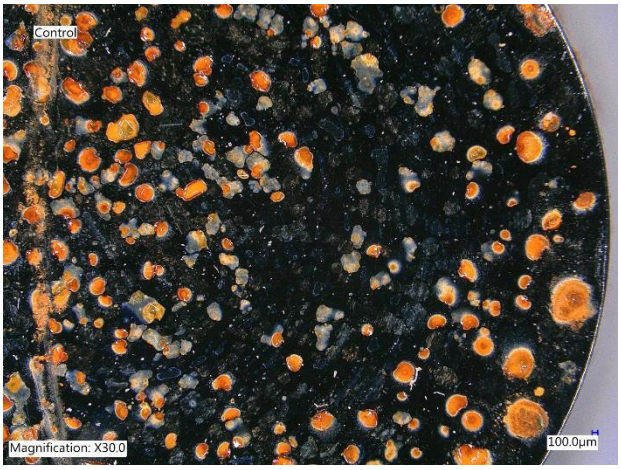

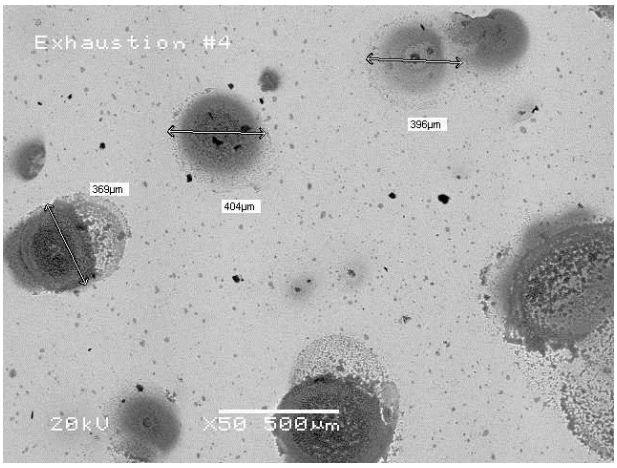

Laboratory Test to Evaluate the Vapor-Inhibiting Ability of Daubert NOX-RUST Vapor wrapper for Temporary Protection of Ferrous Surfaces after Exhaustion Test (MIL-STD-3010C)

For:

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Enviromentally Safe VpCI®/MCI® Technologies

Corrosion protection effectiveness of the Daubert NOX-RUST Vapor wrapper of the low carbon steel (UNS G10100) samples was investigated using MIL-STD-3010C procedures outlines in Test Method 4031. Test Method 4031 details procedures to determine the corrosion inhibiting effectiveness of VCI (Vapor corrosion inhibitor) as a coating or treatment on substrate materials in the as received and after exhaustion (aged) condition. This test method consists of two steps, exhaustion cycle followed by evaluation the vapor-inhibiting ability (VIA).

Samples of the Daubert NOX-RUST Vapor wrapper paper (Fig. 1) was provided for this evaluation. Samples of this paper were cut to 2 by 8 inches for the exhaustion tests or environmental aging test. Exhaustion test was conduct in apparatus showed in Fig. 2-3. The exhaustion test was conducted at 140 ^{o}F for 12 days. During this tests, air maintained at ~50% Relative humidity (%RH) and pumped at rate of ~100 cubic centimeters per minute into the test tube. To achieve the proper relative humidity, air passed through a ~26% by volume mixture of glycerin/distilled water. Four exhaustion tests were conducted and after, completion of samples were cut to 1x6 inch specimens for the VIA tests.

Corrosion behavior of carbon steel (UNS G10100) samples were studied in using Mil-STD 3010C VIA test method (similar to the NACE TM 208-2018 Standard) after conducting exhaustion test. This laboratory test method evaluates the vapor-inhibiting ability (VIA) of various forms of VCI materials for temporary corrosion protection of ferrous metal surfaces. The VIA corrosion test method provides for standard conditions in a test jar of water-saturated, warm air without the presence of accelerating contaminants. Water vapor and VCI transport are confirmed and corrosion protection is evaluated in this test method. The VIA tests consist of four steps of sample conditioning or saturation for 20 hours at 22 ^{o}C, cooling cycle at 2^{o}C, pre-warming at 50^{o}C, followed by three hours at 22 ^{o}C for specimen conditioning. After the last three hour conditioning period, the steel samples were inspected for visible water condensation. Following verification of water condensation on each sample, visual examination of the surface was done and microscopic observation was conducted to determine the corrosion rating for each sample. Fig. 4 shows the test setup for the VIA test. The corrosion criteria for rating steel specimens consist of grade 0 (worst case, heavy corrosion attacks) through grade 4 (no noticeable corrosion attacks), Fig. 5 shows the grading method based on NACE TM 208. To have a valid VIA test, the control sample must have grade 0 (heavy corrosion); samples with no inhibitor should receive worst grade. The control samples consistently rated a grade 0 for all VIA tests, therefore, validating the test method. Relative humidity and the temperature of each test jar were monitored by (Sensirion) sensors and data logging software.

VIA tests were conducted on 10 steel samples (one control sample, one as-received paper and six after exhaustion (aged) cycles. The VIA visual observations are shown in Figures 6-14. Fig. 7 shows the VIA tests before exhaustion test on the Daubert paper in as-received condition. The test showed a satisfactory corrosion protection with Grade of better than 3, indicating that this paper can protect steel from corrosion attacks prior to aging.

All samples that were tested with exhausted (aged) paper suffered of severe corrosion and showed surface pits exceed 300 micrometers in diameter. The corrosion grading per TM-208 indicated that the control sample had Grade 0, all samples tested in presence of the Daubert NOX-RUST Vapor wrapper rating were also Grade 0 (based on NACE method or grade 4 based on the 3010C).

SEM surface condition of samples after VIA tests is shown in Figures 15-22. No significant difference in corrosion behavior was observed between control specimens all those specimens exposed to Daubert NOX-RUST Vapor wrapper.

In summary, Daubert NOX-RUST Vapor wrapper showed no corrosion protection in the VIA test method after aged by exhaustion tests, and steel samples suffered of severe corrosion attacks.

