COLMAC COIL Manufacturing Inc.

Technical Bulletin

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Corrosion Resistance of Heat Exchanger Fin Materials to Potassium Hydroxide Sodium Hypochlorite-Based Cleaning Chemicals and Ammonia

INTRODUCTION

The goal of these tests is to determine the corrosive effects of potassium hydroxide and sodium hypochlorite-based industrial cleaners on commonly used heat exchanger fin materials. These materials include aluminum, stainless steel, carbon steel, copper, copper-nickel, and Electrofin coated aluminum. The samples were submerged in the cleaning chemicals, held for 250 hours, and then compared to the original sample.

TESTING METHODS

TESTING STANDARDS

The ASTM Standard, G31-72 Standard Practice for Laboratory Immersion Corrosion Testing of Metals, was followed to improve the accuracy and reproducibility of this corrosion testing experiment. This standard outlines specific testing procedures, including: sample preparation, setup of testing apparatus, cleaning of the sample after testing, and interpretation of the results. The standard states a +/- 10 percent deviation in results is possible if similar test conditions are used on similar samples. ASTM G31-72 describes two methods for determining corrosion rates. The first is a mass loss test to determine the rate of corrosion in terms of mils per year, while the second is by visual comparison between the control sample and the test sample. The mass loss method is very difficult to use because a fin material could experience pitting and severe corrosion at isolated spots on a sample without losing even a measurable amount of material. For this reason, a visual inspection and comparison of the material after being submerged for given time periods is much more useful. The NACE Standard TM0169-2000 Standard Test Method for Laboratory Corrosion Testing of Metals was also used as a reference for additional corrosion testing techniques. The NACE standard specifically covers the solution preparation in greater detail and provides a checklist to ensure all data is recorded.

SAMPLE PREPARATION

The fin samples were produced using standard construction techniques appropriate for each fin material. The samples were taken from newly produced 5/8" and 7/8" patterned fin stocks in both waffle ripple and waffle flat patterns. The samples were cut from sheets of fins into approximately 3" x 6" pieces weighing approximately 20 grams. The fins were cleaned in an acetone bath and wiped dry. This process removed oil and other metal residues remaining from the manufacturing.

CLEANING CHEMICALS

For the preliminary tests two different cleaning chemicals were used, Sunny-Sol 150 and FRM 63-CB. Sunny-Sol 150 is a sodium hypochlorite solution containing 12.5% active ingredient and trace amounts of sodium hydroxide. Sunny-Sol 150 is essentially a more concentrated form of household bleach and is designed to be diluted with water at a 1 oz per 5 gal concentration or .16% resulting in chlorine concentrations of 200 ppm. Sunny-Sol is used to sanitize food processing equipment after initial cleaning has been performed. As a disinfectant, the solution is sprayed on, allowed to sit for 2 minutes, and then rinsed clean with water. The second cleaner FRM 63-CB is a foaming alkaline cleaner containing 10% potassium hydroxide and 1% sodium hypochlorite. FRM 63-CB has also been authorized for use in food processing plants by the U.S.D.A. at a recommended maximum 3.9% concentration. FRM 63-CB is applied by foam nozzles or high pressure sprays and rinsed clean with water. Additional tests were performed on four of the finstocks using a household ammonia-based cleaner containing a 10% by weight concentration of ammonium hydroxide.

FIN MATERIALS

Eleven different types of fin stocks, all available as options for Colmac Coil heat exchangers, were selected for the corrosion test. These fin stocks include the following:

1. Copper C11000 series
2. Aluminum 1100 series
3. Carbon steel
4. Stainless steel 304 series
5. Stainless steel 316 series
6. Copper-nickel 95/5
7. Aluminum 1100 series with polycoat finish
8. Aluminum 1100 series with Electrofin coating
9. Aluminum 1100 series with Heresite coating
10. Aluminum 5052 series
11. Carbon steel coated with hot dipped galvanized

CORROSION TESTING

The cleaning solutions were all mixed in separate plastic containers using a 2000 ml +/- 20 ml graduated cylinder to add water and a 50 ml +/- 1 ml graduated cylinder to add the cleaning solution. The ASTM standard states, "The test solution shall be large enough to avoid any appreciable change in the test solutions corrosiveness through either exhaustion of corrosive constituents or accumulation of corrosion products that might affect further corrosion" [2]. 15000 ml of total cleaning solution was used for every test. To achieve the correct ratio the Sunny Sol 150 solution was mixed as 14976 ml of water to 24 ml of Sunny Sol 150, while the FRM 63 CB solution was mixed at 14415 ml of water to 585 ml FRM 63 CB.

