	ASTM B209	N/A
	2024-T3, uncoated	ASTM B209	As referenced in B209
	7075-T6, uncoated	ASTM B209	As referenced in B209
	7075-T6, anodized, chromic acid per MIL-A-8625 Type I, Class 1 non-dyed	ASTM B209	As referenced in B209
	7075-T6, anodized, sulfuric acid MIL-A-8625 Type IIB	ASTM B209	As referenced in B209
	7075-T6, chromate conversion coated MIL-DTL-5541, Class 1A, Type II no hexavalent chrome	ASTM B209	As referenced in B209
Copper & Alloys	Silicon bronze alloy C65100, or equivalent	ASTM B96	N/A
	Leaded brass alloy C36000, or equivalent.	ASTM B96	N/A
	Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000 , uncoated	ASTM B152	N/A
	CuNi 90-10	ASTM B152	N/A
Steel (Carbon, Alloy)	1010 (or 1020) carbon steel, uncoated (and coated per below)	ASTM A635	N/A
	Ion Vapor Deposition (IVD) aluminum		
	Tin		
	Silver		
	Cadmium		
	Nickel		
	Zinc		
Stainless Steel	440C, heat treated	ASTM A276	Quench and temper to hardness of 55-60 HRC
Nickel & Alloys	IN 200, uncoated	ASTM B162	N/A
Titanium & Alloys	6Al-4V	ASTM B265	N/A
Solder	60-Sn – 40 Pb	ASTM B32	N/A

1. NEED TO ADD 304 STAINLESS TO THIS LISTING
2. NEED TO ADD STELLITE, TUNGSTEN CARBIDE, SILICON CARBIDE AND CHROME PLATED BRASS TO THIS LISTING.

APPENDIX D**METALLIC MATERIAL PLATING REQUIREMENTS****References**

- (1) U. S. Navy Alternative Fuels Program, Immersion Testing of Metallic and Non-Metallic Materials, Rev. 1, 4/16/10

This document summarizes the key ordering requirements for the platings to be used on the metallic specimens for the alternative fuel immersion testing to be conducted per the reference (1) protocol.

These platings for fuel wetted parts were identified through review of drawings and other documentation as detailed in reference (1). In all cases the platings identified were only in generic terms such ‘tin’ or ‘silver with no details regarding plating method, thickness, etc. Such details are necessary for procurement of the test specimens, so this document provides the necessary details based on past experience.

Because diesel fuel and the algae-based and other similar alternative fuels are not aggressive corrosion environments, the approach for specifying the coating thickness requirements is to use thickness corresponding to the ‘moderate’ application designation where used in the plating specifications, specifically 0.0003” minimum for tin plating per ASTM B545 and zinc plating per ASTM B633, which corresponds to Class 3 for the ion-vapor-deposited aluminum per AMS2427 and Class 2 for cadmium per AMS-QQ-P-416. The silver plating ASTM B700 and nickel plating ASTM B689 plating specifications do not include a standard thickness at 0.0003” minimum, so the standard thickness at 0.0002” minimum is specified because actual thickness values will likely be somewhat greater.

The plating method is not expected to affect plating corrosion performance in these tests, but for consistency the electrodeposited process is specified for all the platings except for aluminum, for which ion vapor deposition is the preferred process.

PLATING TYPE	APPLICABLE SPECIFICATION	ORDERING REQUIREMENTS (spec ref)	RECOMMENDATION FOR IMMERSION TESTS
Ion Vapor Deposited (IVD) Aluminum	Aerospace Material Specification (AMS) 2427D, July 2007 Aluminum Coating Ion Vapor Deposition	Coating Thickness (3.4.1.1, Table 1) -3 0.0003-0.0008” (336 hrs salt spray resistance) -5 0.0005-0.0010” (504 hrs salt spray resistance) -10 0.0010-0.0015” (672 hrs salt spray resistance)	Class 3 (0.0003-0.0008”)
		Supplementary chromate treatment for ferrous base metals <u>Optional</u>	N/A
		Acceptance standards Testing frequency Statistical sampling plan Corrosion test	N/A

PLATING TYPE	APPLICABLE SPECIFICATION	ORDERING REQUIREMENTS (spec ref)	RECOMMENDATION FOR IMMERSION TESTS
Tin	ASTM B545-97 (reapproved 2009) Standard Specification for Electrodeposited Coatings of Tin	Service Class (thickness - min) (4.2) <u>See attached description of typical applications for each class</u> Class A – 2.5 um (0.0001”) Class B – 5 um (0.0002”) Class C – 8 um (0.0003”) Class D – 15 um (0.0006”) Class E – 30 um (0.0012”) Class F – 1.5 um (0.00006”)	Class C (0.0003” min) (0.0006” max)
		Substrate composition (6.1)	Carbon steel, AISI 1010 or 1020
		Location of significant surfaces (3.1.2)	Both sides of coupon
		<u>Optional</u> Additional underplating Surface appearance Hydrogen embrittlement relief	N/A
Silver	ASTM B700-08 Standard Specification for Electrodeposited Coatings of Silver for Engineering use	Type (purity) (4.2) 1 – 99.9% min 2 – 99.0% min 3 – 98.0% min	Type 3
		Grade (surface appearance) (4.3) A – Mat B – Bright C – Bright (polished A) D - Semibright	Grade A
		Class (supplementary surface treatment) (4.4) N – no treatment S – chromate	Class N
		Thickness (6.6, Table X3.1) 1 um min (0.00004”) 2.5 um (0.0001”) 5 (0.0002”) 10 (0.0004”) 20 (0.0008”) >40 (0.0016”)	5 um min (0.0002”) (0.0004” max)
		Nature of substrate	Carbon steel, AISI 1010 or 1020
		Significant surfaces (3.2.2)	Both sides of coupon
		Appearance (6.7)	Per standard commercial practice

PLATING TYPE	APPLICABLE SPECIFICATION	ORDERING REQUIREMENTS (spec ref)	RECOMMENDATION FOR IMMERSION TESTS
		Uniformity as specified in manufacturing document	
		Underplates (6.3.4) Nickel for copper substrate	
		Testing requirements (various sections) adhesion, hardness, absence of embrittlement, solderability, spectral reflectance, electrical conductivity	
		Sampling plans, QA (7)	
Cadmium	AMS-QQ-P-416 Rev. C, 9/09 Plating, Cadmium (Electrodeposited)	Type (1.2.1) I – As plated II – Chomrate treatment III – Phosphate treatment	Type I
		Class (thickness - min) (1.2.2) 1 – 0.0005 in 2 – 0.0003 in 3 – 0.0002 in	Class 2 (0.0003" min) (0.0005" max)
Nickel	AMS 2403 <i>NOTE. AMS appears to be the preferred specification in lieu of ASTM B689, which is provided for information below.</i>	Thickness	0.0002" min 0.0005" max
	ASTM B689-97 (reapproved 2008) Standard Specification for Electroplated Engineering Nickel Coatings	Classification (plating bath additives) (4.1) Type 1 – None Type 2 – Sulfur or other compounds Type 3 – Dispersed submicron particles	
		Thickness Class (min) (4.2) Class 5 – 5 um (0.0002") Class 25 – 25 um (0.001") Class 50 – 50 um (0.002") Class 100 – 100 um (0.004") Class 200 – 200 um (0.008") Class X – as specified	Class 5 (0.0002" min)
		Significant surfaces (3.1)	Both sides of coupon
		Optional Number of test specimens for destructive tests; thickness,	N/A

PLATING TYPE	APPLICABLE SPECIFICATION	ORDERING REQUIREMENTS (spec ref)	RECOMMENDATION FOR IMMERSION TESTS
		adhesion, porosity, hydrogen embrittlement tests; required base metal grinding; base metal surface finish; appearance; post-treatment grinding; dimensional tolerances; microhardness;	
Zinc	ASTM B633- (reapproved 2008) Standard Specification for Electroplated Engineering Nickel Coatings	Thickness (min) (Service Condition – SC) (4.1) SC4 (very severe) – 25 um (0.001”) SC3 (severe) – 13 um (0.0005”) SC2 (moderate) – 8 um (0.0003”) SC1 (mild) – 5 um (0.0002”)	SC2 (0.0003” min) (0.0005” max)
		Finish (supplementary treatments) (4.2) Type I – as plated Type II – chromate - colored Type III – chromate – colorless Type IV – phosphate	Type I
		Location of significant surfaces (5.2.3)	Both sides of coupon
		<u>Optional</u> Luster; corrosion resistance test; hydrogen embrittlement test; sample size for inspection; supplementary requirements	N/A

Electrodeposited Tin - ASTM B545

Class	Minimum Thickness	Typical Applications
A	2.5 μm (100 $\mu\text{in.}$)	Mild service conditions, particularly where the significant surface is shielded from the atmosphere (as in electronic connector housings). To provide corrosion and tarnish resistance where greater thicknesses may be detrimental to the mechanical operation of the product (for example, small electrical spring contacts and relays). Class A is often used for tin coatings that are not to be soldered, but must function as low-resistance electrical contact surfaces.
B	5 μm (200 $\mu\text{in.}$)	Mild service conditions with less severe requirements than Class C (below). Applications are as follows: precoating on solderable basis metals to facilitate the soldering of electrical components; as a surface preparation for protective painting; for antigalling purposes; and as a stop-off in nitriding. Also found on baking pans after reflow.
C	8 μm (320 $\mu\text{in.}$), (10 μm (400 $\mu\text{in.}$) for steel substrates)	Moderate exposure conditions, usually indoors, but more severe than Class B. Examples are electrical hardware (such as cases for relays and coils, transformer cans, screened cages, chassis, frames, and fittings) and for retention of the solderability of solderable articles during storage.
D	15 μm (600 $\mu\text{in.}$) (20 μm (800 $\mu\text{in.}$) for steel substrates)	Severe service, including exposure to dampness and mild corrosion from moderate industrial environments. Examples are fittings for gas meters, automotive accessories (such as air cleaners and oil filters), and in some electronic applications.
E	30 μm (0.0012 in.)	Very severe service conditions, including elevated temperatures, where underlying metal diffusion and intermetallic formation processes are accelerated. Thicknesses of 30 to 125 μm (0.0012 to 0.005 in.) may be required if the coating is subjected to abrasion or is exposed to slowly corrosive liquids or corrosive atmospheres or gases. Thicker coatings are used for water containers, threaded steel couplings of oil drilling strings, and seacoast atmospheres.
F	1.5 μm (60 $\mu\text{in.}$)	Coatings subject to mild etchants are included. Similar to Class A, but for shorter-term contact applications and short shelf-life requirements, subject to purchaser approval.

APPENDIX E**ADDITIONAL METALLIC MATERIALS BEING CONSIDERED**

A review of Coast Guard fuel wetted components showed that the fuel wetted materials are covered by the selected materials in Table 1 except as noted below for the 378' WHEC High Endurance Cutter Fairbanks Morse 38TD8-1/8 MDE. These materials may also be included on the same type of engines used in Navy ships, so are being evaluated for inclusion in the test matrix. Sample ordering requirements are provided if needed.

- Chrome plated brass ball in centrifuge fuel valves.