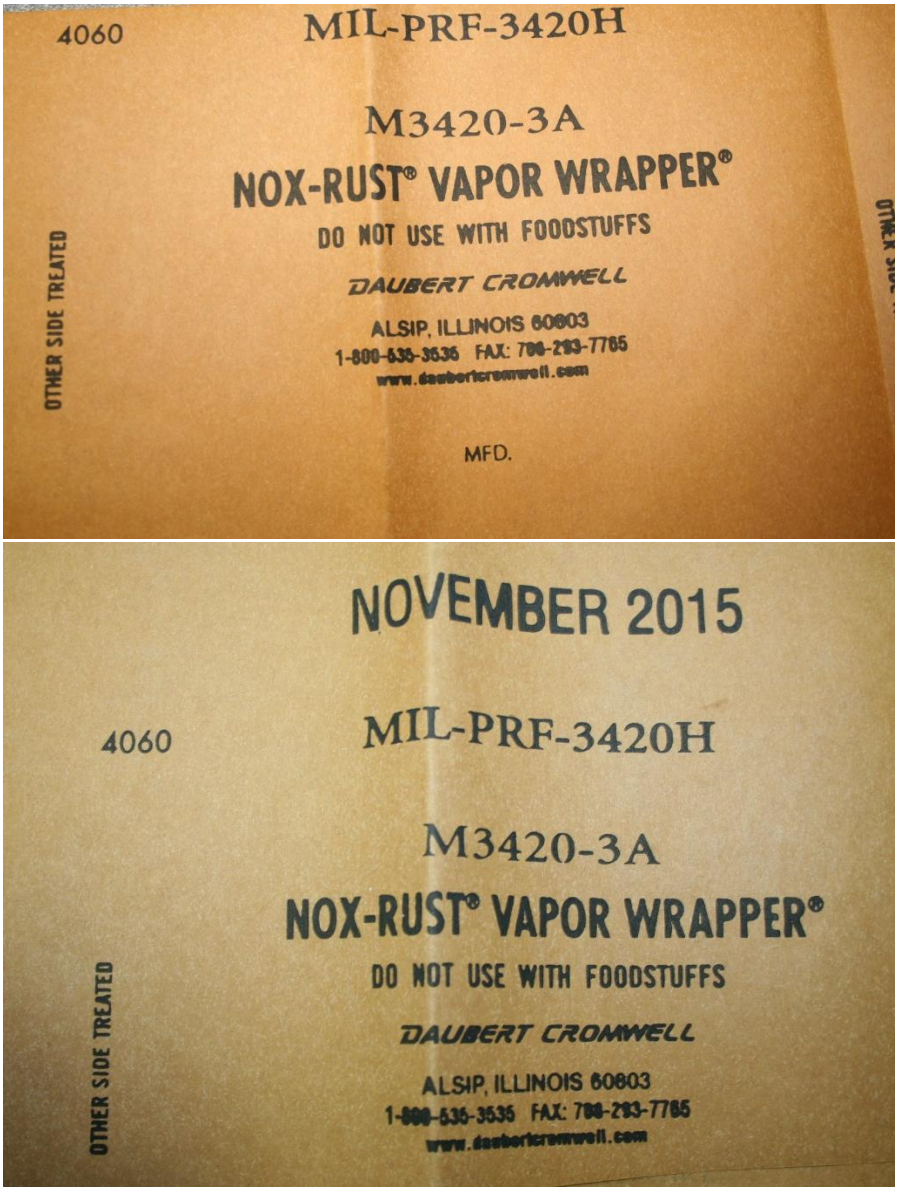


Fig. 1: Daubert NOX-RUST Vapor wrapper used in this investigation

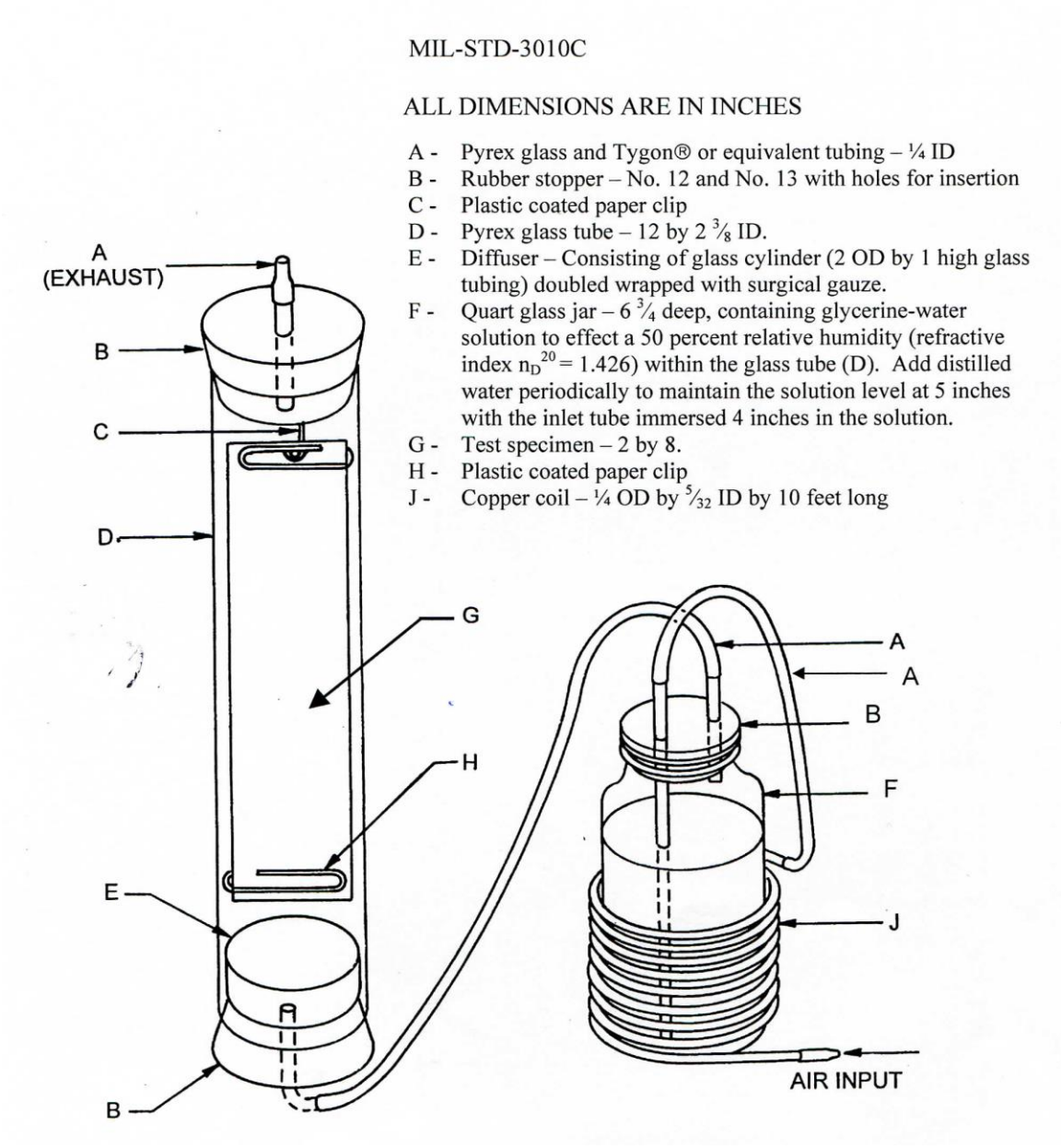


Fig. 2: Exhaustion apparatus for the VCI coated materials.

Fig. 3: Apparatus used for the Exhaustion tests on the VCI coated wrapper paper, MIL-STD 3010-C

MIL-STD-3010C on Daubert NOX-RUST Vaper Wrapper

Non-Exhausted (aged) paper two samples after exhaustion tests

Control Daubert wrapper paper samples after exhaustion

Figure 4: Photo of the VIA test setup for the Daubert NOX-RUST Vapor wrapper corrosion effectiveness evaluation.