Figure 1: Testing containers containing test specimens and cleaning chemical

Each sample was tested in separate plastic containers with the fin sample placed collar down, suspending the fin in the solution the height of the fin collar above the bottom of the container. After the samples were placed in the cleaning solution, a tight sealing lid was placed over the containers to prevent evaporation and contamination as described by NACE standard TM0169-2000 [1]. The ambient room temperature was maintained at approximately 70 degrees Fahrenheit and the samples were not moved. The solution was not aerated or circulated in the container in any way.

The samples were kept submerged in the cleaning solution for 250 hours or 15000 minutes. The idea was to simulate a 10-minute cleaning once per day, every day for four years.

AMMONIUM HYDROXIDE CORROSION TESTING

The tests using ammonia were tested using 1000 ml of an ammonia cleaning solution using 20-gram samples of four fin stocks, copper-nickel 95/5, carbon steel coated with hot dipped galvanized, aluminum 1100 series, and copper C11000 series. The tests were performed by submerging the fin stocks in the ammonia for 500 hours to simulate the continuous contact with the fins.

RESULTS

The results of the corrosion tests are grouped first by fin material type, then by type of cleaner used, showing a before and after picture for each material type.

COPPER C11000

The test using Sunny-Sol 150 shown in Figures 3 and 4 shows some surface pitting, which appears very evenly distributed. The total amount of corrosion appears to be very minor and would not adversely affect coil performance. The test using FRM 63-CB shown in Figures 5 and 6 shows only minor corrosion. Small green patina formations were also evident on the surface of the fins after the samples were removed from the cleaning solution. These became more evident after the sample was cleaned and exposed to air for several days. The FRM 63-CB sample shows a much more dull finish indicating that the entire surface has been slightly etched, but it appears it would not affect coil performance.

Figure 2: Copper C11000 sample before corrosion testing

Figure 3: Copper C11000 after 250 hours submerged in a .16% Sunny-Sol 150 water solution

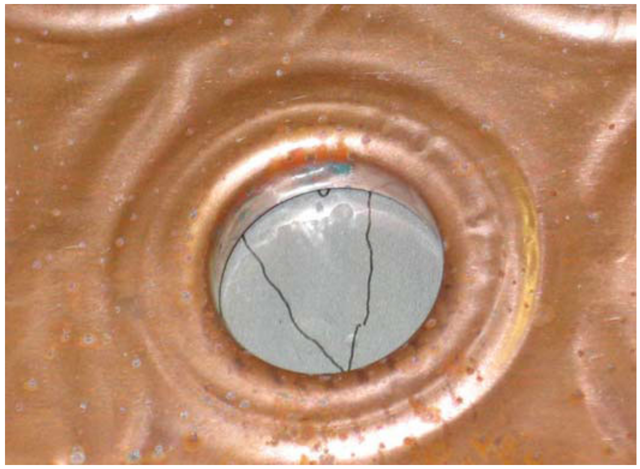

Figure 4: Copper C11000 after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 5: Copper C11000 after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 6: Copper C11000 after 250 hours submerged in a 3.9% FRM 63-CB water solution

ALUMINUM 1100

The test using Sunny-Sol 150 shown in Figures 8 and 9 shows some surface corrosion, which appears in pockets distributed evenly over the entire surface. When the sample was removed from the cleaning solution, white precipitate had formed around the pockets of corrosion. The total amount of corrosion appears to be minor and is mostly the result of the aluminum oxide layer which forms on the surface and protects the underlying metal. The test using FRM 63-CB shown in Figure 10 shows almost complete corrosion of the fin material after only 250 hours. Figure 10 shows the result of the solution being strained through cheese cloth to recover the un-dissolved fin sample. As a result, we re-ran the test with the sample being removed at 60 hours and is shown in Figure 11. The sample showed significant corrosion and begins to totally break apart at 100 hours.