Sample ordering requirements

Brass material: UNS C26000, C26800, C27200, or C28000 per ASTM B36
Plating: 0.0002-0.0006" thick per AMS 2406

- Silicon carbide, tungsten carbide, or Stellite seats in fuel boost pumps

Sample ordering requirements (from Metal Sample catalog)

Silicon carbide (standard grade)
Tungsten carbide 8% cobalt (Co) binder
Stellite 1 (UNS R30002) or Stellite 3 (UNS R30103)

APPENDIX F

10310
Ser 612/14-262
X1453
8 SEPT 2014

MEMORANDUM

From: Code 612 (E. Hakun)
To: Code 614 (S. Murray)

Subj: **ALTERNATIVE FUELS (DSH, HD CD-1, HD CD-2) PROGRAM, IMMERSION TESTING OF METALLIC MATERIALS – METALLURGICAL ANALYSIS**

Ref: (a) US Navy Alternative Fuels Program, Materials Immersion Test Protocol, Rev. 2, 6 AUG 2010
(b) E-mail from NSWC Code 614 (S. Murray) to NSWC Code 612 (E. Hakun) dated 16 SEPT 2013
(c) E-mail from NSWC Code 614 (S. Murray) to NSWC Code 612 (E. Hakun) dated 3 APR 2014
(d) MIL-DTL-16884L, Detail Specification, Fuel, Navy Distillate, 23 OCT 2006
(e) NSWC Memo, Ser 612/11-078, 5 DEC 2011

Encl: (1) Alternative Fuels Program, Immersion Testing of Metallic Materials –Metallurgical Analysis

1. The Naval Surface Warfare Center, Carderock Division – Ship Systems Engineering Station (NSWCCD-SSES), Metallurgy and Fasteners Branch, Code 612 was tasked as outlined in reference (a) to conduct an evaluation of metallic materials after exposure to a series of tests utilizing three (3) potential alternative fuels, Direct Sugar to Hydrocarbon (DSH) and two (2) forms of Hydrotreated Depolymerized Cellulosic Diesel (HD CD). The latter two (2) fuels were identified as HD CD-1 and HD CD-2, respectively, per reference (b). The HD CD-1 was missing the lighter distillation fractions while the HD CD-2 contained all distillation fractions, per reference (c). The data obtained would be utilized for comparison to the standard Navy distillate fuel, reference (d), NATO F-76, which was a previously tested petroleum based fuel with results obtained via reference (e).

2. The approach conducted for the analysis was to examine and evaluate test coupons of various metals after subjecting them to the alternative fuels in the following conditions: static immersion testing, flow testing as well as immersion testing with concentration of potential biological effects in fuel/seawater and fuel/distilled water mixtures.

3. At the completion of each of the tests, an analysis was conducted consisting of a visual examination, stereoscopic examination, Scanning Electron Microscope (SEM) examination (where necessary) and a metallographic analysis. The final report is provided as enclosure (1).

4. The following conclusions were drawn as a result of this investigation:

The metallurgical analysis conducted on the alternative fuels DSH, HDCD-1 and HDCD-2, displayed similar results in the static immersion and flow testing when compared with the previously evaluated NATO F-76 fuel. There was no observed metallurgical change in the metallic material coupons, with no evidence of corrosive attack of the base metals or attack of the coupon surfaces at the crevice sites. The F-76 fuel exhibited indications of general pitting on the carbon steel coupons with electrodeposited zinc plating. The pitting, though, was only evident in the plating not the base metal. In this study, the DSH, HDCD-1 and HDCD-2 fuels did not exhibit any evidence of pitting of the zinc plating. A difference, however, was observed with the leaded brass coupons that were immersion tested in the DSH fuel. The DSH fuel caused the leaded brass coupons to darken, having a deep blue colored appearance. Retesting by the Corrosion and Coatings Engineering Branch, Code 614, of three (3) additional leaded brass coupons in the DSH fuel again resulted in the coupons turning blue; however, they were brighter in appearance. SEM and metallographic evaluation, however, disclosed no evidence of any corrosive attack in the original testing or the retesting.

For the immersion testing, designed to concentrate potential biological effects in fuel/seawater and fuel/distilled water mixtures, corrosive attack and pitting was observed on the aluminum and carbon coupons subjected to each fuel/seawater mixture as well as the carbon steel coupons that were subjected to each fuel/deionized water mixture. Pit depths were similar for the carbon steel coupons subjected to the fuel/seawater mixture: DSH fuel (0.0025 in.), HDCD-1 fuel (0.003 in.), HDCD-2 (0.002 in.), and for the F-76 fuel (0.004 in.). There was, however, some variation of pit depth observed on the aluminum coupons that were subjected to the fuel/seawater mixture: the HDCD-1 fuel had the least depth (0.005 in.), followed by the F-76 fuel (0.012 in.), then the DSH fuel (0.025 in.), and lastly the HDCD-2 fuel. While the pitting was only evident on the seawater immersed side for the DSH, HDCD-1, and F-76 fuels, the HDCD-2 fuel displayed pitting on both the seawater immersed side (0.030 in.) and at the fuel/seawater interface. The pit observed at the fuel/seawater interface initiated at the edge of the coupon and had a width of 0.070 in., penetrated inward 0.032 in. and through the coupon cross sectional thickness (0.064 in.). For the carbon steel coupons subjected to the fuel/deionized water mixture, the HDCD-1 fuel had the shallowest pit depth (0.0015 in.), followed by the F-76 (0.0055 in.), then the DSH fuel (0.011 in.), and finally the HDCD-2 fuel (0.013 in.). The pitting on these coupons was observed in close proximity/adjacent to the fuel/deionized water interface for the DSH, HDCD-1, and F-76 fuels. The pitting observed on the HDCD-2 coupons was on the deionized water side.

5. NSWCCD-SSS technical point of contact for this matter is Eric Hakun, Code 612, Commercial (215) 897-1453, Defense Switched Network (DSN) 443-1453, eric.hakun@navy.mil.



ERIC HAKUN
Materials Engineer

cc: 612 (file)

REFERENCES

- (a) US Navy Alternative Fuels Program, Materials Immersion Test Protocol, Rev. 2, 6 AUG 2010
- (b) MIL-DTL-16884L, Detail Specification, Fuel, Navy Distillate, 23 OCT 2006
- (c) E-mail from NSW Code 614 (S. Murray) to NSW Code 612 (E. Hakun) dated 3 APR 2014
- (d) ASTM G31, Standard Practice for Laboratory Corrosion Testing of Metals, MAY 2004

INTRODUCTION

The Naval Surface Warfare Center, Carderock Division – Ship Systems Engineering Station (NSWCCD-SSES), Metallurgy and Fasteners Branch, Code 612 was tasked as noted in reference (a) to conduct an evaluation of metallic materials found in Navy and Coast Guard shipboard fuel systems following exposure to various test conditions utilizing three (3) potential alternative fuels, Direct Sugar to Hydrocarbon (DSH) and two (2) forms of Hydrotreated Depolymerized Cellulosic Diesel (HD CD), in comparison to the previously evaluated standard Navy distillate fuel, reference (b), NATO F-76. The latter fuel will simply be referred to as F-76 for the remainder of this analysis report. The two (2) forms of Hydrotreated Depolymerized Cellulosic Diesel (HD CD) were identified by NSWCCD-SSES, Corrosion and Coatings Engineering Branch, Code 614, as HD CD-1 and HD CD-2, respectively. The HD CD-1 was missing the lighter distillation fractions while the HD CD-2 contained all distillation fractions, per reference (c).

The approach utilized for the test program was to examine and evaluate coupons of various metals prior to and after subjecting them to the alternative fuels in the following conditions: static immersion testing, flow testing as well as immersion testing, where there was a concentration of potential biological effects in fuel/seawater and fuel/distilled water mixtures. NSWCCD-SSES, Corrosion and Coatings Engineering Branch, Code 614, procured the coupons and performed the testing.

At the completion of each of the tests, a metallurgical analysis was conducted on the coupons by NSWCCD-SSES, Code 612 consisting of a visual examination, stereoscopic examination, Scanning Electron Microscope (SEM) examination (if necessary) and a metallographic analysis. The results of this analysis are presented below.

PROCEDURE

Table 1 show the various base metals (and applied coatings/surface finishes) that were tested in this program.

Table 1
General Alloy Family, Specific Material and Coating/Finish

GENERIC DESIGNATION	SPECIFIC MATERIAL
Aluminum Alloys	• 356-T6, uncoated • 2024-T3, uncoated • 7075-T6, uncoated • 7075-T6, anodized (chromic acid) • 7075-T6, anodized (sulfuric acid) • 7075-T6, chromate conversion coated • 5052, uncoated, UNS A95052
Copper Alloys	• Silicon bronze alloy C65100, or equivalent • Leaded brass alloy C36000, or equivalent. • Unalloyed, Electrolytic Tough Pitch (ETP) – CDA 110, UNS C11000 , uncoated • CDA706, CuNi 90-10
Steel (Carbon)	• 1010 carbon steel, uncoated • 1010 carbon steel, hot dipped galvanized • 1010 carbon steel, with Ion Vapor Deposition (IVD) aluminum plating (Class 3 thickness 0.0003 to 0.0008 in.) • 1010 carbon steel, with Ion Vapor Deposition (IVD) aluminum plating (Class 10 thickness-0.0010 to 0.0015 in.) • 1010 carbon steel, with Electrodeposited tin plating • 1010 carbon steel, with Electrodeposited silver plating • 1010 carbon steel, with Electrodeposited cadmium plating • 1010 carbon steel, with Electrodeposited nickel plating • 1010 carbon steel, with Electrodeposited zinc plating
Stainless Steels	• 440C, heat treated • 304, UNS S30403
Nickel Alloy	• IN 200, uncoated
Titanium Alloy	• 6Al-4V
Solder	• 60Sn – 40Pb

A total of twenty (20) coupons of each metal were utilized. Each of the coupons was approximately ½-in. wide X 3-in. long X 1/16-in. thick. In addition, each coupon contained a hole approximately ¼-in. dia. located ½ in. from one end. The specific testing conducted on all of the coupons consisted of the following:

1. Immersion Testing: Static Immersion testing in accordance with the practices of reference (d). The metal coupons were suspended in each fuel type on a Teflon coated wire attached to the Teflon[®] lid liner of a 475 mL (16 oz.) wide-mouth glass jar. There were:

- a. three (3) coupons of the same material type per jar, and
- b. two (2) crevice corrosion assemblies using Teflon[®] crevice washers and nylon bolts/nuts per jar.

The jars were filled with a known volume of the fuel in order to completely cover the coupons. The coupons were suspended in each of the fuels. All jars were placed into a water temperature controlled bath and heated to 120 °F for 180 days.

2. Flow Testing: Flow testing also in accordance with practices of reference (d). A moving fuel test was performed where the corrosion coupon materials were mounted on racks and immersed in a circulating bath of each fuel heated to 120 °F. There were again:
 - a. three (3) coupons of the same material type, and
 - b. two (2) crevice corrosion assemblies using Teflon[®] crevice washers and nylon bolts/nuts.

All coupon types were exposed at one time.

3. Immersion Testing, biological effects in each fuel/seawater and each fuel/distilled water: 180 day static immersion test in fuel/water mixtures at 120 °F using a constant temperature water bath to maintain temperature. The waters used were natural seawater from the New Jersey shore and deionized water from the NSWCCD-SSES Code 614 laboratory. Cleaned and weighed metallic coupons (3 each) of carbon steel per UNS C10100, stainless steel per UNS S30403 and aluminum per UNS A95052 were suspended on Teflon[®] wire in 240 mL (8 oz.) sealed glass jars (one coupon per jar) containing an equal volume of fuel/seawater and fuel/distilled water. One half of each coupon was in the fuel layer and the other half in the seawater or deionized water layer, respectively, under static conditions. There was no attempt to replenish the fuel or seawater/deionized water during the test period.

RESULTS

Initial Examination

A visual and low magnification (< 50X) examination was conducted on all of the coupons in the as-received condition. In addition, transverse metallographic cross sections were taken to further document the surface condition of the coupons prior to any tests being conducted. Figures 1 - 3 show example photographs of some of the coupons to illustrate their appearance, as-received.