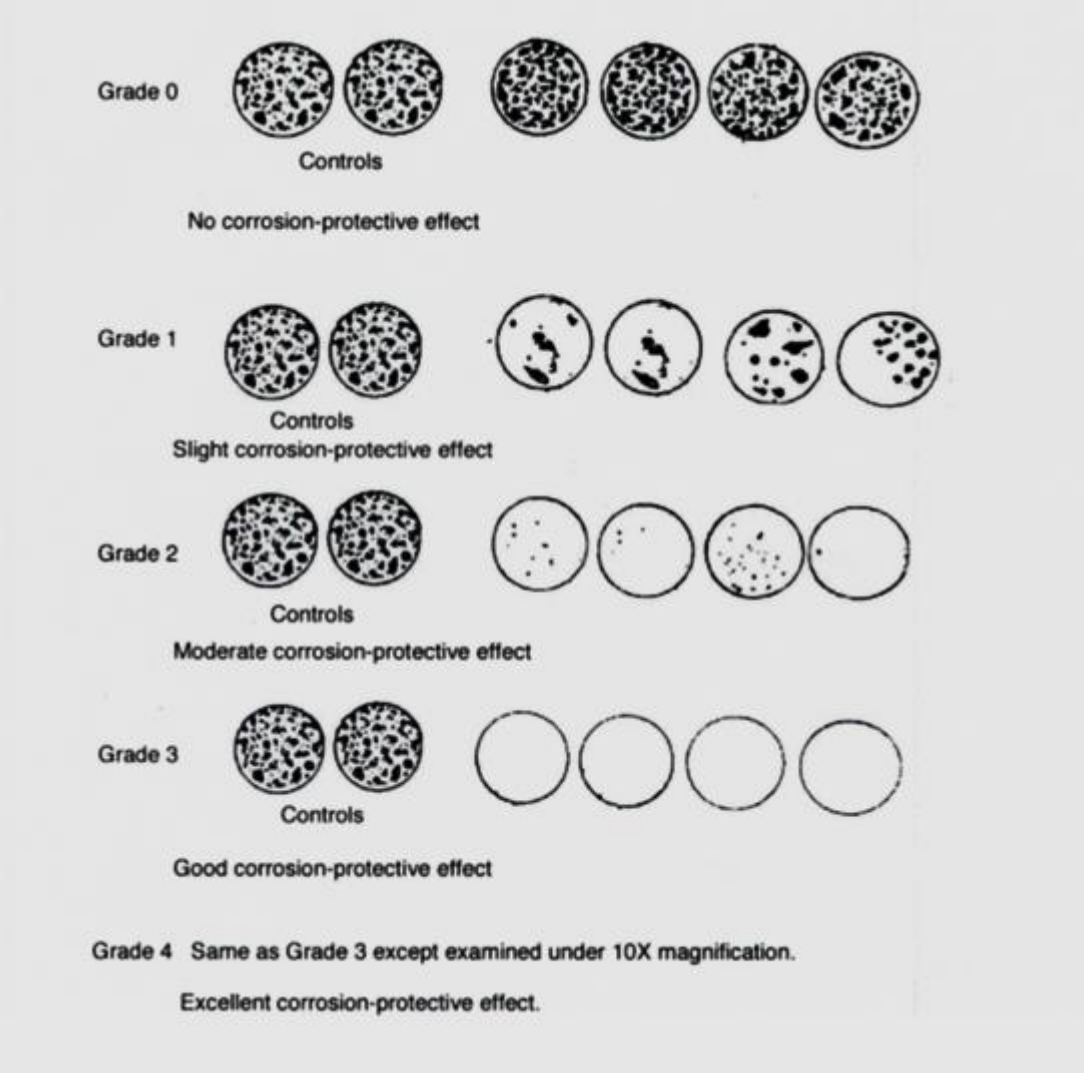
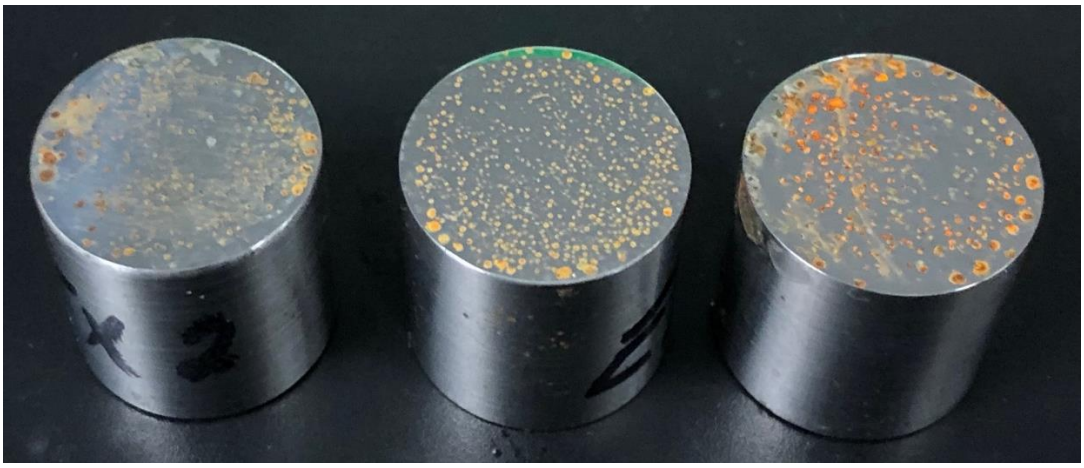
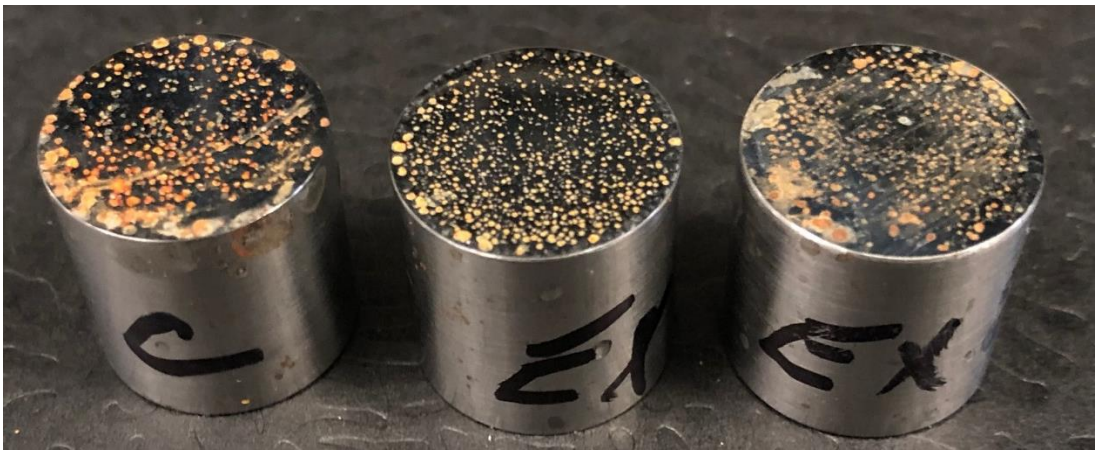


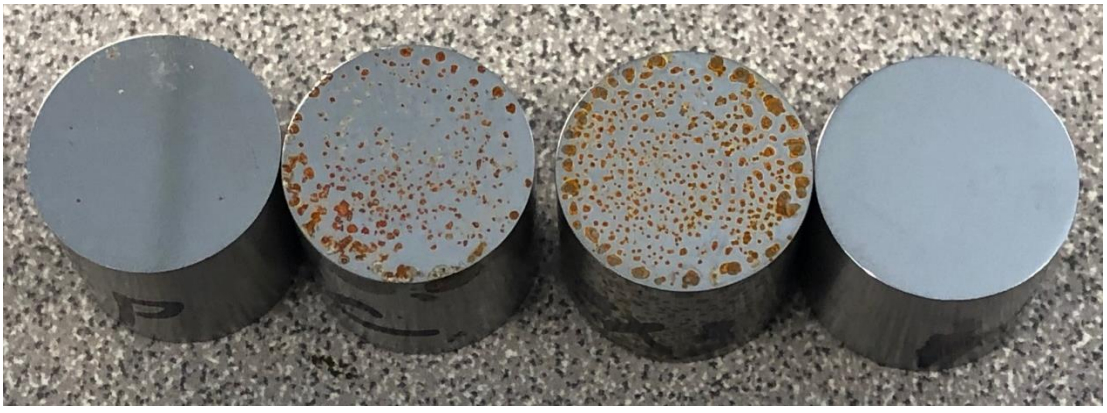
Fig. 5: Typical visual patterns for rating corrosion attacks on sample surface after VIA test (NACE Method 208).



Sample with Daubert paper#2 sample with Daubert paper#1 Control



Control Sample with Daubert paper#3 sample with Daubert paper#4



Sample before test Control Exhausted #3 As-received paper

Fig. 6: Comparison of VIA test results for non-tested sample, As-received paper and after exhaustion tests on the Daubert paper. Grade is zero for samples after exhaustion test, while the test results for the As-received paper is satisfactory (better than grade 3).