Figure 7: Aluminum 1100 sample before corrosion testing

Figure 8: Aluminum 1100 after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 9: Aluminum 1100 after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 10: Aluminum 1100 after 250 hours submerged in a 3.9% FRM 63-CB water solution

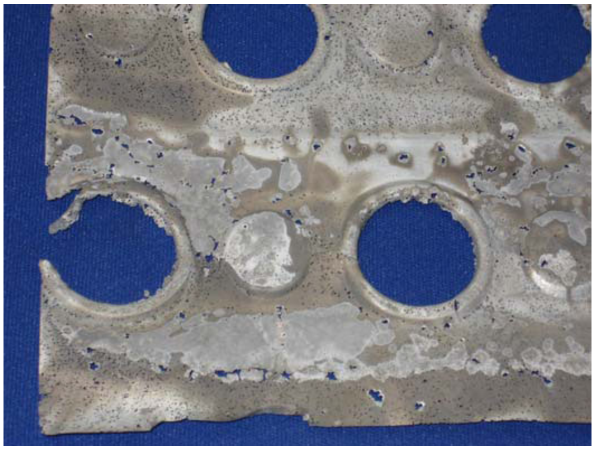

Figure 11: Aluminum 1100 after 60 hours submerged in a 3.9% FRM 63-CB water solution

CARBON STEEL

The test using Sunny-Sol 150 shown in Figures 13 and 14 shows significant corrosion with rust forming on large portions of the fin. The total amount of corrosion is significant and would adversely affect coil performance. The test using FRM 63-CB shown in Figures 15 and 16 shows virtually no corrosion. The FRM 63-CB sample shows a much more dull finish indicating that the entire surface has been slightly etched, and appears it would not affect coil performance. There is, however, one portion of the fin that showed significant corrosion which is most likely caused from contamination and the attack of a dissimilar metal.

Figure 12: Carbon steel sample before corrosion testing

Figure 13: Carbon steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

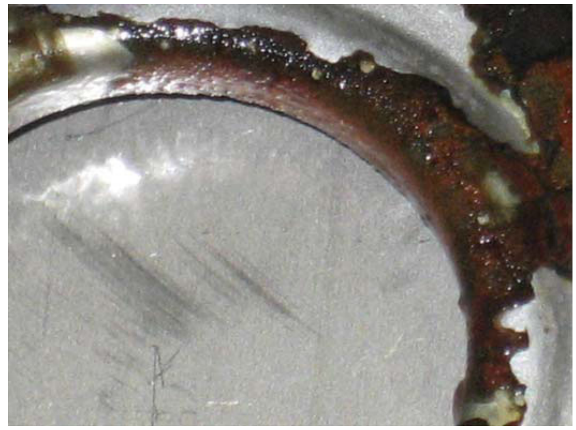

Figure 14: Carbon steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 15: Carbon steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 16: Carbon steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

STAINLESS STEEL 316

The test using Sunny-Sol 150 shown in Figures 18 and 19 shows no corrosion; the cleaner acts only to clean the metal surface more thoroughly than acetone. The test using FRM 63-CB shown in Figures 20 and 21 also shows no corrosion, but possibly a slight tarnishing.

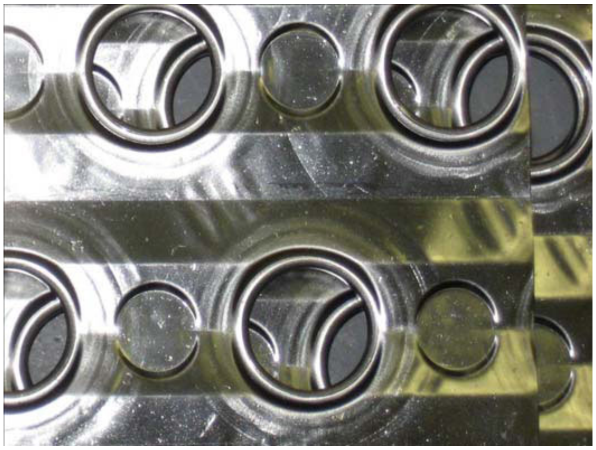

Figure 17: 316 Stainless steel sample before corrosion testing

Figure 18: 316 Stainless steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 19: 316 Stainless steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 20: 316 Stainless steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 21: 316 Stainless steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

COPPER-NICKEL 95/5

The test using Sunny-Sol 150 shown in Figures 23 and 24 shows minor pitting that is similar to the copper C11000 sample. The test using FRM 63-CB shown in Figures 25 and 26 shows no corrosion and cleans the surface very effectively.