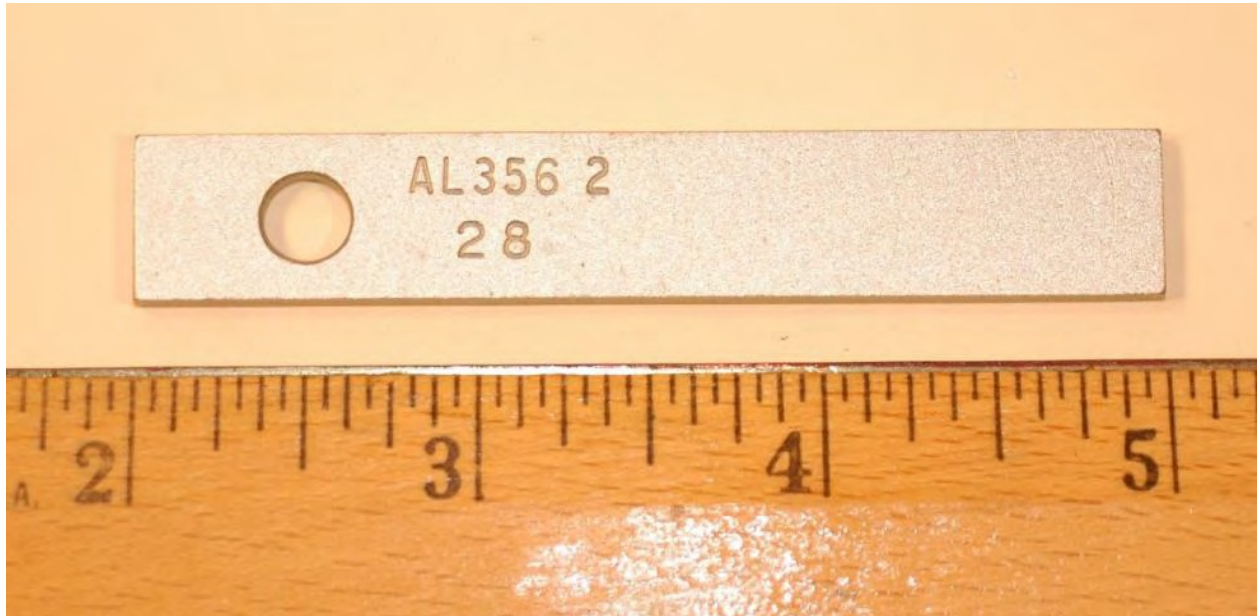


Figure 1. An example of one (1) of the Aluminum coupons, type 356, uncoated, as received.



Figure 2. An example of one (1) of the IVD Aluminum Class 3 plated carbon steel coupons, as received.



Figure 3. An example of one (1) of the copper alloy coupons, leaded brass alloy CDA360 (UNS C36000), as received.

Immersion Test Results

Examination of all of the coupons exposed to the DSH, HDCCD-1, and HCDC-2 fuels displayed similar results when compared with the previously evaluated F76 fuel. There was no observed metallurgical change in the base materials, with no evidence of corrosive attack of the base metals or attack of the coupon surfaces at the crevice sites. Macroscopic examination disclosed no appreciable change in appearance with the exception of the leaded brass coupons and the carbon steel coupons that were electrodeposited with zinc. Regarding the leaded brass coupons – the DSH fuel caused the leaded brass coupons to darken, having a deep blue appearance (Figure 4). The surface of one (1) of the DSH exposed coupons was examined utilizing the Scanning Electron Microscope (SEM)/Energy Dispersive Spectroscopy (EDS) to characterize any difference in chemical constituents. EDS provides semi-quantitative chemical composition with the compositions generally classified as major (wt. % > 10%), minor (wt. % of 1-10 %), or trace (wt. % < 1%). The results displayed major amounts of copper and zinc, along with minor amounts of lead, carbon, oxygen and silicon. The copper, zinc and lead are all expected since they are part of the base chemistry of UNS C36000. The carbon, oxygen, and silicon constituents would appear to be a component of the dark surface film. SEM and microscopic evaluation disclosed no evidence of any corrosive attack.

Due to the unusual appearance, the immersion test was repeated by Code 614 on the leaded brass coupons subjected to the DSH fuel. A photograph showing these coupons is shown in Figure 5. The coupons again had a blue color, although they were brighter in color in comparison to the previously tested coupons. The surface of one (1) of these DSH exposed coupons (07) was also examined utilizing the Scanning Electron Microscope (SEM)/Energy

Dispersive Spectroscopy (EDS) to characterize any difference in chemical constituents. The results displayed major amounts of copper and zinc, along with minor amounts of lead, carbon, oxygen and silicon, similar to the results from the first set of samples tested. SEM and microscopic evaluation again disclosed no evidence of any corrosive attack.



Figure 4. Macro photograph of the leaded brass coupon that were immersion tested in the DSH fuel. Note the dark blue colored appearance.

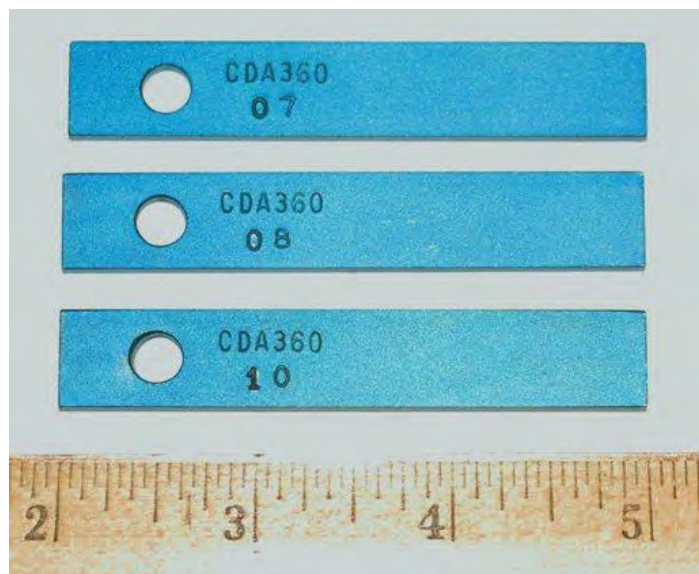


Figure 5. Macro photograph of the leaded brass coupons that were immersion tested in the DSH fuel. Repeated test by Code 614. Note the bright blue colored appearance.

For the carbon steel coupons that had the electrodeposited zinc plating, there was discernible general pitting that was observed macroscopically, with the SEM and microscopically for the F-76 fuel (Figures 6 - 8). The depth of the pits was approximately 0.0009 in. for the F-76 fuel; however, the pits did not penetrate the base metal. No pitting was observed on any of these coupons that were subjected to the DSH, HDCD-1, and HDCD-2 fuels, photomicrographs of which are shown in Figures 9 - 11, respectively.



Figure 6. Macro photograph of a carbon steel coupon that had the electrodeposited zinc plating, static immersion tested in the F-76 fuel. Fine pits were observed. Mag.: 50X

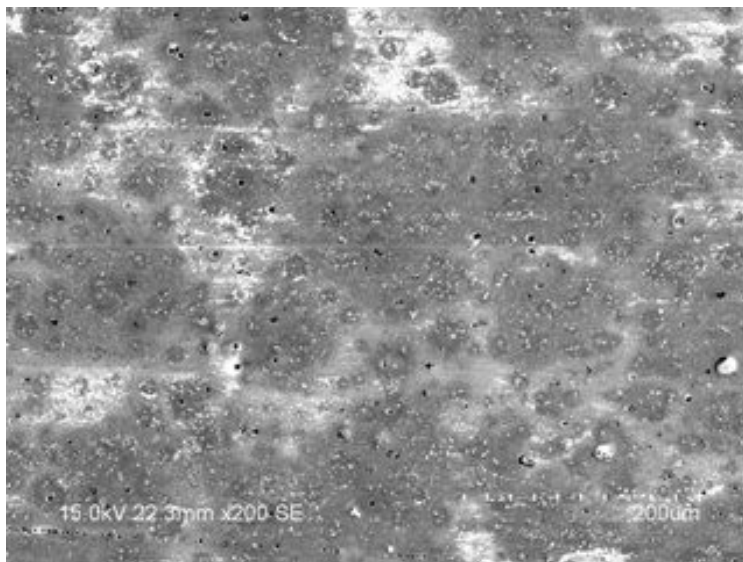


Figure 7. SEM photograph of a carbon steel coupon that had the electrodeposited zinc plating, static immersion tested in the F-76 fuel. Fine pits are evident. Mag.: 200X



Figure 8. Photomicrograph of a carbon steel coupon that had the electrodeposited zinc plating, static immersion tested in the F-76 fuel. Fine pits, indicated by the white arrows, are evident in the zinc plating, extending to a maximum depth of 0.0009 in. As polished, Mag.: 200X

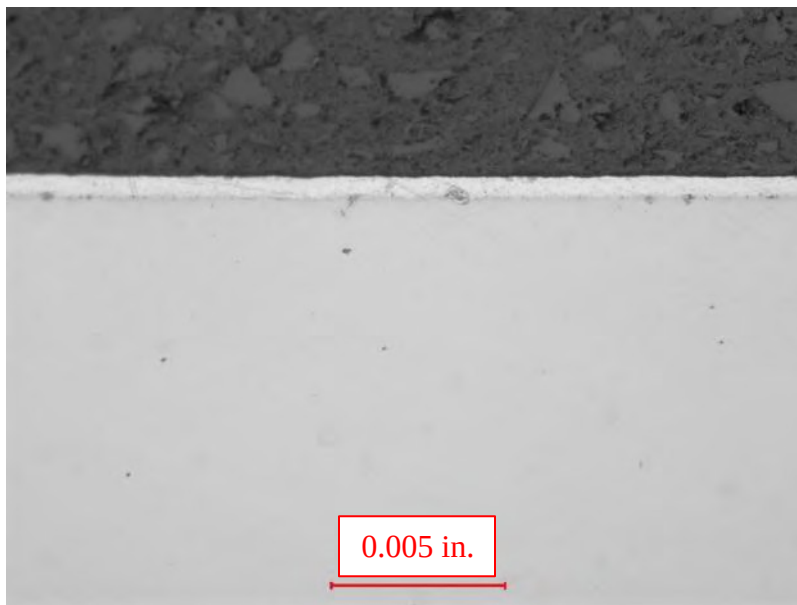


Figure 9. Photomicrograph of a carbon steel coupon that had the electrodeposited zinc plating, static immersion tested in the DSH fuel. There was no evidence of any pitting attack. As polished, Mag.: 200X

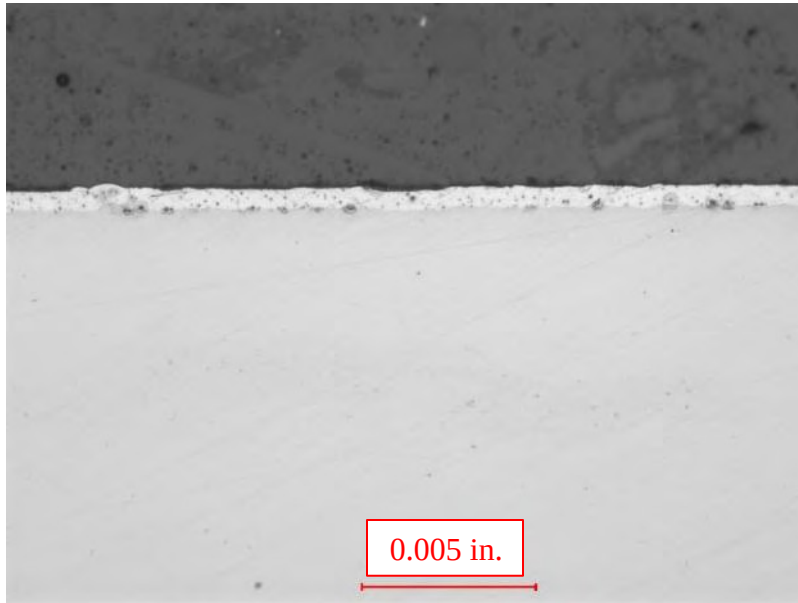


Figure 10. Photomicrograph of a carbon steel coupon that had the electrodeposited zinc plating, static immersion tested in the HDCD-1 fuel. There was no evidence of any pitting attack. As polished, Mag.: 200X