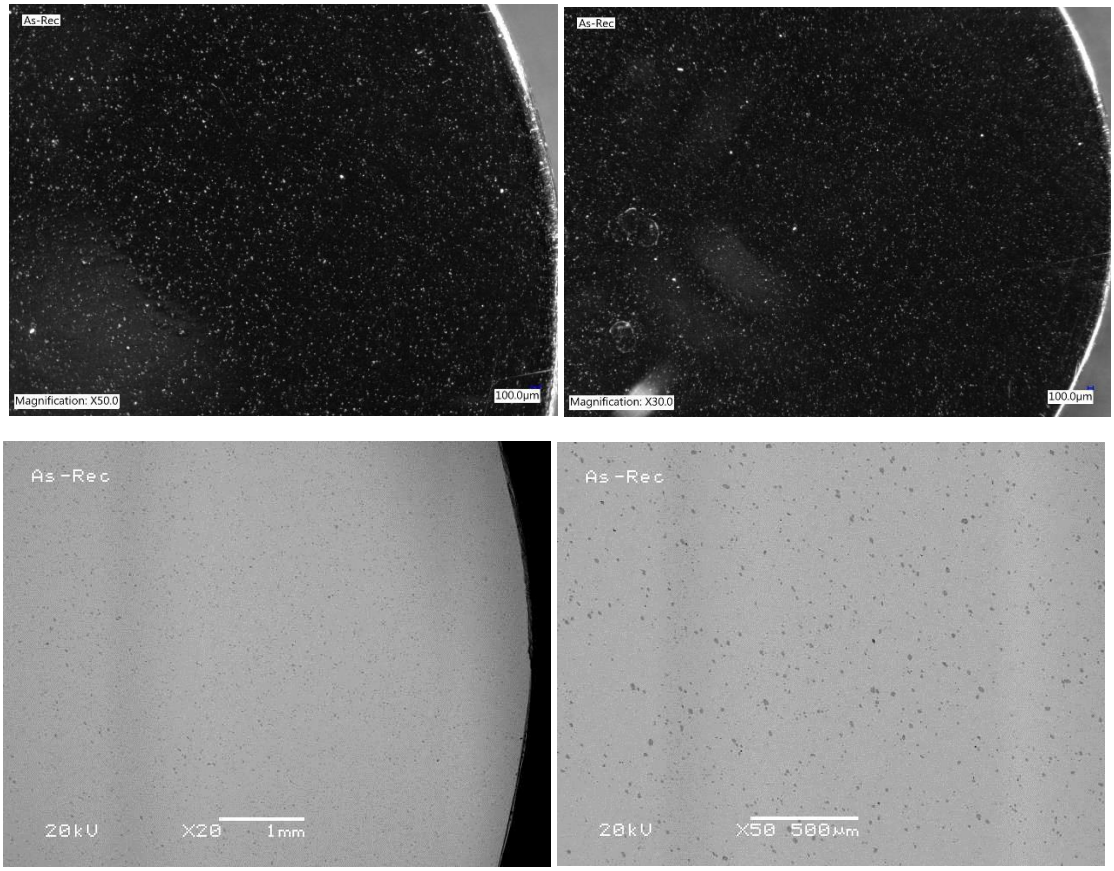


Fig. 7: VIA tests before exhaustion test on the Daubert paper in as-received condition,

A satisfactory corrosion protection was achieved, indicating that before aging this paper can protect steel samples. (Grade is better than 3).

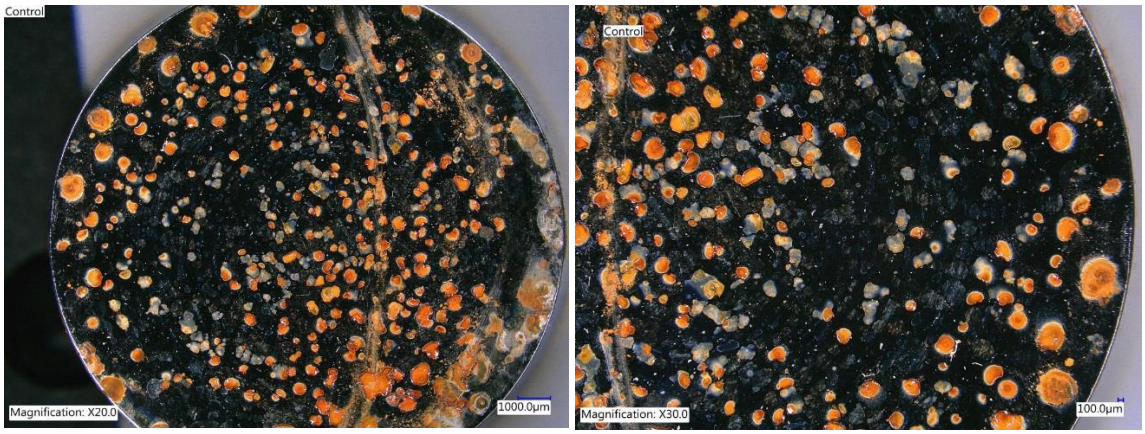


Fig. 8: Optical micrographs of the Control sample in the VIA tests. Grade is 0, most of surface pits are larger than 300 um. Results validated the VIA test.

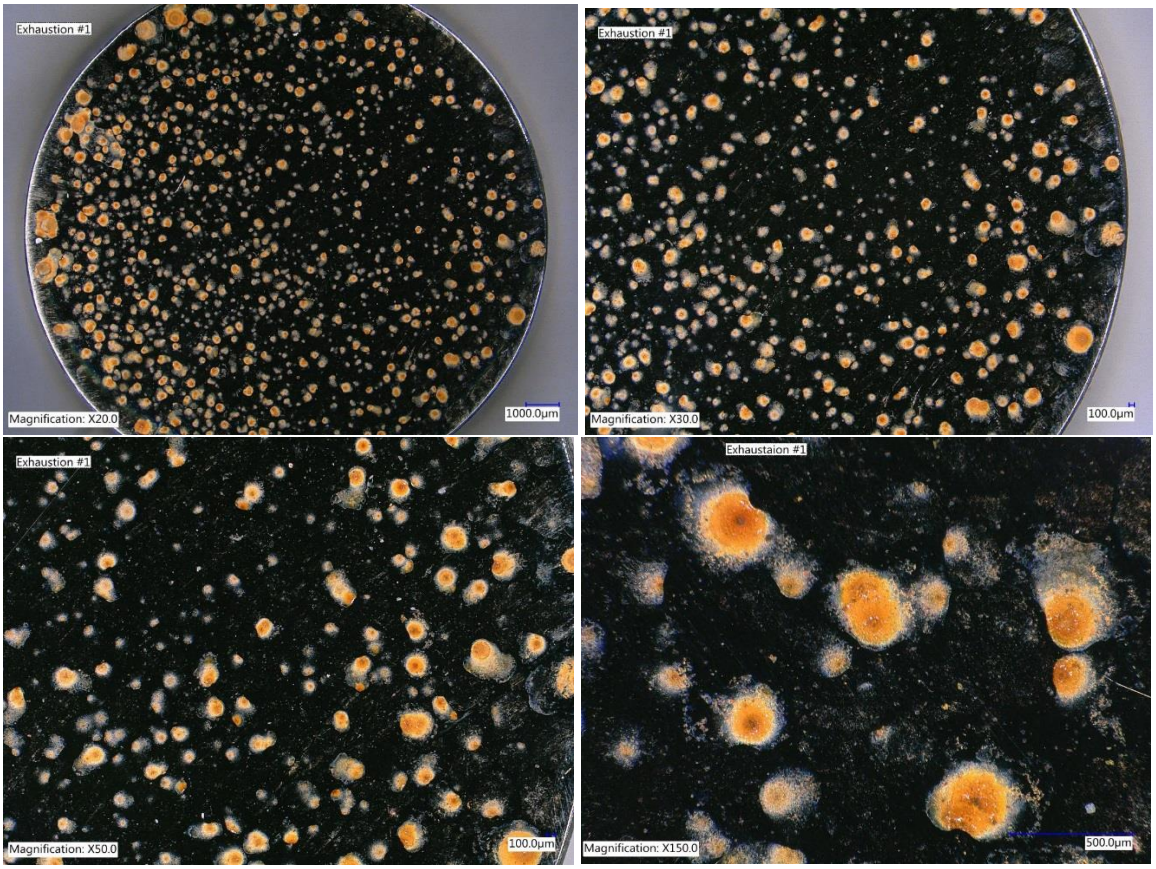


Fig. 9: Optical micrographs of VIA test on sample #1 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um

