A CLOSER EXAMINATION OF THE CLAIMS OF EXCELLENT CORROSION RESISTANCE OF STAINLESS STEEL: TEXTBOOK MISCONCEPTIONS AND MISINTERPRETATIONS

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Abstract – This paper examines misconceptions and misinterpretations concerning the common assertion in textbooks that stainless steels has excellent corrosion resistance due to the addition of alloying elements such as nickel (Ni), chromium (Cr), and molybdenum (Mo).

A closer look at this claim reveals underlying assumptions that lead to this imprecise statement. Corrosion experiments have been established in a course in engineering materials that expose these assumptions.

Following a discussion of the tests and their results, it is suggested that statements in textbooks that stainless steel has excellent corrosion resistance should be qualified. It is hoped that by bringing this shortcoming to the attention of engineering educators, the misconceptions and misinterpretations can be corrected.

Keywords: Corrosion resistance, misconceptions, misinterpretations, stainless steel, students, textbook.

respond that its superior corrosion properties are due to the addition of 12%Cr or more, and that the addition of Ni and Mo will provide further resistance to corrosion in severe environments.

Students can come to the misleading conclusion that stainless steel and related alloys are the ultimate solution for any corrosion problem.

This paper's subject matter is based on the author's personal experience and observations that many textbooks used by engineering freshmen commonly classify stainless steel as having excellent corrosion resistance. To bring this misconception to students attention, the author developed simple corrosion experiments to demonstrate that under some conditions even stainless steel can suffer corrosion.

The test and typical results are presented here for the benefit of teachers (as well as researchers) and, of course, students.

1. INTRODUCTION

During the writer's years of teaching an introductory course in materials science and other materials-related engineering courses in Memorial University and University of Manitoba, curious freshmen have questioned the statement commonly found in textbooks that stainless steels has excellent corrosion resistance [1].

Such a misconception occurs particularly when teacher present courses on materials properties or on the classification of metals and their alloys such as stainless steels, such courses include materials selection, materials physics, materials chemistry, materials, manufacturing processes, and fracture of materials. These courses, one way or the other, introduce various engineering alloys suitable for corrosive environments with stainless steel alloys being the most common.

Freshmen often ask the question why, stainless steel, since it is largely steel, has such excellent corrosion resistance in comparison to pure steel. Teachers often

2. METHODOLOGY

Twelve samples of aluminum (Al), steel (Fe) and stainless steel (S.S) (36 in total) are prepared by sectioning and each sample ground and polished with 600 grit sand paper, degreased in a detergent solution, and dried. The 36 samples are evaluated for the occurrence of crevice corrosion after experiencing different levels of and different durations in corrosive environments. It is important to note that the dimensions of the test samples are not critical in the development of crevice corrosion.

The critical factor is that elastic bands placed around each sample are tightly held against the sample at its centre so that crevice corrosion can form underneath the band. Typically, tighter elastic bands promote greater localized corrosive attack.

Elastic bands were used for reproducibility of results and to simulate "real world" crevice corrosion that occurs when, for example, two strips of sheet metals are held together by a nut and bolt or a screw. Crevice corrosion developed underneath washers often remains hidden and

is not discovered in its early stages. This form of simple but undetected crevice corrosion can lead to catastrophic disaster (e.g. Aloha Airlines Boeing 737 in 1988). The severity of the crevice environment increases over time, such that the local attack rate can accelerate with time.

In the tests, the elastic bands are used to suspend the sample in the beaker containing the solutions. Two samples of each material are suspended in each beaker. Three solution concentrations of NaCl and FeCl₃ were prepared - 0.1%, 1% and 10%. One sample of the two in each beaker was removed after 3 days and the other sample after 7 days (See Fig. 1).

Fig. 1. Samples immersed in NaCl solution (first row), and in FeCl₃ solutions (second row).

For consistency of description, students were required to record the level of crevice corrosion in one of the following four categories: none observed; slight; moderate; severe. Also, pH values were measured and recorded before samples were immersed. For the NaCl solutions with concentrations of 0.1%, 1% and 10% the pH values were 9, 9.2, and 9.7, respectively, and for FeCl₃ solutions with concentrations of 0.1%, 1% and 10% the respective pH's were 2.9, 2.8 and 2.0. On Day 03, one sample was extracted from each beaker and the elastic bands carefully removed. Samples were then evaluated for the degree of crevice corrosion (if any) beneath each elastic band.

This procedure was repeated for the second set of samples immersed until Day 07.