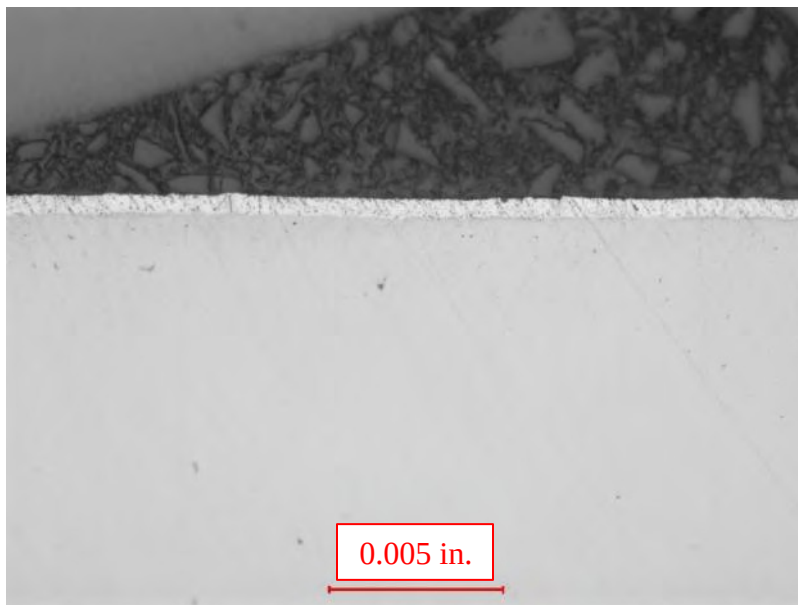


Figure 11. Photomicrograph of a carbon steel coupon that had the electrodeposited zinc plating, static immersion tested in the HDCD-2 fuel. There was no evidence of any pitting attack. As polished, Mag.: 200X

Testing of the crevice corrosion assemblies, as detailed on page 4 in paragraph 1b. above, displayed similar results for the three (3) fuels in comparison to the F-76 fuel. The coupons showed evidence of discernible staining at the washer locations, particularly the four (4) copper alloy coupons. Figures 12 - 19 show photographs of typical stains observed for a couple of the

copper alloy coupons where the crevice washers and flat washers were in contact with the coupons.



Figure 12. Macro photograph of Cu-Ni alloy CDA 706, after immersion testing in DSH fuel as a crevice corrosion assembly. Note the stains that developed at the crevice washer site. Mag.: 10X



Figure 13. Opposite side of the coupon shown in Figure 12. Macro photograph of Cu-Ni alloy CDA 706, after immersion testing in DSH fuel as a crevice corrosion assembly. Note the stains that are evident on the flat washer side. Mag.: 10X



Figure 14. Macrophotograph of Cu-Ni alloy CDA 706, after immersion testing in HDCD-1 fuel as a crevice corrosion assembly. Note the stains that developed at the crevice washer site. Mag.: 10X



Figure 15. Opposite side of the coupon shown in Figure 14. Macrophotograph of Cu-Ni alloy CDA 706, after immersion testing in HDCD-1 fuel as a crevice corrosion assembly. There was evidence of staining on the flat washer side. Mag.: 10X



Figure 16. Macro photograph of Cu-Ni alloy CDA 360, after immersion testing in HDCD-2 fuel as a crevice corrosion assembly. Note the stains that developed at the crevice washer site. Mag.: 10X



Figure 17. Opposite side of the coupon shown in Figure 16. Macro photograph of Cu-Ni alloy CDA 360, after immersion testing in HDCD-2 fuel as a crevice corrosion assembly. Note the stains that are evident on the flat washer side. Mag.: 10X



Figure 18. Macrophotograph of Cu-Ni alloy CDA 360, after immersion testing in F-76 fuel as a crevice corrosion assembly. Note the stains that developed at the crevice washer site. Mag.: 10X



Figure 19. Opposite side of the coupon shown in Figure 18. Macrophotograph of Cu-Ni alloy CDA 360, after immersion testing in F-76 fuel as a crevice corrosion assembly. Note the stains imparted on the flat washer side. Mag.: 10X

Further stereoscopic examination, however, disclosed no evidence of any initiated crevice sites. Metallographic cross sections taken through the stains revealed no indication of any attack. Significant stains were also observed on the following coupons:

- a) aluminum alloys - 2024-T3 (F-76 and HDCD-2), 7075-T6 (F-76 and HDCD-1), and 5052-H32 (F-76),
- b) carbon steel coupons- plain (DSH), electroplated with silver (F-76) and electroplated with cadmium (F-76, DSH, and HDCD-2).

In each case, higher magnification examination showed no crevice sites or indication of attack.

Flowing Test Results

Examination of all of the coupons exposed to the alternative fuels, DSH, HDCD-1, and HDCD-2, compared to the F-76 fuel, as noted on page 4 in paragraph 2a. above, also displayed similar results to the static immersion testing. Once again, the majority of the coupons had no noticeable change with the exception of the carbon steel coupons that had the electrodeposited zinc plating exposed to F-76 fuel. There was discernable pitting that was observed macroscopically, with the SEM and microscopically. The maximum depth of the pits was approximately 0.0005 in.; however, the pits did not penetrate the base metal.

Testing of the crevice corrosion assemblies, as detailed on page 4 in paragraph 2b. above, also exhibited similar results for all three (3) fuels. The four (4) copper alloy coupons again showed evidence of discernible staining at the washer locations. Further examination, however, confirmed no evidence of any initiated crevice sites. Metallographic cross sections taken through the stains revealed no indication of any attack. Obvious stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76), 7075-T6 (F-76, HDCD-1, and HDCD-2), and 5052-H32 (F-76),
- b) carbon steel coupons- plain (F-76, DSH and HDCD-1), electroplated with silver (F-76, DSH, HDCD-1 and HDCD-2), electroplated with IVD Aluminum Class 3 and Class 10 (DSH and HDCD-1)

In each case, closer stereoscopic and microscopic examination showed no crevice sites or indication of attack.

Immersion Testing, biological effects in fuel/seawater and fuel/deionized water

For the fuel/seawater testing, on the 5052-H32 aluminum coupons, a pit was observed on one (1) of the three (3) coupons tested with the DSH fuel (Figure 20). The pit was present on the seawater side and extended to a depth of approximately 0.025 in. (Figure 21).

For the HDCD-1 fuel/seawater testing on the aluminum coupons, pits were observed on two (2) of the three (3) tested coupons on the seawater immersed side. The pit depth was determined to be approximately 0.005 in.



Figure 20. Stereophotograph of one (1) of the aluminum coupons, after immersion testing in the DSH fuel/seawater mixture. Note the pit present in the seawater side of the coupon. Mag.: 8X

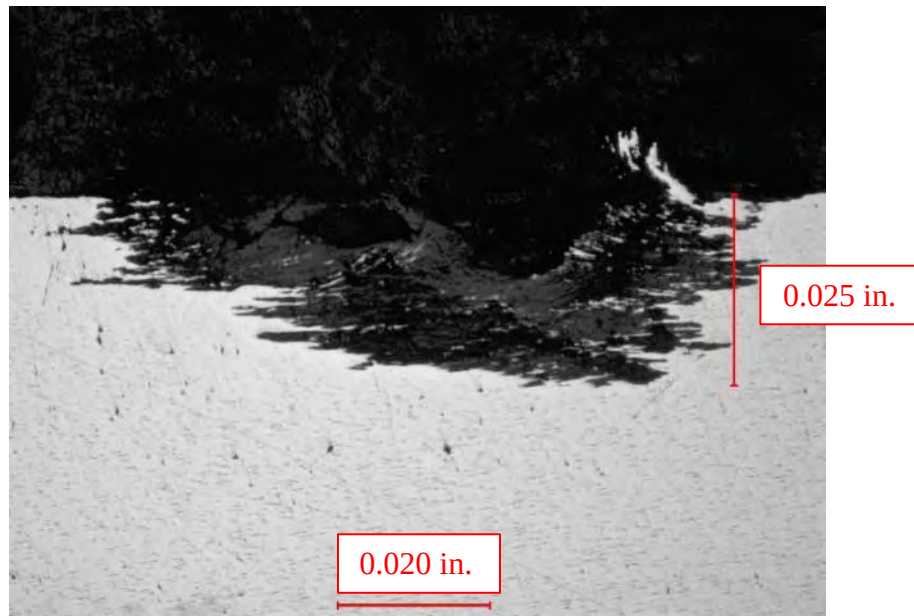


Figure 21. Photomicrograph showing a metallographic cross section taken through the pit shown in Figure 20, which extended to a depth of approx. 0.025 in. As polished, Mag.: 30X

For the HDCD-2 fuel/seawater testing on the aluminum coupons, pits were observed on all three (3) tested coupons. Two (2) of the coupons showed pits present on the seawater side, with one (1) of the pits extending to a depth of 0.030 in. (Figures 22 and 23). These pits were located on the short end/side of the coupon immersed in the seawater. The pit on the second coupon appeared to be superficial (Figure 24). The third coupon had a pit at the fuel/seawater interface which extended inward a total of 0.032 in. (Figures 25 and 26), when measured from the end of the coupon. The pit width (0.070 in.) was widest at the fuel/seawater interface at the edge of the coupon. In addition, the pit penetrated the entire coupon cross sectional thickness (0.064 in.).

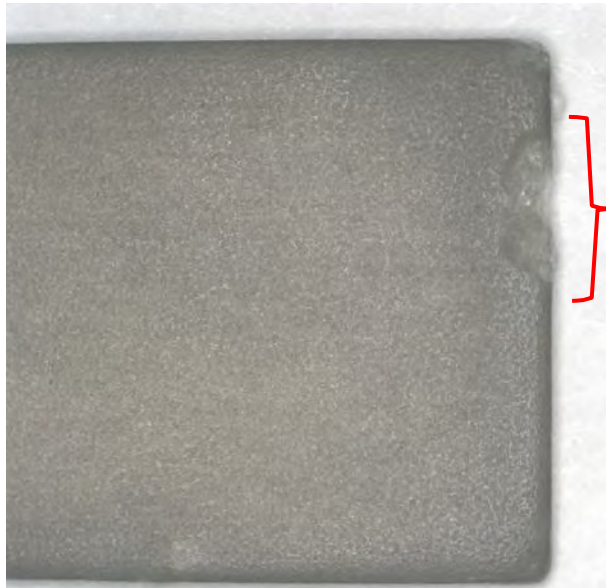


Figure 22. Stereophotograph of one (1) of the aluminum coupons, after immersion testing in the HDCD-2 fuel/seawater mixture. Note the pitting present in the seawater side, at the end of the coupon, which is highlighted within the red bracket. Mag.: 8X

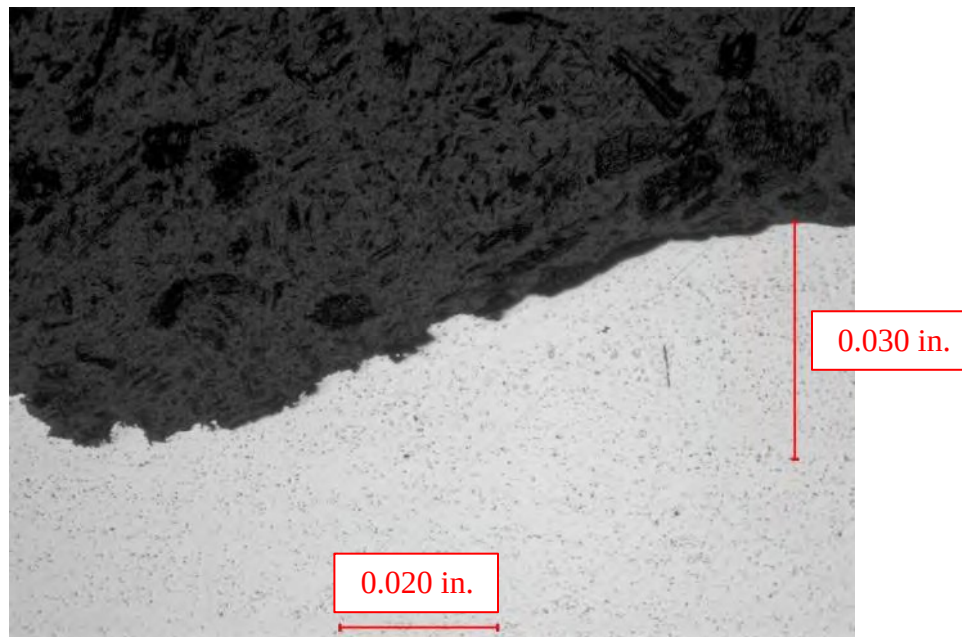


Figure 23. Photomicrograph showing a metallographic cross section taken through the pitting shown in Figure 22, which extended to a depth of approximately 0.030 in. As polished, Mag.: 30X