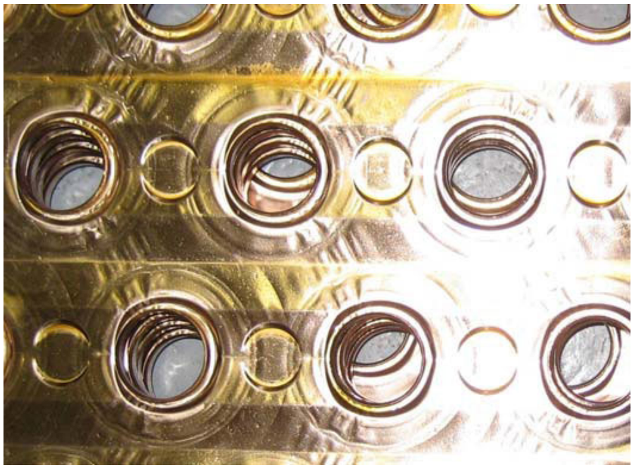

Figure 22: 95/5 Copper-nickel sample before corrosion testing

Figure 23: 95/5 Copper-nickel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

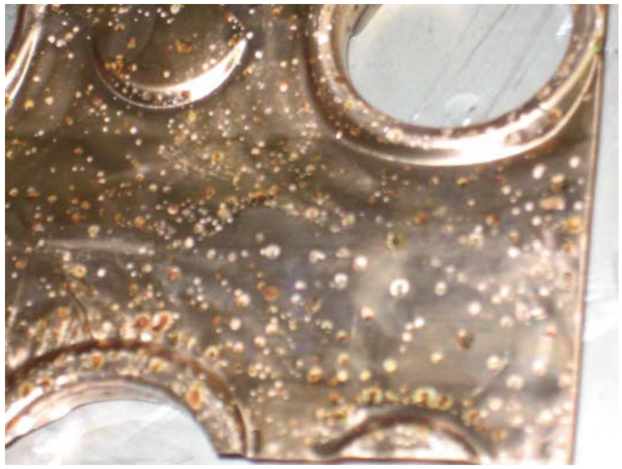

Figure 24: 95/5 Copper-nickel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

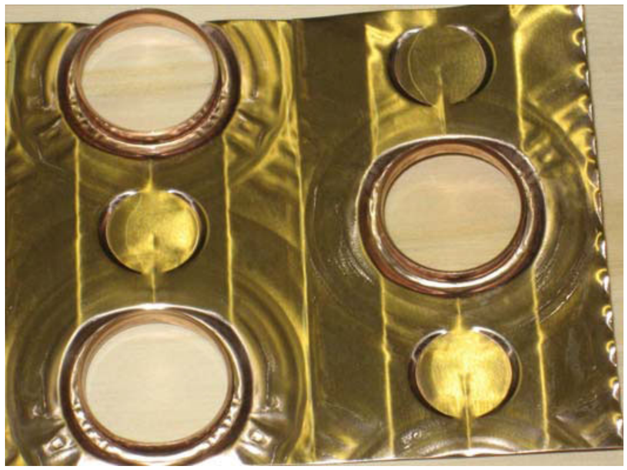

Figure 25: 95/5 Copper-nickel after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 26: 95/5 Copper-nickel after 250 hours submerged in a 3.9% FRM 63-CB water solution

POLYCOATED ALUMINUM

The test using Sunny-Sol 150 shown in Figures 28 and 29 shows only minor pitting in locations where the coating has been removed. The test using FRM 63-CB shown in Figures 30 and 31 shows corrosion being initiated at end exposed edges and where cuts form in the polycoat from the fin press dies. The aluminum is essentially removed from in between the two polycoat layers on the top and bottom, and very little aluminum remained after 250 hours.

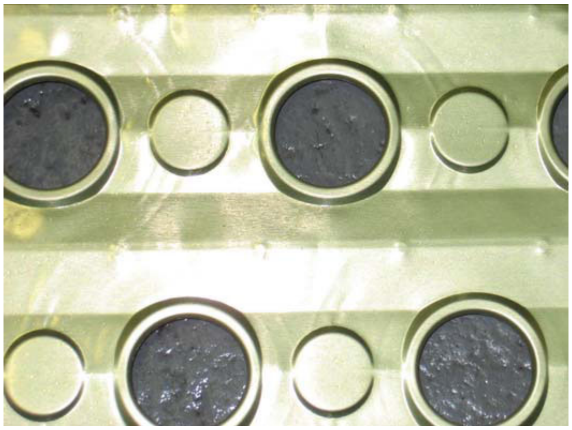

Figure 27: Aluminum polycoat sample before corrosion testing

Figure 28: Aluminum polycoat after 250 hours submerged in a .16% Sunny-Sol 150 water solution