3. RESULTS AND DISCUSSIONS

Students found that the NaCl solutions in three different concentrations did not produce any visible effects on Al, Fe, and S.S. samples even when the exposure time increased to 7 days (see Fig. 2 and Fig. 3), i.e. no crevice corrosion was observed.

Fig. 2. No crevice observed in Al, Fe, S.S. samples immersed in NaCl solution on Day 03.

Fig. 3. No crevice corrosion observed for Al, Fe, S.S. samples in NaCl solutions on Day 07.

For the three FeCl₃ solutions no crevice corrosion was observed on Al after 3 days, whereas for higher concentrations of 1% and 10% FeCl₃ slight and moderate visible corrosion was observed on Fe samples. For stainless steel (S.S) moderate and severe corrosion occurred with concentrations of 1% and 10% FeCl₃ (see Fig. 4).

Fig. 4. Moderate crevice for Fe, severe crevice for S.S sample in FeCl_3 solution on Day 03.

It can be clearly seen that as solution concentration increases so does the severity of crevice corrosion. Furthermore, the three materials exposed for 7 days in FeCl_3 solutions showed different levels of corrosion. In Al samples, no crevice corrosion was observed (Fig. 5), but the Fe samples had evidence of slight to moderate corrosion at 1% and 10% respectively. The S.S. samples exhibited crevice corrosion even at the lowest concentration of 0.1%, and moderate to severe crevice corrosion at 1% and 10% respectively (Fig. 5).

Fig. 5. Moderate crevice corrosion observed in Fe and severe in S.S. in FeCl_3 solution on Day 07.

Al samples immersed in NaCl solutions and those immersed in FeCl_3 solutions exhibited no crevice corrosion in any of the three concentrations (0.1%, 1% and 10% NaCl) after 3 and after 7 days of exposure. The Fe samples experienced moderate crevice corrosion only with the highest FeCl_3 solution concentration (10% FeCl_3). S.S. in 10% FeCl_3 solution exhibited the most severe crevice corrosion of any of the materials. Severe crevice corrosion was noted from Day 03 and many of these samples were dissolved and depleted after 7 days.

After students have evaluated their data they can be asked, “What would happen if S.S. samples were immersed in FeCl_3 solution for a month? Why did additions of alloying elements Ni, Cr, and Mo not prevent corrosion as presented in textbook? Why did the Fe samples exhibit better resistance to corrosion than S.S.?”

The test results expose some misconceptions that students can have concerning stainless steels. Teachers should address these misconceptions where the course textbook has not made some qualifications on the generally excellent corrosion resistance of S.S. in many environments.

Students should be taught that under certain environments stainless steel has the potential for greater crevice corrosion than steel itself.

Another area requiring explanation for students is the effect of the addition of alloying elements in superalloys and the corrosion resistance relative to stainless steel. It is known that the addition of Mo to superalloy (Ni-Cr) will further increase resistance to corrosion as compared to the Mo free alloy. However, the addition of Mo to stainless steels does not increase resistance to corrosion and the Mo-bearing stainless steel remains susceptible to corrosion [2, 3].

Why do additions of Mo to superalloy (Ni-Cr) increase resistance to corrosion, whereas additions of Mo to stainless steels do not remain a puzzle that is not yet understood? Students should be aware of this fact so as not to have the misconception that Mo additions always increase corrosion resistance.

4. STUDENTS REACTIONS

For students, the experimental work described in this paper proved very effective in qualifying and drawing attention to the general statement commonly found in textbooks that stainless steel has excellent corrosion resistance.

Some typical student comments regarding the corrosion experiment are as follows. (1) Prior to the completion of the experiment students expected and believed steel samples would suffer most crevice corrosion and stainless steel samples would be the most

resistant. (2) The corrosion experiment is very simple in principle and set up yet critical and interesting, but more time was needed for observation to witness how stainless steel samples will dissolve in 10%FeCl₃ solution. (3) Stainless steel showed good corrosion resistance in the sodium chloride solution. (4) The experiment provided an excellent example of the corrosion process. (5) Learning from observing is more convincing than book learning.

In general, the students' responses to the lab experiment were overwhelmingly positive. Though the work load is small, the lab is effective because it involves active learning and allows students to use their powers of observations to validate for themselves the misinformation commonly found in textbooks that stainless steel has excellent corrosion resistance. Students' positive comments indicate that the lab experiment was generally well received and of value.

5. CONCLUSIONS AND SUGGESTIONS

The author recommends that textbooks in which qualifications about the excellent corrosion resistance of stainless steel alloys have not been made should be corrected so as to avoid misunderstanding by engineering educators and the general public.

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