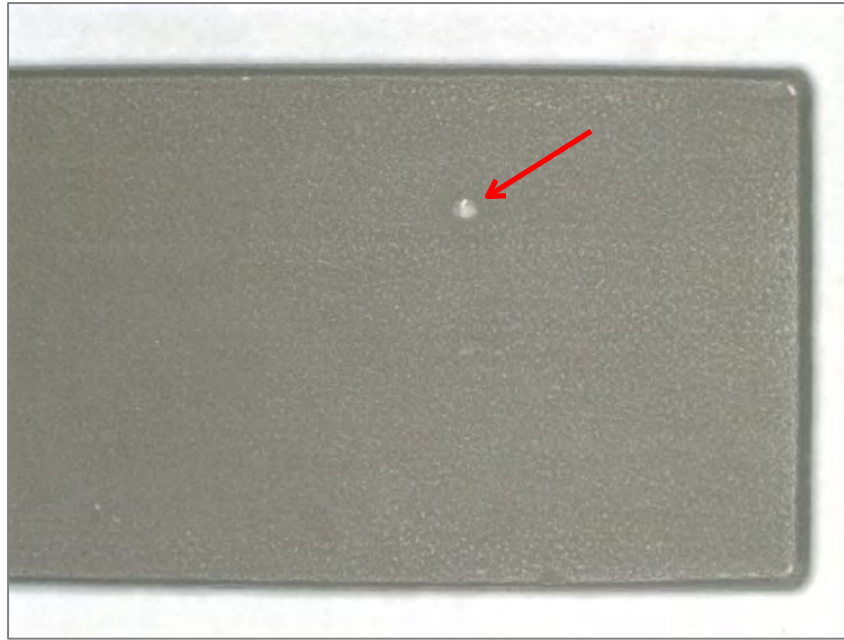


Figure 24. Stereophotograph of another one (1) of the aluminum coupons, after immersion testing in the HDCD-2 fuel/seawater mixture. Note the one (1) superficial pit present on the seawater immersed side (identified by the red arrow). Mag.: 10X

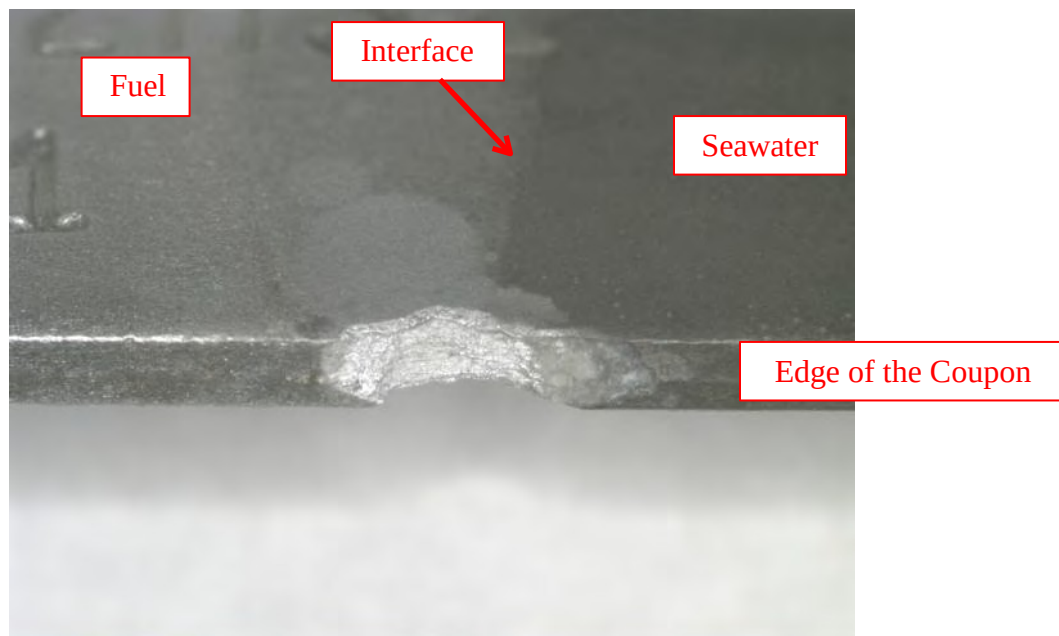


Figure 25. Stereophotograph of one (1) of the aluminum coupons, after immersion testing in the HDCD-2 fuel/seawater mixture. Here the pit was present at the fuel/seawater interface, at the edge of the coupon. Mag.: 15X

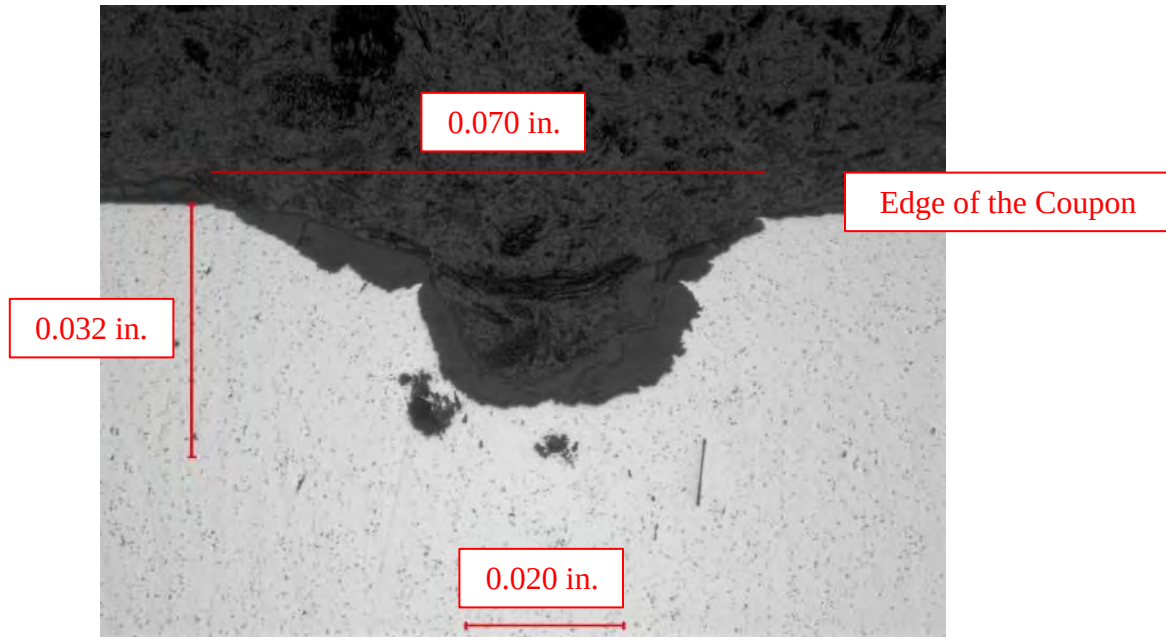


Figure 26. Photomicrograph showing a metallographic cross section taken through the pitting shown in Figure 25, which extended inward approximately 0.032 in. The width of the pit was measured to be 0.070 in., along the edge of the coupon. As polished, Mag.: 30X

For the prior F-76 fuel/seawater testing on the aluminum coupons, an individual pit was also observed on one (1) of the three (3) tested coupons. The pit was similarly on the seawater immersed side (Figures 27 and 28). The pit depth was determined to be approximately 0.012 in.



Figure 27. 35mm macrophotograph of the aluminum coupons, after immersion testing in F-76 fuel/seawater mixture. Note the pit present on the bottom coupon that was immersed in the seawater (identified by the white arrow). The portion that was immersed in the fuel was on the left, and the portion immersed in the seawater was on the right. Mag.: 0.5X



Figure 28. Enlarged view of the bottom coupon shown in Figure 27. The pit is located on the seawater side. Mag.: 4X

For the 304 stainless steel coupons, staining was observed on the seawater side of the samples (Figure 29); however, there was no evidence of any attack on the DSH, HDCD-1, HDCD-2, or F-76 fuel coupons.

Examination of the carbon steel coupons revealed evidence of oxidation as well as general overall corrosion on the seawater side on all four (4) fuels – DSH, HDCD-1, HDCD-2, and the F-76. Pitting was observed with maximum depths of 0.0025 in. measured for the DSH fuel sample, 0.003 in. for the HDCD-1 fuel sample, 0.002 in. for the HDCD-2 fuel, and 0.004 in. for the F-76 fuel (Figures 30 - 37).

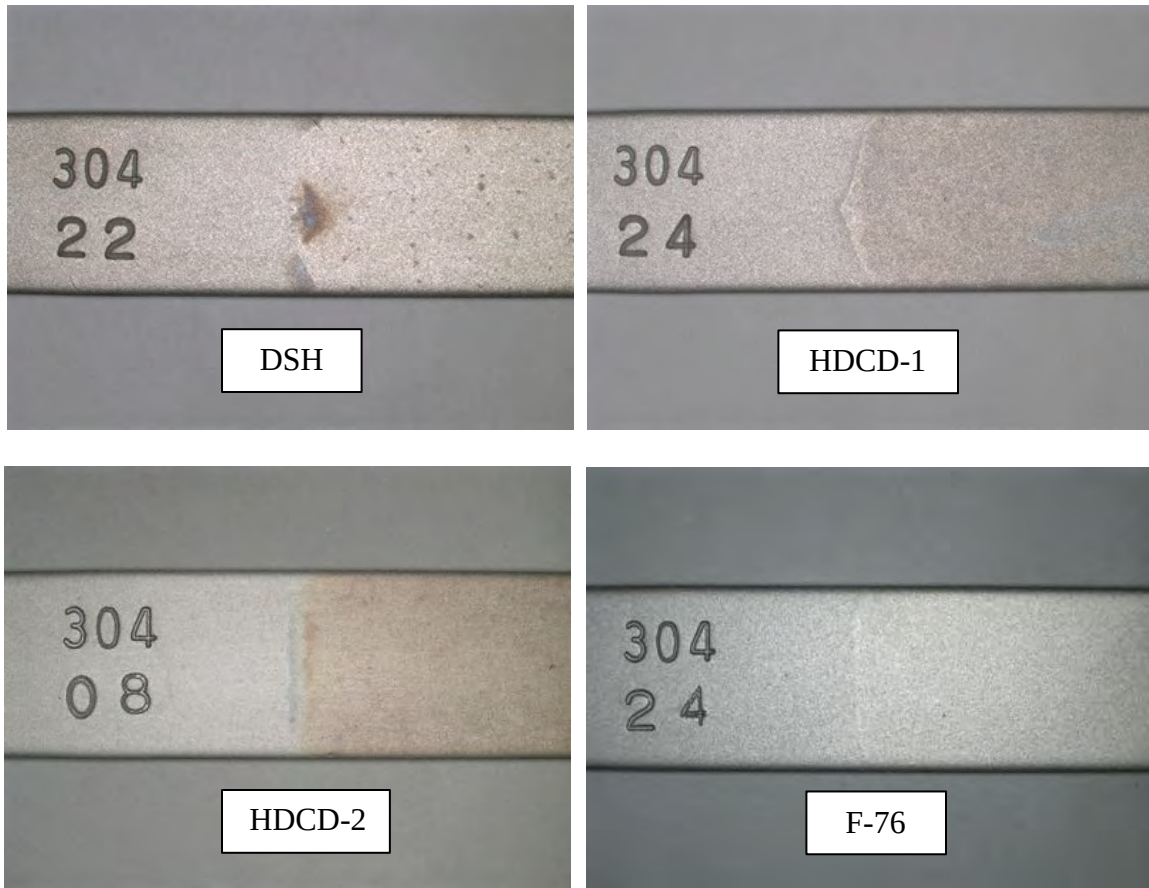


Figure 29. 35mm photographs of the 304 stainless steel coupons after immersion testing in the respective fuel/sea water mixture. The portion of each coupon that was immersed in the respective fuel was on the left, and the portion immersed in the seawater was on the right. The coupons exhibited slight staining. Mag.: 0.5X