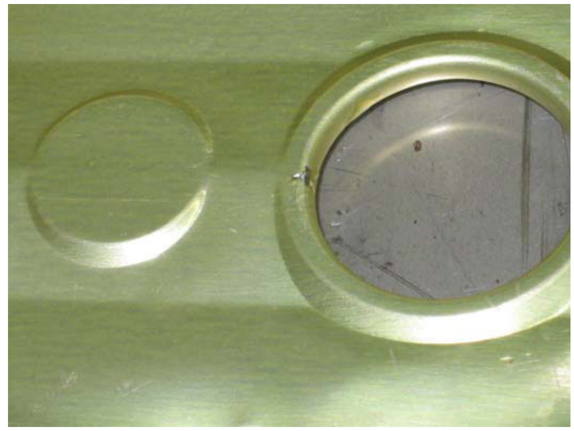

Figure 29: Aluminum polycoat after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 30: Aluminum polycoat after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 31: Aluminum polycoat after 250 hours submerged in a 3.9% FRM 63-CB water solution

ELECTROFIN COATED ALUMINUM

The test using Sunny-Sol 150 shown in Figures 33 and 34 shows only minor corrosion at locations where the coating has been removed. The test using FRM 63-CB shown in Figures 35 and 36 shows corrosion being initiated at the exposed edges. FRM 63-CB also causes the coating to become brittle and flake off the sample.

Figure 32: Aluminum Electrofin sample before corrosion testing

Figure 33: Aluminum Electrofin after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 34: Aluminum Electrofin after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 35: Aluminum Electrofin after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 36: Aluminum Electrofin after 250 hours submerged in a 3.9% FRM 63-CB water solution

304 STAINLESS STEEL

The test using Sunny-Sol 150 shown in Figures 38 and 39 shows no corrosion; the cleaner acts only to clean the metal surface more thoroughly than acetone. The test using FRM 63-CB shown in Figures 40 and 41 shows minimal corrosion with some surface tarnishing in addition to the formation of a white scale. This scale is not easily removed by light scrubbing, but can be removed by scraping the surface leaving no visible corrosion beneath. Both cleaners appear to be acceptable for use on 304 stainless steel.

Figure 37: 304 Stainless steel sample before corrosion testing

Figure 38: 304 Stainless steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 39: 304 Stainless steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 40: 304 Stainless steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

Figure 41: 304 Stainless steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

5052 ALUMINUM

The test using Sunny-Sol 150 shown in Figures 48 and 49 shows severe corrosion in several locations while the majority of the fin appears relatively unaffected. Where corrosion is present, the chemical cleaner has completely removed small portions of the fin. The test using FRM 63-CB shown in Figure 50 shows the sample being completely dissolved; only very small specs of the fin sample remain after 250 hours.

Figure 42: 5052 Aluminum sample before corrosion testing

Figure 43: 5052 Aluminum after 250 hours submerged in a .16% Sunny-Sol 150 water solution

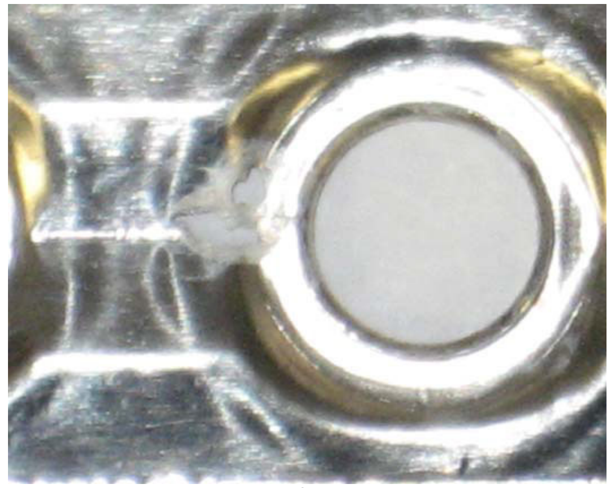

Figure 44: 5052 Aluminum after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 45: 5052 Aluminum after 250 hours submerged in a 3.9% FRM 63-CB water solution

HOT DIPPED GALVANIZED STEEL

The test using Sunny-Sol 150 shown in Figures 52 and 53 shows surface corrosion of the galvanized coating, but does not appear to have reached the underlying carbon steel. The test using FRM 63-CB shown in Figures 54 and 55 shows much less corrosion and isolated pockets of a black tarnish forming on top of the galvanized coating.