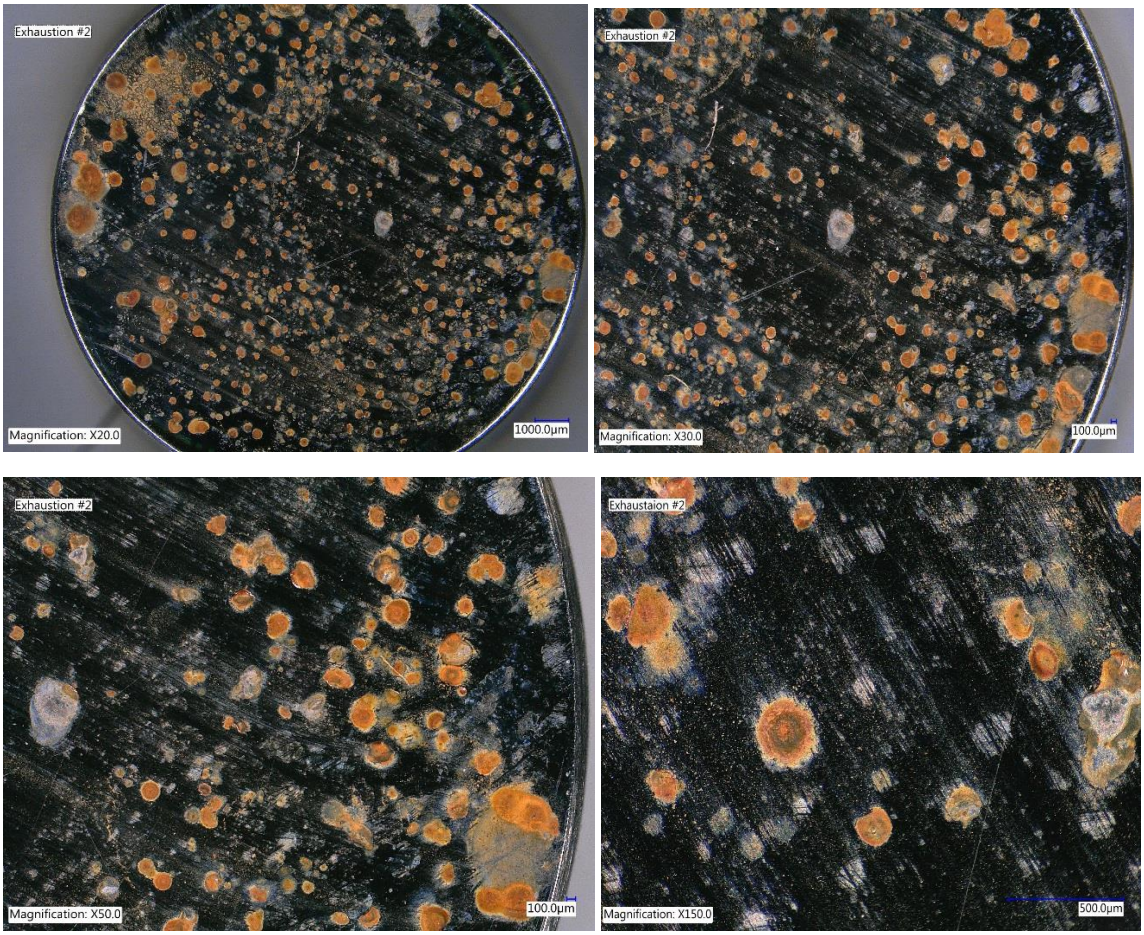


Fig. 10: Optical micrographs of VIA test on sample #2 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

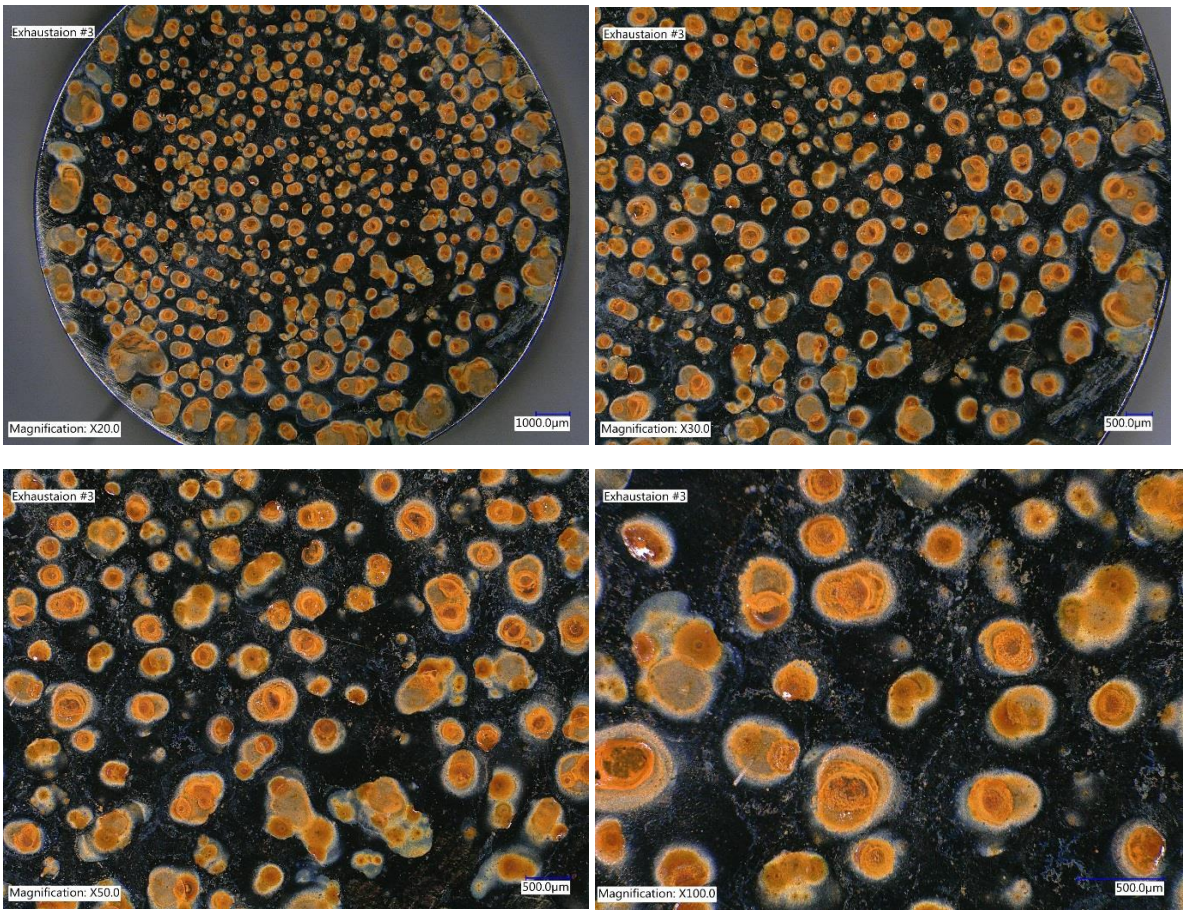


Fig. 11: Optical micrographs of VIA test on sample #3 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

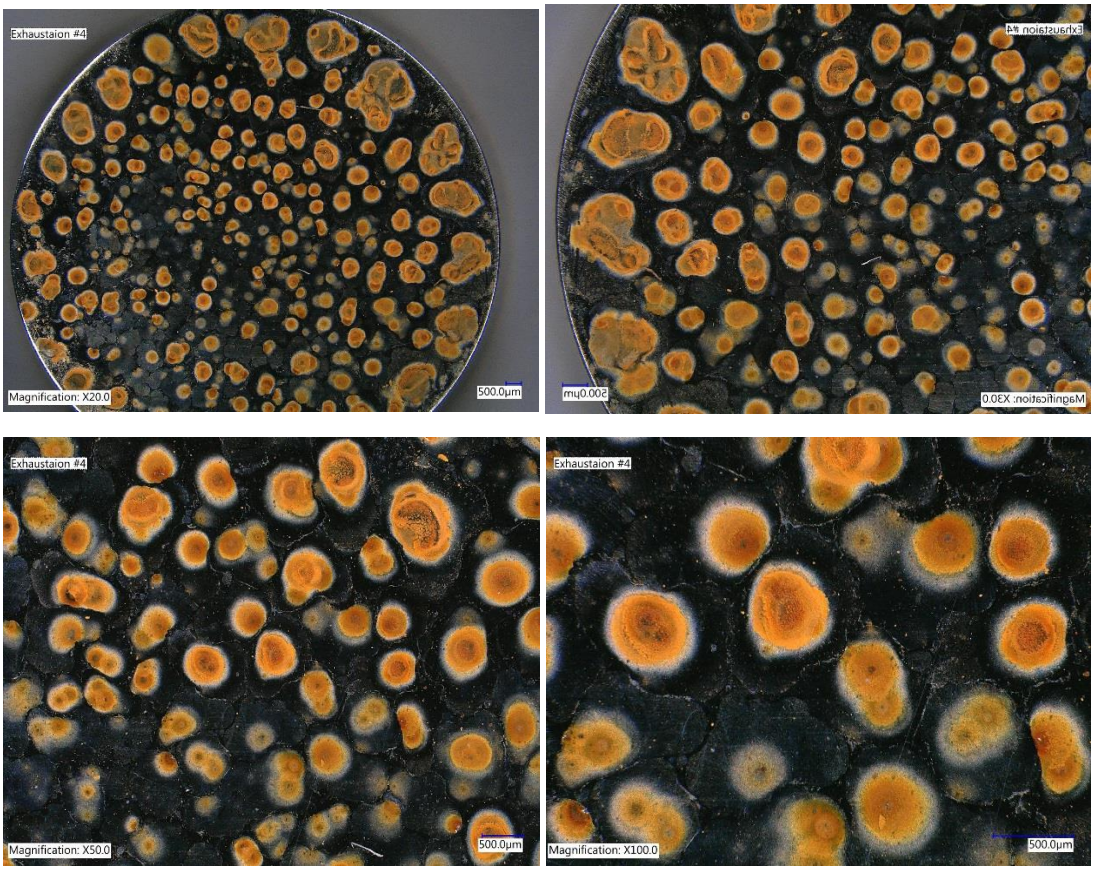


Fig. 12: Optical micrographs of VIA test on sample #4 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