Figure 30. Macrophotograph of a carbon steel coupon, after immersion testing in the DSH fuel/sea water mixture. The portion that was immersed in the DSH fuel was on the left, and the portion immersed in the seawater was on the right. Oxidation, general corrosion, and pitting were evident at the fuel/sea water interface as well as on the portion that was immersed in the seawater. Mag.: 5X

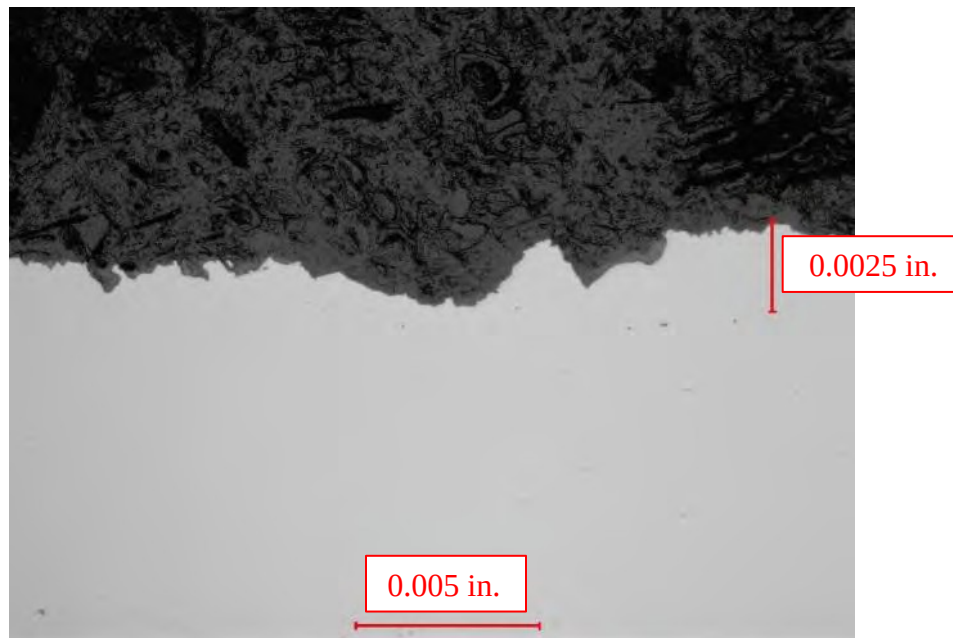


Figure 31. Photomicrograph taken in close proximity to the fuel/seawater interface of one (1) of the carbon steel coupons, after immersion testing in the DSH fuel/seawater mixture. The maximum pit/corrosion depth was approximately 0.0025 in. As polished, Mag.: 200X

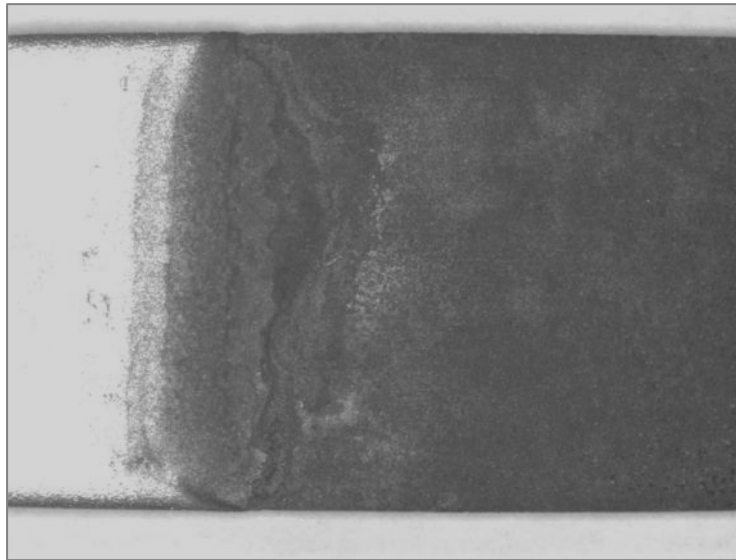


Figure 32. Macro photograph of a carbon steel coupon, after immersion testing in the HD CD-1 fuel/seawater mixture, showing an enlarged view of the fuel/seawater interface. The portion that was immersed in the HD CD-1 fuel was on the left, and the portion immersed in the seawater was on the right. Oxidation, general corrosion and pitting are evident at the fuel/seawater interface. Mag.: 10X

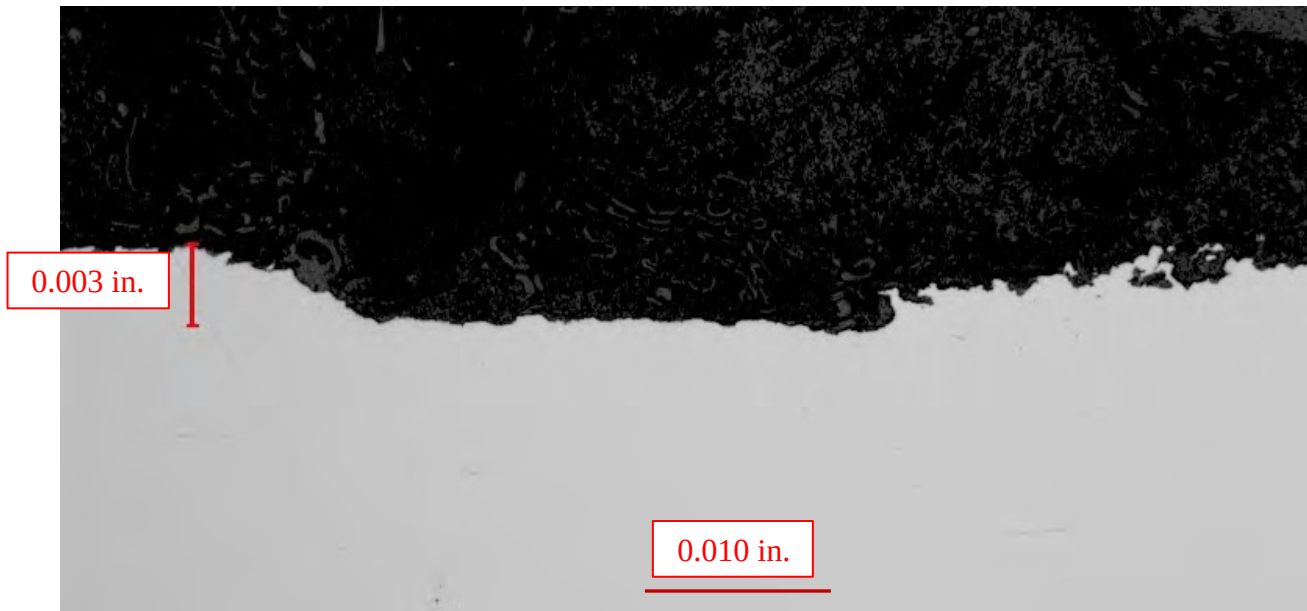


Figure 33. Photomicrograph showing an enlarged view of the area shown in Figure 32, taken in close proximity to the HDCD-1/seawater surface of one (1) of the carbon steel coupons, after immersion testing in the HDCD-1 fuel/seawater mixture. The maximum pit/corrosion depth was approximately 0.003 in. As polished, Mag.: 100X



Figure 34. Macro photograph of a carbon steel coupon, after immersion testing in the HDCD-2 fuel/seawater mixture, showing an enlarged view of the fuel/seawater interface. The portion that was immersed in the HDCD-2 fuel was on the left, and the portion immersed in the seawater was on the right. Oxidation, general corrosion and pitting were evident, particularly at the fuel/seawater interface. Mag.: 10X

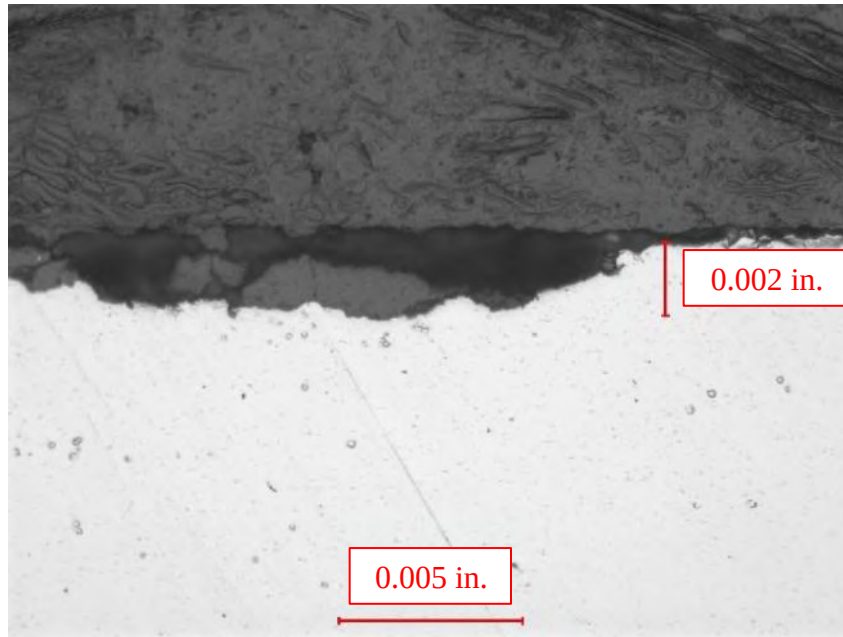


Figure 35. Photomicrograph showing an enlarged view of the area shown in Figure 34, taken in close proximity to the HDCCD-2/seawater surface of one (1) of the carbon steel coupons, after immersion testing in the HDCCD-2 fuel/seawater mixture. The maximum pit/corrosion depth was approximately 0.002 in. As polished, Mag.: 200X



Figure 36. Macro photograph of the carbon steel coupon, after immersion testing in F-76 fuel/seawater mixture. The portion that was immersed in the F-76 fuel was on the left, and the portion immersed in the seawater was on the right. Some oxidation and general corrosion were also evident on the portion that was immersed in the seawater. Mag.: 1.2X

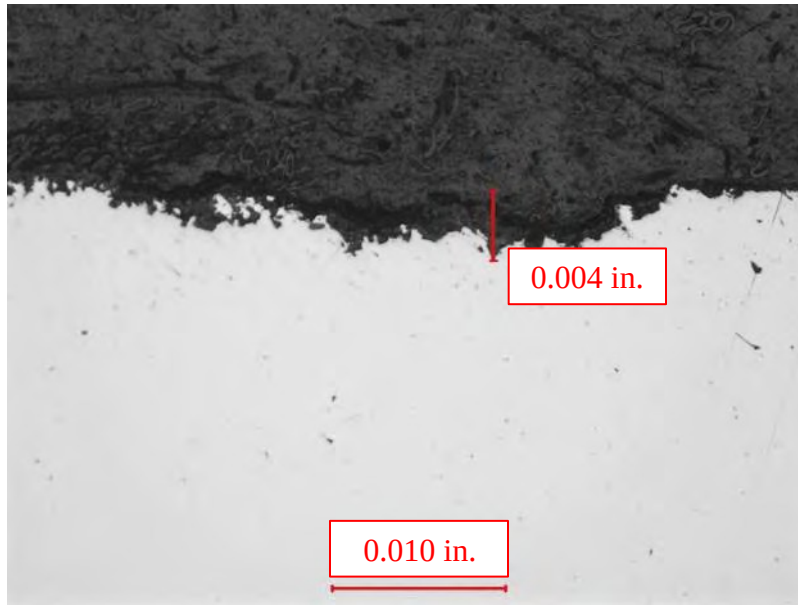


Figure 37. Photomicrograph taken in close proximity to the fuel/seawater interface surface of one (1) of the carbon steel coupons shown in Figure 36, after immersion testing in F-76 fuel/seawater mixture. The maximum pit/corrosion depth was approximately 0.004 in. As polished, Mag.: 100X