Figure 46: Hot dipped galvanized steel sample before corrosion testing

Figure 47: Hot dipped galvanized steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 48: Hot dipped galvanized steel after 250 hours submerged in a .16% Sunny-Sol 150 water solution

Figure 49: Hot dipped galvanized steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

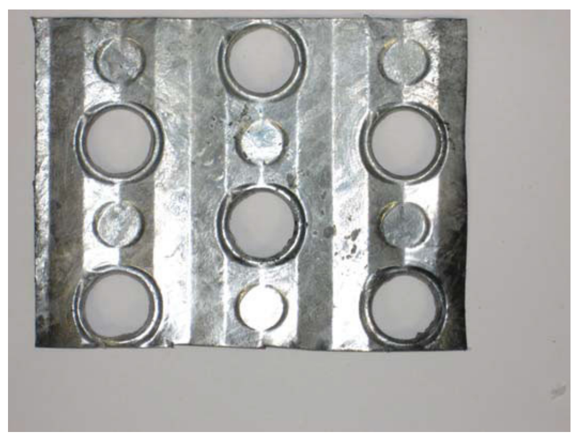

Figure 50: Hot dipped galvanized steel after 250 hours submerged in a 3.9% FRM 63-CB water solution

AMMONIUM HYDROXIDE

The tests using ammonium hydroxide all show some kind of surface oxidation on the fin stock, but no significant corrosion or fin deterioration. Future tests involving higher concentrations of ammonium hydroxide or pure ammonia may need to be completed also.

Figure 51: Copper-nickel 95/5 after 500 hours submerged in a 10% ammonium hydroxide solution

Figure 52: Copper C11000 after 500 hours submerged in a 10% ammonium hydroxide solution

Figure 53: Hot dipped galvanized steel after 500 hours submerged in a 10% ammonium hydroxide solution

Figure 54: 1100 series aluminum after 500 hours submerged in a 10% ammonium hydroxide solution

CONCLUSIONS

Based on experimental results, the following tables contain the complete list of fin materials describing their compatibility with each type of cleaner during a 250-hour submerged test simulating 4 years of 10-minute daily cleanings.

250 HOUR RESULTS

Chlorinated Cleaner: sodium hypochlorite-based		
Sunny-Sol 150		
Fin Material	**Compatibility**	**Description**
Copper C11000	**Compatible**	Very minor pitting
Aluminum 1100	**Compatible**	Surface oxidation
Carbon Steel	**Incompatible**	Significant corrosion
Stainless steel 316	**Compatible**	No visible corrosion
Copper-Nickel 95/5	**Incompatible**	Surface pitting
Aluminum 1100 w/ polycoat finish	**Compatible**	No visible corrosion
Aluminum 1100 w/ Electrofin coating	**Compatible**	No visible corrosion
Stainless steel 304	**Compatible**	Very minor corrosion similar to stainless steel 316
Black Heresite	**Compatible**	Very minor pitting corrosion—not enough to adversely affect fin performance
Aluminum 5052	**Incompatible**	Corrosion in several locations
Hot dipped galvanized steel	**Compatible**	Surface oxidation

Foaming Alkaline Cleaner: potassium hydroxide-based		
FRM 63-CB		
Fin Material	**Compatibility**	**Description**
Copper C11000	**Compatible**	No visible corrosion
Aluminum 1100	**Incompatible**	Significant corrosion
Carbon Steel	**Compatible**	Minor surface oxidation
Stainless steel 316	**Compatible**	No visible corrosion
Copper-Nickel 95/5	**Compatible**	No visible corrosion
Aluminum 1100 w/ polycoat finish	**Incompatible**	Chemical dissolves aluminum portion at cracks, creases and edges
Aluminum 1100 w/ Electrofin coating	**Incompatible**	Chemical causes cracks to develop in the surface coating allowing material to easily flake off exposing base aluminum
Stainless steel 304	**Compatible**	Minor corrosion
Black Heresite	**Incompatible**	Significant corrosion—primarily around fin collar
Aluminum 5052	**Incompatible**	Completely dissolved material before test was complete
Hot dipped galvanized steel	**Compatible**	Minor surface oxidation

500 HOUR RESULTS

Ammonium Hydroxide 10% solution

The tests using ammonium hydroxide all show some surface oxidation on the fin stock, but no significant corrosion or fin deterioration. Future tests involving higher concentrations of ammonium hydroxide or pure ammonia may need to be completed also.

REFERENCES

1. NACE International, The Corrosion Society. Laboratory Corrosion Testing of Metals. NACE Standard TM0169-2000, Item No. 21200. March 28, 2000. Houston, TX. ISBN 1-57590-098-X
2. ASTM International. Standard Practice for Laboratory Immersion Corrosion Testing of Metals. 2004. West Conshohocken, PA.

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