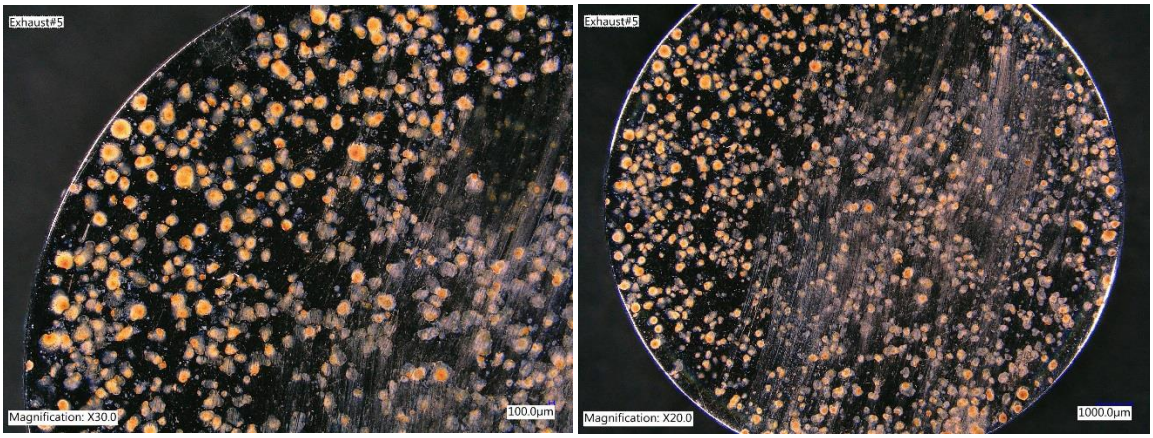


Fig. 13: Optical micrographs of VIA test on sample #5 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

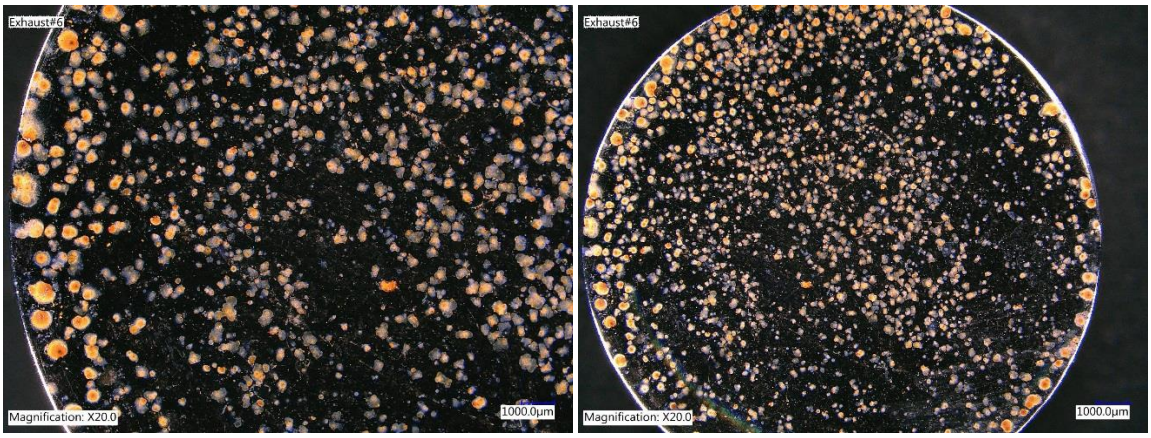


Fig. 14: Optical micrographs of VIA test on sample #6 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

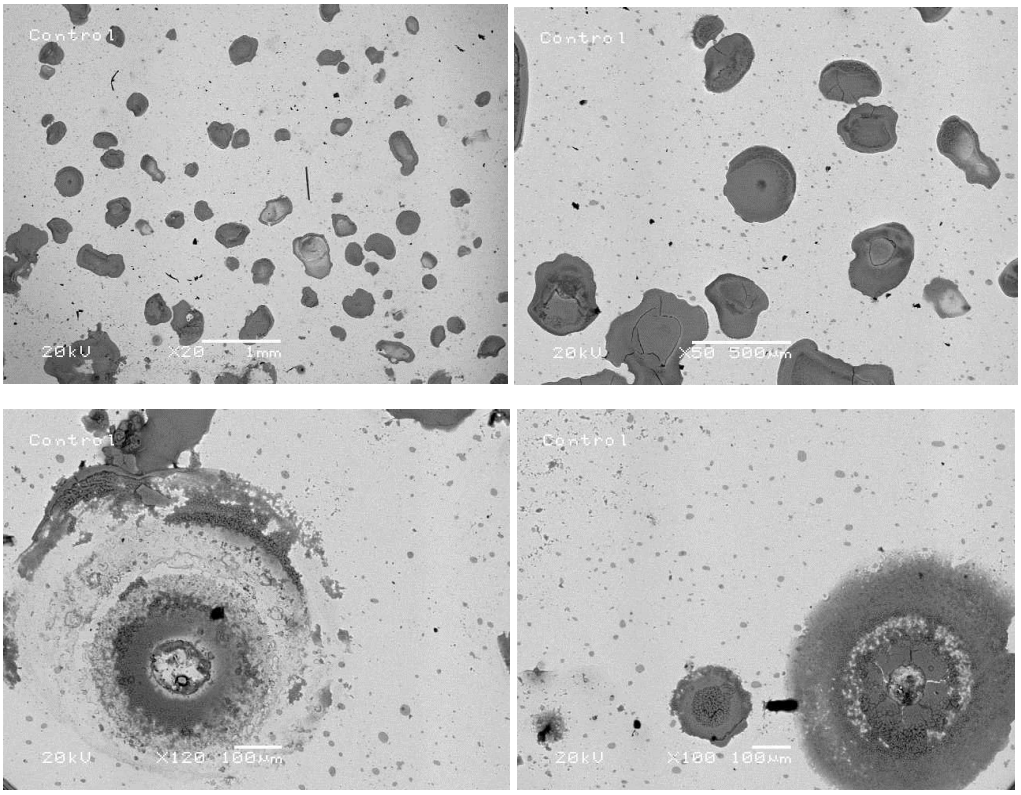


Fig. 15: SEM micrographs of the Control sample in the VIA tests. Grade is 0, most of surface pits are larger than 300 um. Results validated VIA test.

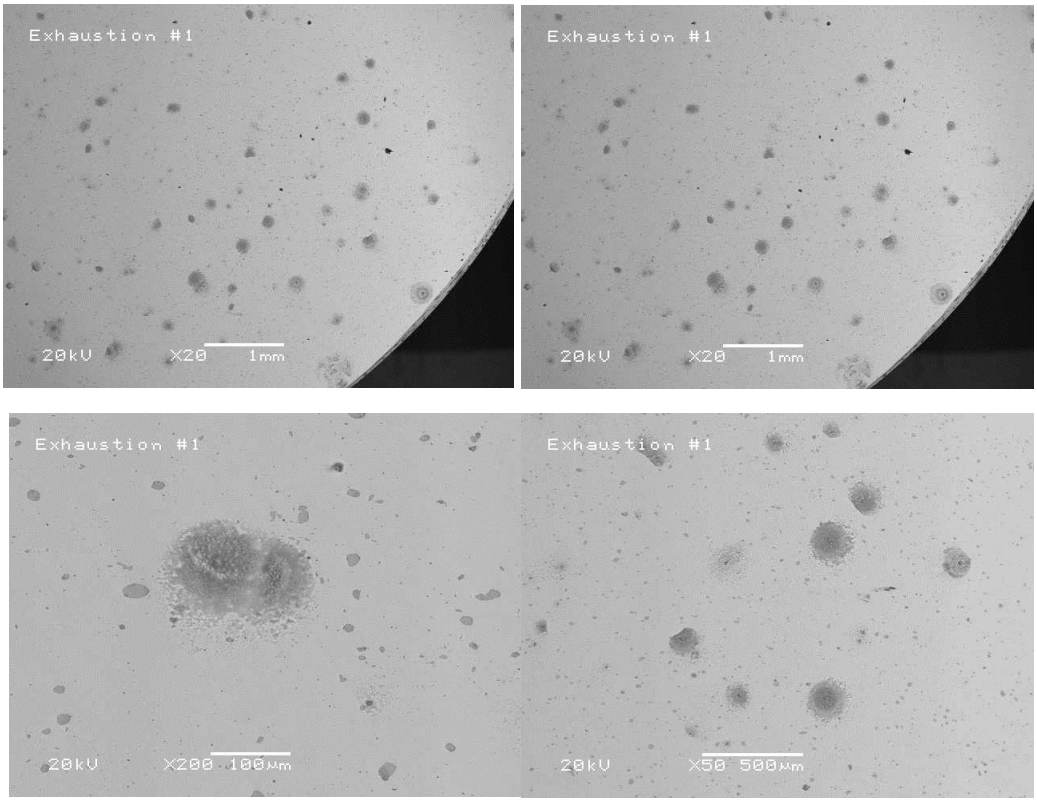


Fig. 16: SEM micrographs of VIA test on sample #1 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um