For the fuel/deionized water testing on the aluminum coupons, staining was observed on the water side of the samples – for all three (3) alternative fuels – DSH, HDCD-1, and HDCD-2 as well as the previously tested F-76 fuel. Stereoscopic and metallographic examination revealed that there was no evidence of any corrosive attack. For the 304 stainless steel coupons, slight staining was also exhibited on the deionized water side of the samples. Once again, there was no evidence of any attack on the alternative fuels (DSH, HDCD-1, and HDCD-2) or the F-76 fuel. Examination of the carbon steel coupons disclosed evidence of oxidation as well as corrosion on the deionized water side of all four (4) fuels. Maximum depth of pitting for the DSH fuel samples extended to 0.011 in., for the HDCD-1 fuel to 0.0015 in. and for the HDCD-2 fuel to 0.013 in.; interestingly the greatest pit depths were observed on the fuel side of the DSH and HDCD-1. Pitting was present with maximum depths of 0.0055 in. measured for the previously tested F-76 fuel sample. Photomicrographs showing the pitting are displayed in Figures 38 - 45.



Figure 38. Macrophotograph of a carbon steel coupon, after immersion testing in the DSH fuel/deionized mixture. The portion that was immersed in the DSH fuel is on the left, and the portion immersed in the deionized water is on the right. Oxidation, general corrosion and pitting are evident on the deionized water side. The largest pitting was observed on the fuel side, directly adjacent to the fuel/deionized water interface. Mag.: 5X

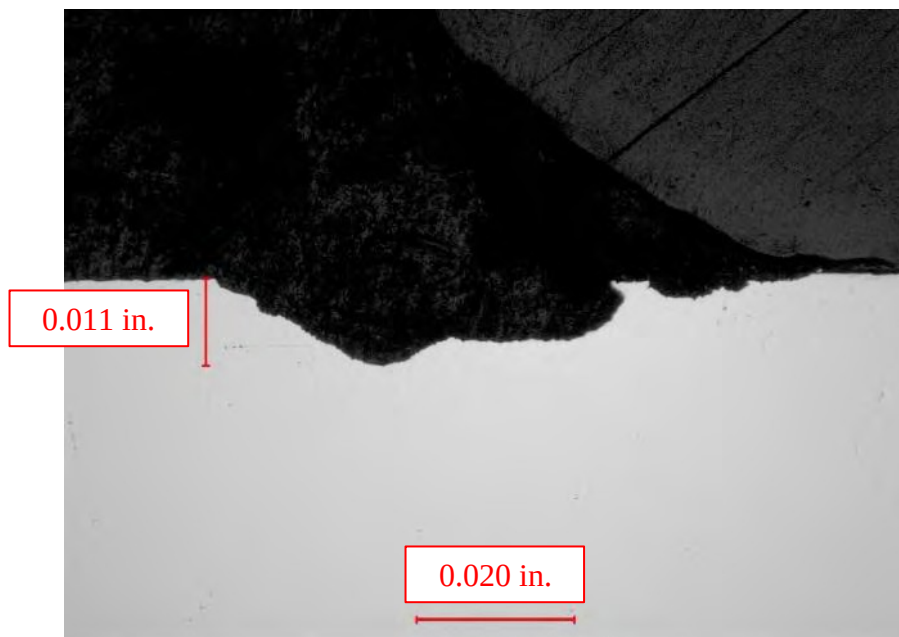


Figure 39. Photomicrograph of the DSH fuel immersed surface, in close proximity to the fuel/deionized water interface, of one (1) of the carbon steel coupons after immersion testing in the DSH fuel/deionized water mixture. The maximum pit/corrosion depth was approximately 0.011 in. As polished, Mag.: 30X

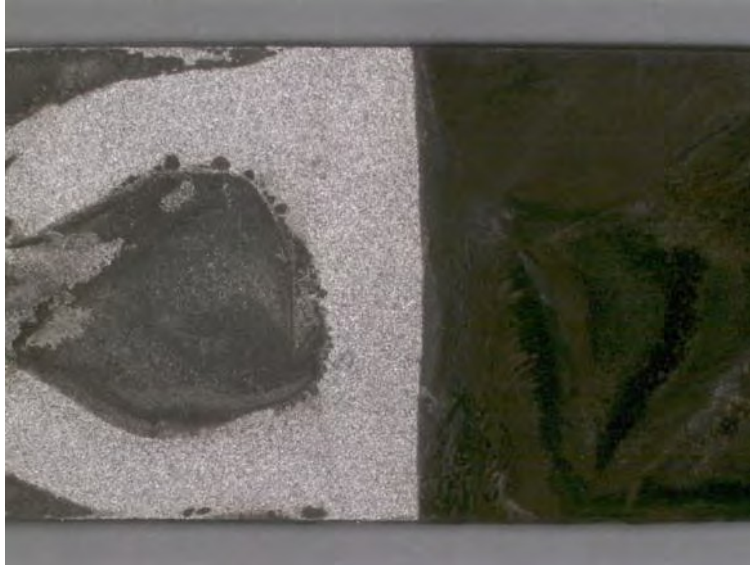


Figure 40. Macro photograph of a carbon steel coupon, after immersion testing in the HD CD-1 fuel/deionized water mixture. An enlarged view of the fuel/deionized water interface. The portion that was immersed in the HD CD-1 fuel was on the left, and the portion immersed in the deionized water was on the right. Oxidation, general corrosion and pitting were evident on the deionized water side. Pitting was also observed on the fuel side, adjacent to the fuel/water interface. Mag.: 10X

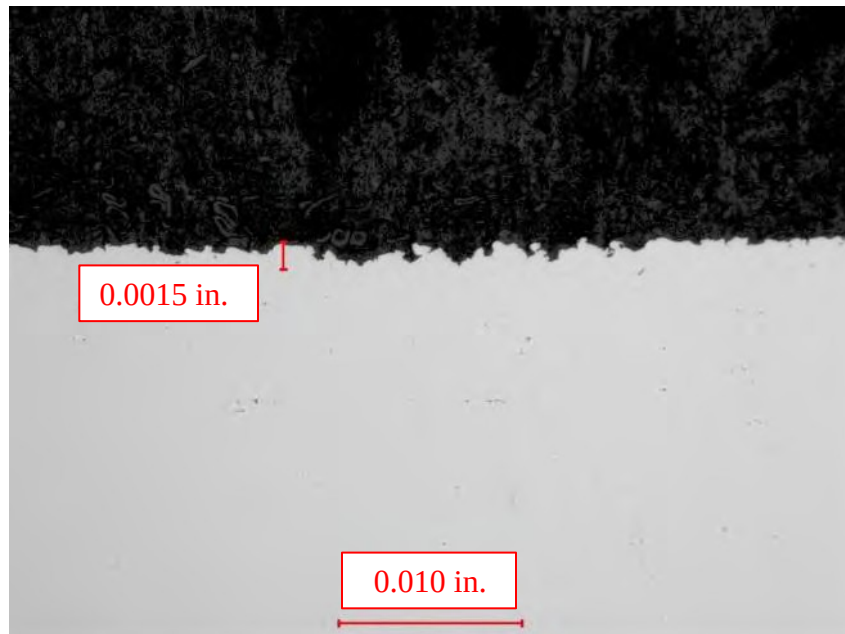


Figure 41. Photomicrograph of the HD CD-1 fuel immersed surface, in close proximity to the fuel/ deionized water interface, of one (1) of the carbon steel coupons, after immersion testing in the HD CD-1 fuel/deionized water mixture. The maximum pit/corrosion depth was approximately 0.0015 in. As polished, Mag.: 100X



Figure 42. Macro photograph of a carbon steel coupon, after immersion testing in the HDCD-2 fuel/deionized water mixture which shows an enlarged view of one (1) of the coupons that was immersed in the deionized water portion. Oxidation, general corrosion and pitting were evident. A cluster of pits was identified within the red circle. Mag.: 10X

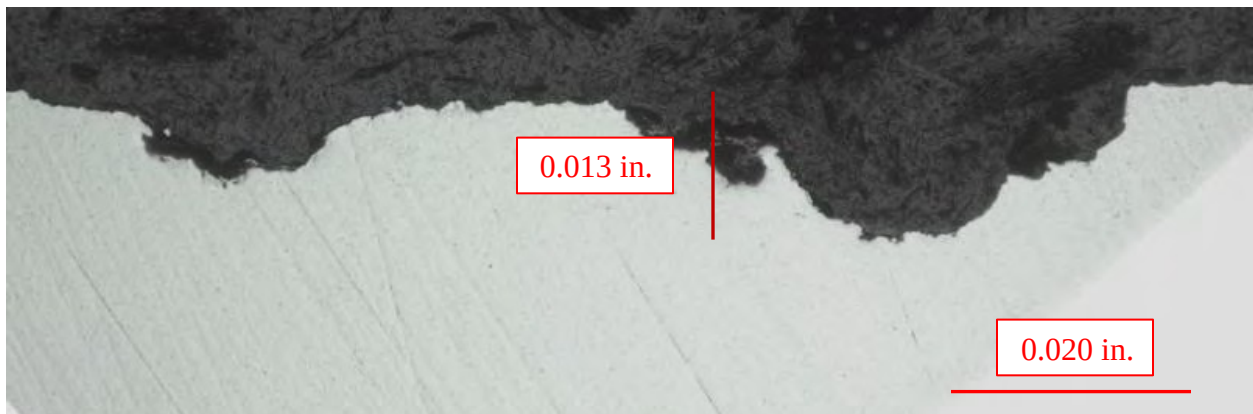


Figure 43. Photomicrograph taken through the cluster of pits shown in Figure 42. The maximum pit/corrosion depth was approximately 0.013 in. As polished, Mag.: 30X



Figure 44. Macrophotograph of the carbon steel coupons, after immersion testing in the F-76 fuel/deionized water mixture. The portion that was immersed in the fuel was on the left, and the portion immersed in the deionized water was on the right. Oxidation and general corrosion were evident on the portion that was immersed in the deionized water on the top two (2) coupons. There was some attack noted in the water side in close proximity to the fuel/deionized water interface. The bottom coupon, for some unknown reason, was not corrosively attacked. SEM/EDS analysis verified that the coupon was carbon steel; the lack of oxidation on the deionized water side cannot be explained. Mag.: 0.5X

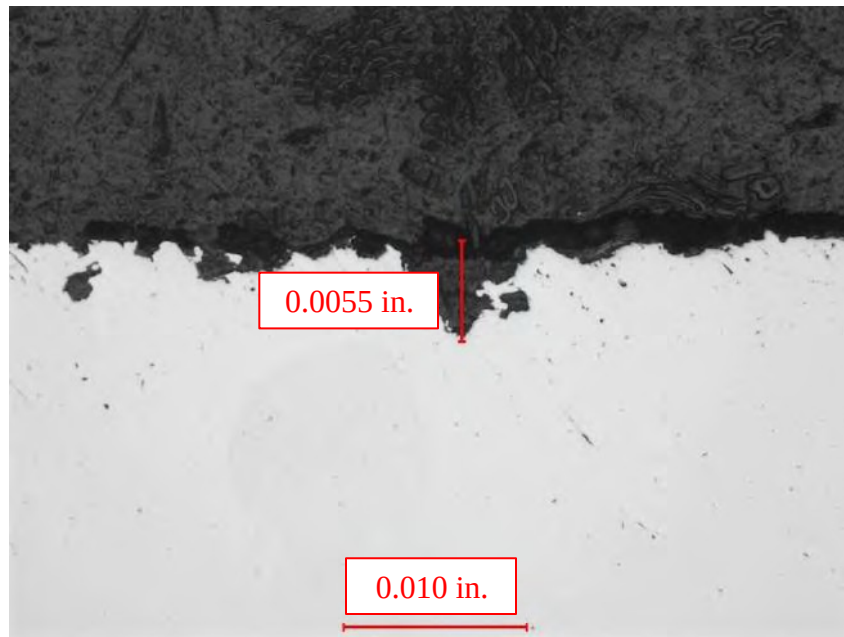


Figure 45. Photomicrograph of the deionized water surface, in close proximity to the fuel/deionized water interface, of one (1) of the carbon steel coupons, after immersion testing in the F-76 fuel/deionized water mixture. The maximum pit/corrosion depth was approximately 0.0055 in. As polished, Mag.: 100X

A summary of the results of the Immersion Testing, biological effects in fuel/seawater and fuel/distilled water are presented in Tables 1 and 2.