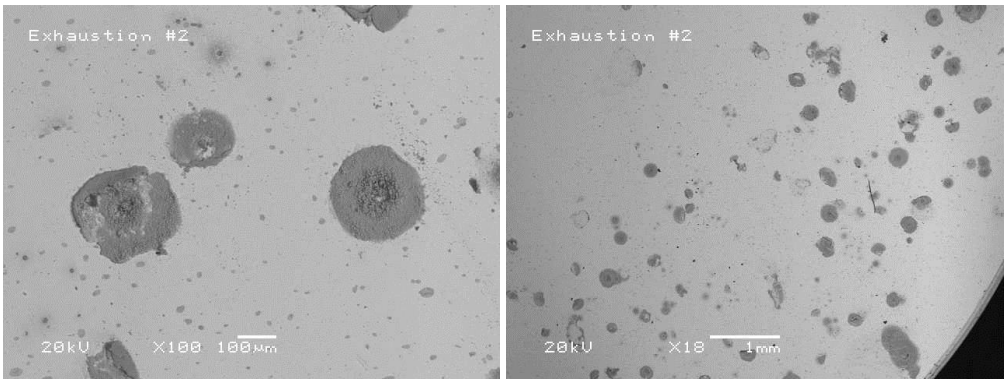


Fig. 17: SEM micrographs of VIA test on sample #2 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um

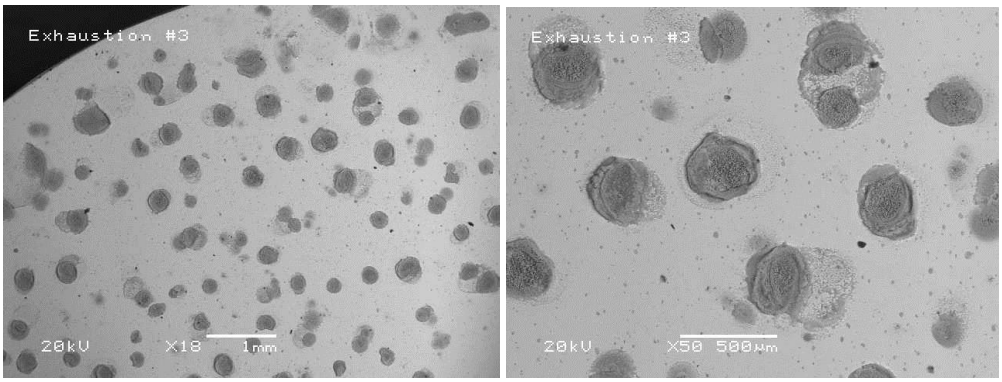


Fig. 18: SEM micrographs of VIA test on sample #3 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

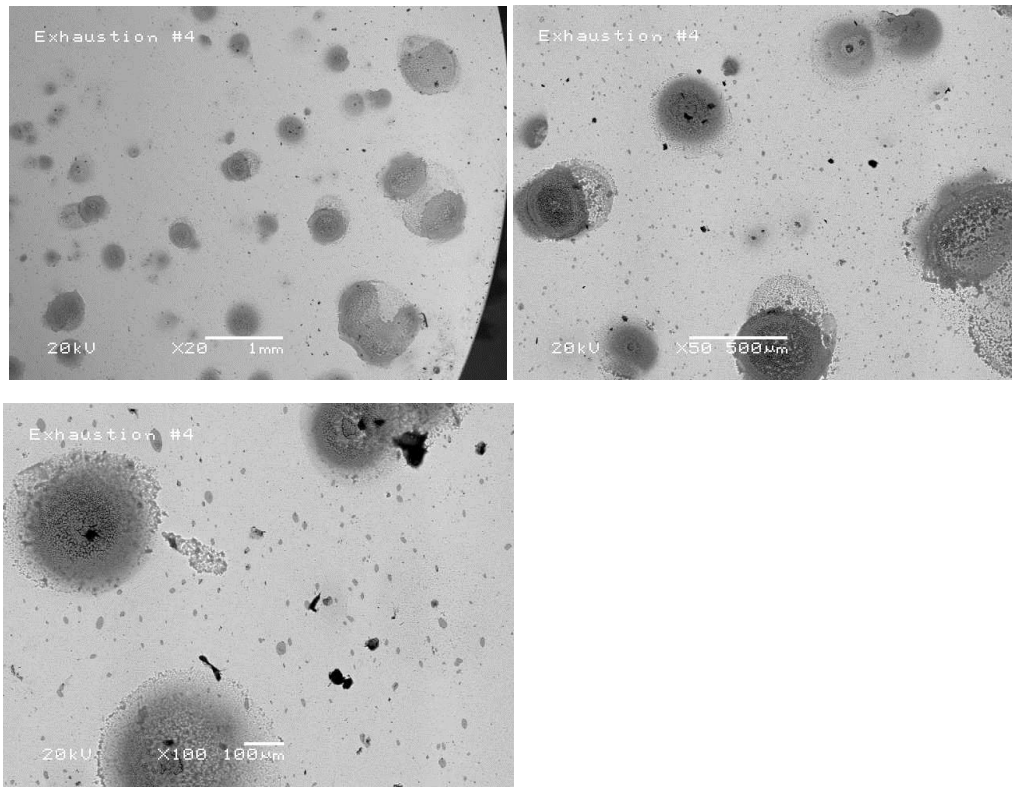


Fig. 19: SEM micrographs of VIA test on sample #4 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