Table 1
Results of the Fuel/Seawater Testing

Fuel/Seawater	5052H32 Al	304 S/S	Carbon Steel
DSH	Pits present on 1/3 coupons, Max Depth: 0.025 in.	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons- Max. Depth: 0.0025 in.
HDCD-1	Pits present on 2/3 coupons, Max Depth: 0.005 in.	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.003 in.
HDCD-2	Pits present on 3/3 coupons, 1: Superficial 1, Depth: 0.030 in. 1, Width : 0.070 in., Inward: 0.032 in. and Through Coupon Cross Section: 0.064 in.	Stains	Oxidation/Corrosion and Pits present on 1/3 coupons - Max. Depth: 0.002 in.
F-76	Pits present on 1/3 coupons, Max Depth: 0.012 in.	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.004 in.

Table 2
Results of the Fuel/Deionized Testing

Fuel/Deionized Water	5052H32 Al	304 S/S	Carbon Steel
DSH	Stains	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.011 in.
HDCD-1	Stains	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.0015 in.
HDCD-2	Stains	Stains	Oxidation/Corrosion and Pits present on 3/3 coupons - Max. Depth: 0.013 in.
F-76	Stains	Stains	Oxidation/Corrosion and Pits present on 2/3 coupons - Max. Depth: 0.0055 in.

DISCUSSION

The static immersion and flow testing conducted on the alternative fuels DSH, HDCD-1, and HDCD-2, when compared with the previously tested F-76 fuel, indicate similar results on all of the metals when evaluated macroscopically, microscopically, and metallurgically.

In the static immersion tests, the majority of the coupons displayed no appreciable change with the exception of the leaded brass coupons and carbon steel coupons that had the electrodeposited zinc plating. While there was some discoloration of the leaded brass coupons in all four (4) fuels, there was no evidence of any corrosive attack. The DSH fuel caused the leaded brass coupons to darken, having a deep blue colored appearance. Retesting by Code 614 of three (3) additional coupons in the DSH fuel again resulted in the coupons turning blue; however, this time they were brighter in appearance. SEM and metallographic evaluation disclosed no evidence of any corrosive attack. For the carbon steel coupons with the electrodeposited zinc plating, there was general pitting that was observed macroscopically, with the SEM as well as microscopically in F-76 fuel samples. The depth of the pits was approximately 0.0009 in. for the F-76 fuel; however, the pits did not penetrate the base metal. Only the plating was attacked. No pitting was observed in the carbon steel coupons with the electrodeposited zinc plating that were exposed to the DSH, HDCD-1, and HDCD-2 fuels.

Static immersion testing of the crevice corrosion assemblies also exhibited similar results for the DSH, HDCD-1 and HDCD-2 fuels when compared with the F-76 fuel. While some of the coupons showed evidence of staining at the washer locations, particularly the four (4) copper alloy coupons in all of the fuels, there was no evidence of any initiated crevice sites. Metallographic cross sections taken through the stains confirmed no indication of any attack. Significant stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76 and HDCD-2), 7075-T6 (F-76 and HDCD-1), and 5052-H32 (F-76),
- b) carbon steel coupons- plain (DSH), electroplated with silver (F-76), and electroplated with cadmium (F-76, DSH, and HDCD-2).

In each case, higher magnification examination, coupled with the metallographic evaluation, showed no crevice sites or indication of attack.

Regarding the flowing tests, examination of all of the coupons exposed to alternative fuels DSH, HDCD-1, and HDCD-2, as well as the F-76 fuel also displayed similar results. The majority of the coupons had no noticeable change with the exception of the carbon steel coupons that were finished with the electrodeposited zinc plating. Pitting was observed macroscopically, with the SEM, and microscopically for the coupons exposed to the F-76 fuel with the maximum pit depth measured to be approximately 0.0005 in.; however, the pitting again did not penetrate the base metal. No pitting was observed in the carbon steel coupons with the electrodeposited zinc plating that were exposed to the DSH, HDCD-1, and HDCD-2 fuels.

Testing of the crevice corrosion assemblies, also exhibited similar results for all four (4) fuels. The four (4) copper alloy coupons again showed evidence of staining at the washer locations. Obvious stains were also observed on the following coupons:

- a) aluminum alloys- 2024-T3 (F-76), 7075-T6 (F-76, HDCD-1, and HDCD-2), and 5052-H32 (F-76),
- b) carbon steel coupons- plain (F-76, DSH, and HDCD-1), electroplated with silver (F-76, DSH, HDCD-1, and HDCD-2), electroplated with IVD Aluminum Class 3 and Class 10 (DSH and HDCD-1).

Visual, low and high magnification examination revealed no evidence of any crevice initiation. Metallographic cross sections taken through the stains confirmed no indication of attack.

Evaluation of the biological effects, in mixtures of each of the fuels and seawater as well as each fuel and distilled water, were also conducted via immersion testing and compared with the prior F-76 fuel results. Here, coupons of 5052-H32 aluminum, 304 stainless steel, and carbon steel were tested. For the fuel/seawater testing, on the 5052-H32 aluminum samples, pitting was observed on one (1) of the three (3) coupons tested with the DSH fuel. The pit was present on the seawater side and extended to a depth of approximately 0.025 in. For the HDCD-1 fuel/seawater testing on the 5052-H32 aluminum samples, pits were observed on two (2) of the three (3) tested coupons on the seawater immersed side. The maximum pit depth was determined to be approximately 0.005 in. The HDCD-2 fuel/seawater testing disclosed some degree of pitting on all three (3) of the 5052-H32 aluminum samples. Two (2) of the three (3) coupons displayed pits on the seawater immersed side, one (1) of which was located on the end of the coupon that had a depth of 0.030 in. The second coupon had one (1) pit that was characterized to be superficial. The third coupon had a pit at the fuel/seawater interface which extended inward 0.032 in. when measured from the edge of the coupon. The pit width (0.070 in.) was largest at the fuel/seawater interface at the edge of the coupon. In addition, the pit penetrated the entire coupon cross sectional thickness (0.064 in.). For the F-76 fuel/seawater testing on the 5052-H32 aluminum samples, an individual pit was observed on one (1) of the three (3) tested coupons. The pit was located on seawater immersed side with the maximum pit depth determined to be approximately 0.012 in. The 304 stainless steel coupons tested in the fuel/seawater mixtures only displayed staining from each of the four (4) fuels; there was no evidence of corrosive attack. For the carbon steel coupons, there was general attack in the seawater immersed side as well as pitting observed near the fuel/seawater interface. Maximum pit depths were measured for each of the fuels with the results as follows: DSH (0.0025 in.), HDCD-1 (0.003 in.), HDCD-2 (0.002 in.), and F-76 (0.004 in.).

Some staining was noted on the 5052-H32 aluminum coupons that were subjected to the fuel/deionized water mixture: all four (4) fuels caused some discoloration but no evidence of any attack. Slight staining was also observed on the deionized water side of the 304 stainless steel coupons, with no indication of attack in any of the fuels – DSH, HDCD-1, HDCD-2, and F-76. Examination of the carbon steel coupons revealed evidence of oxidation and corrosion on the

deionized water side of the DSH, HDCD-1, HDCD-2 and the F-76 fuel samples. Pitting also was observed in close proximity to the fuel/deionized water interface, with maximum depths of 0.011 in. measured for the DSH fuel and 0.0015 in. for the HDCD-1. For the HDCD-2 fuel coupons, the maximum pit depth was determined to be 0.013 in., which was in the deionized water immersed side. Lastly, a maximum pit depth of 0.0055 in. was measured for the previously tested F-76 fuel/deionized water coupons, which was close to the fuel/deionized water interface. Of note is that one (1) of the three (3) F-76 fuel/deionized water coupons did not show the corrosive attack on the deionized water side of the coupon; the reason for this is unknown. SEM/EDS analysis confirmed that the coupon was, in fact, carbon steel.

CONCLUSIONS

The metallurgical analysis conducted on the alternative fuels DSH, HDCD-1, and HDCD-2, exhibited similar results in the static immersion and flow testing when compared with the previously evaluated F-76 fuel. There was no observed metallurgical change in the metallic material coupons, with no evidence of corrosive attack of the base metals or attack of the coupon surfaces at the crevice sites. The F-76 fuel exhibited indications of general pitting on the carbon steel coupons with electrodeposited zinc plating. The pitting, though, was only evident in the plating not the base metal. In this study, the DSH, HDCD-1, and HDCD-2 fuels did not exhibit any evidence of pitting on the carbon steel coupons with electrodeposited zinc plating.

The only exception was that of the leaded brass alloy C36000 exposed to the DSH fuel in the static immersion test where the coupons turned a dark blue color. A repeat of the test caused the coupons to turn a brighter blue; however, metallurgical examination disclosed no corrosive attack in either the original testing or the repeat testing.

For the immersion testing, where there was a concentration of potential biological effects in fuel/seawater and fuel/distilled water mixtures, corrosive attack and pitting was observed on the aluminum and carbon coupons subject to each fuel/seawater mixture as well as the carbon steel coupons that were subject to each fuel/deionized water mixture. Pit depths were similar for the carbon steel coupons subjected to the fuel/seawater mixture: DSH fuel (0.0025 in.), HDCD-1 fuel (0.003 in.), HDCD-2 fuel (0.002 in.), and for the F-76 fuel (0.004 in.). There was, however, some variation of pit depth observed on the aluminum coupons that were subjected to the fuel/seawater mixture: the HDCD-1 fuel had the least depth (0.005 in.), followed by the F-76 fuel (0.012 in.), then the DSH fuel (0.025 in.), and lastly by the HDCD-2 fuel, which had the greatest pit depth. Regarding the HDCD-2 fuel, the pitting, located on the seawater immersed side of one (1) coupon, had a depth of 0.030 in. A second coupon had a pit at the fuel/seawater interface, with measurement indicating a width of 0.070 in., extended inward 0.032 in. and through the entire coupon cross section (0.064 in.). In addition, while the pitting was only evident on the seawater immersed side for the DSH fuel, HDCD-1, and F-76 fuel, HDCD-2 displayed pitting on both the seawater immersed side (two (2) coupons) as well as at the fuel/seawater interface (one (1) coupon).

For the carbon steel coupons subjected to the fuel/deionized water mixture, the HDCD-1 fuel had the shallowest pit depth (0.0015 in.), followed by the F-76 (0.0055 in.), then the DSH fuel (0.011 in.), and finally the HDCD-2 fuel (0.013 in.). The pitting on these coupons was observed in close proximity/adjacent to the fuel/deionized water interface for the DSH, HDCD-1, and F-76 fuels. The pitting observed on the HDCD-2 coupons was on the deionized water side.

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