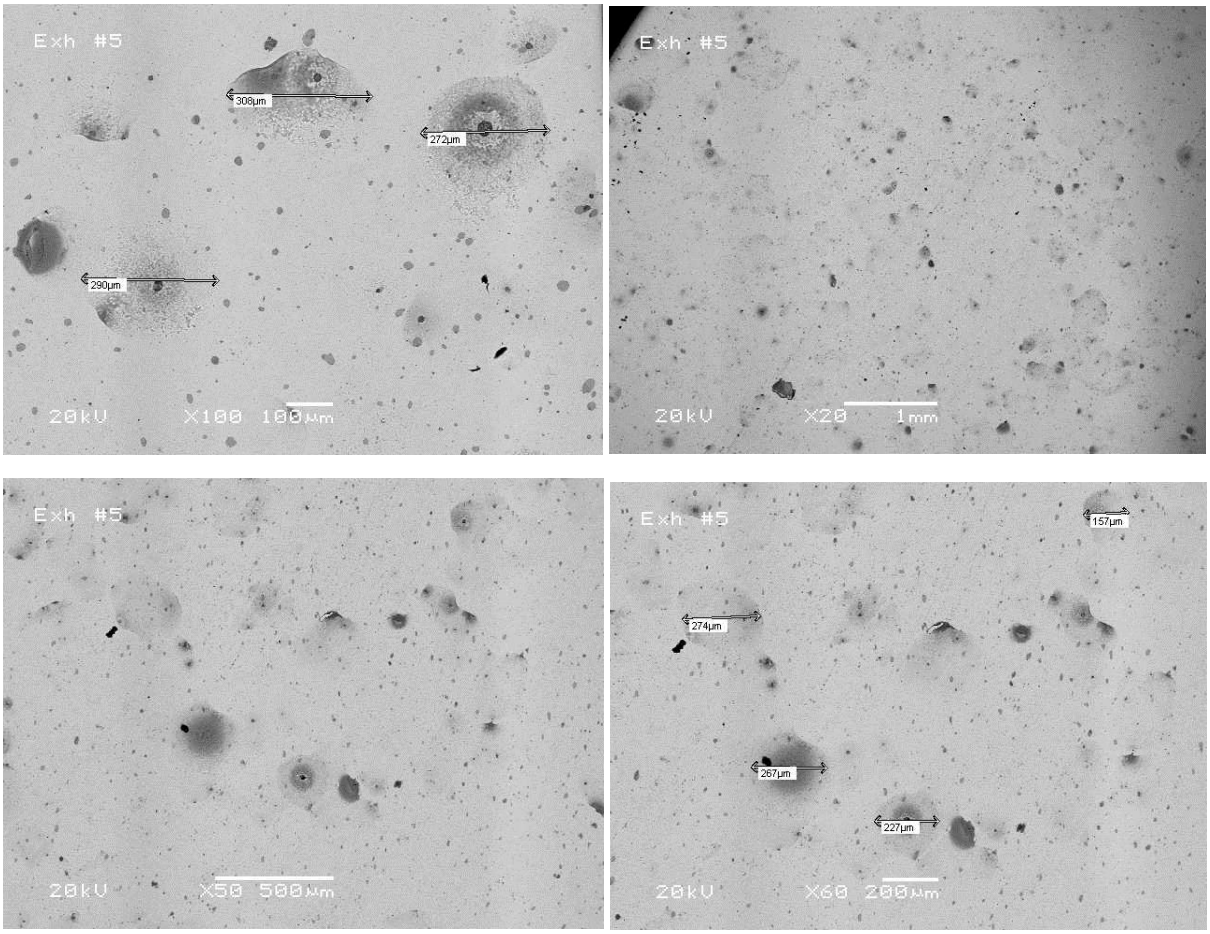


Fig. 20: SEM micrographs of VIA test on sample #5 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.

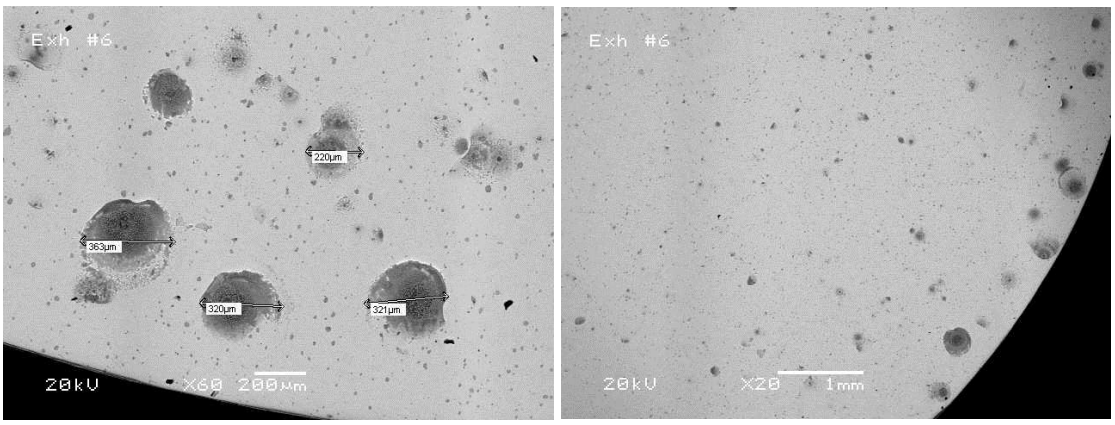
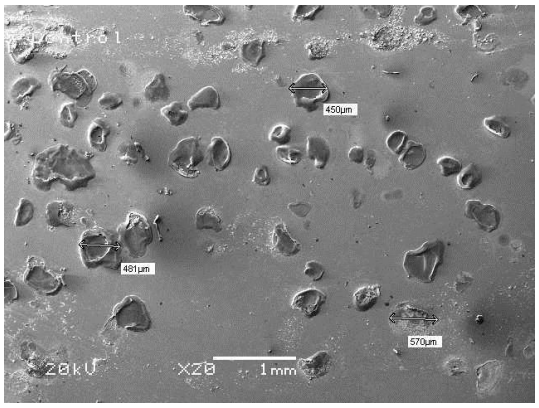
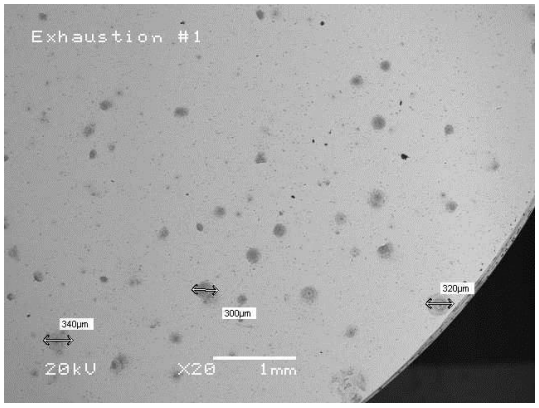


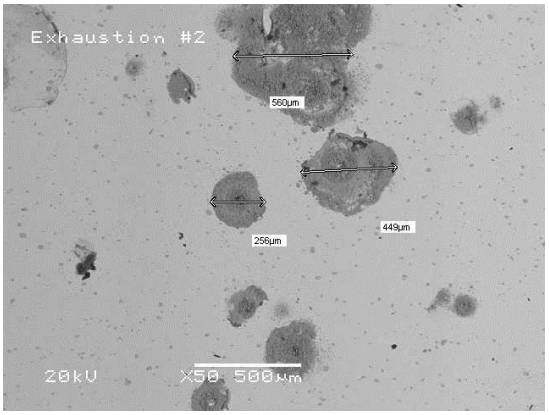
Fig. 21: SEM micrographs of VIA test on sample #6 after exhaustion test on the Daubert paper, Grade is 0, most of surface pits are larger than 300 um.



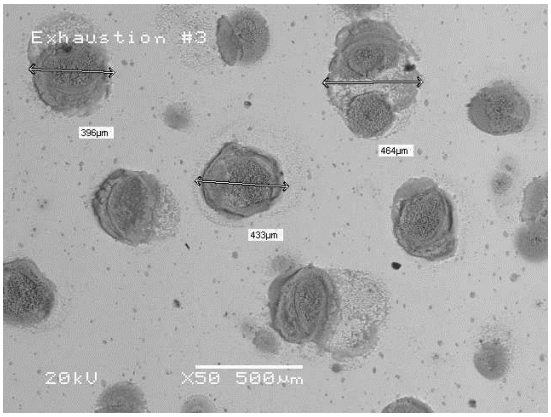
Control



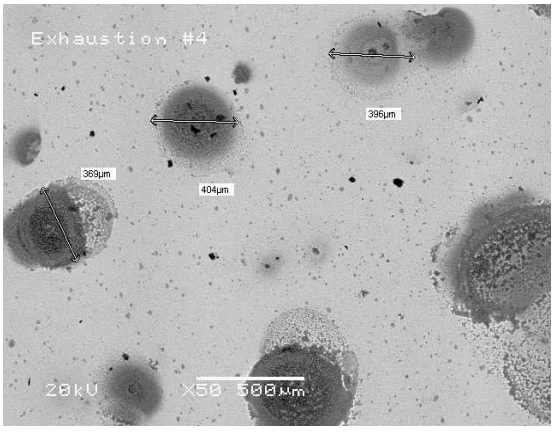
Exhausted#1



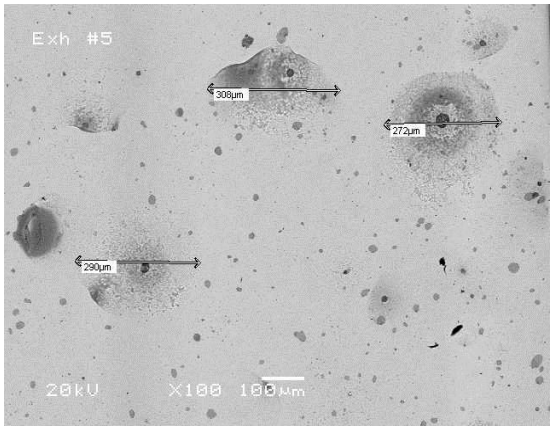
Exhausted#2



Exhausted#3



Exhausted#4



Exhausted#5

Fig. 22: SEM micrographs of VIA test on the Control and five samples after exhaustion test on the Daubert paper. Grade is 0 for all samples and most of surface pits are larger than 300 um.