CORROSION OF HOUSEHOLD MIXER HEADS

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Abstract

Household appliances often utilize polymer-metal bonding, typically achieved through adhesive bonding or press-fitting techniques. Corrosion resistance is a major factor in household appliances, as corrosion can compromise the functionality and aesthetics of household appliances. Stainless steels are a natural choice. However, the nature of polymer-stainless steel bonds can cause susceptibility to crevice corrosion. Crevice corrosion, a localized attack on stainless steel in confined spaces. This study investigates crevice corrosion in mixer heads fabricated with two different grades of stainless steel (1.4016 and 1.4021). Metallographic analysis revealed a ferritic microstructure with higher chromium content for 1.4016, contributing to its superior corrosion resistance compared to the martensitic structure of 1.4021. Both materials exhibited a critical crevice width of 9-10 µm between the plastic head and the steel shaft, facilitating the entrapment of corrosive solutions (confirmed by EDS analysis) and subsequent crevice corrosion. The PREN (pitting resistance equivalent number) calculation further supported the observed behavior, with 1.4016 boasting a higher value (16-18) compared to 1.4021 (12-14). While PREN offers a valuable indicator, it highlights the importance of design considerations to minimize crevice formation. Here, eliminating the gap between plastic and steel through improved design or sealants emerges as a crucial preventive strategy. This study emphasizes the interplay between material selection and design in mitigating crevice corrosion in household appliances. By understanding the factors influencing corrosion susceptibility, manufacturers can optimize material choices and implement design solutions to ensure the longevity and performance of their products.

Keywords: Crevice corrosion, stainless steel, mixer heads

1. INTRODUCTION

Stainless steel is a popular material for household appliances because it is strong, durable, and corrosion-resistant [1]. The corrosion resistance depends on the formation of a passive Cr_2O_3 film. However, stainless steel can still corrode if the passive layer is disrupted. In certain environments, such as when exposed to salt water or food, where there are low pH and Cl^- ions19 [2,3].

Crevice corrosion is a form of localized attack that occurs frequently on metals exposed to stagnant solutions within shielded areas - crevices. It is usually very difficult to detect, predict, and design against due to the size and locations of the corroding crevice. Corrosion-resistant materials are usually the most vulnerable to this form of corrosion, especially stainless steel. Crevice corrosion leads to the breakdown of the passive film in these localized areas, forming pits and cracks [4,5].

In this study, we investigated the corrosion of household mixer heads. The heads were made out of two different grades of stainless steel, ferritic stainless steel1.4016, and martensitic stainless steel 1.4021.

2. MATERIALS, METHODS AND RESULTS

The 1.4016 (AISI 430) is a basic ferritic stainless steel. It is widely used for cutlery, household appliances, heat exchangers, etc. It is ductile, has good formability, and has decent corrosion resistance.

The 1.4021 (AISI 420) is a general-purpose martensitic stainless-steel grade, used in cutlery, surgical instruments, tools for polymer processing, etc. It can achieve relatively high hardness, much higher than ferritic or austenitic grades.

The chemical compositions were analyzed by XRF (Thermo Scientific Niton XL3t GOLDD+) for Cr, Si, and Mn. C and S were analyzed by combustion (ELTRA CS800).

The mixer heads had visible corrosion products on the polymer/steel contact as shown in **Figure 1.** We cut the mixer heads lengthwise through the head to measure the width of the gap between the plastic and steel. We also made a longitudinal cross-section of the stem for microstructural analysis and visually inspected the areas under the polymer. The visual inspection showed that the corrosion appeared only on the polymer – steel interphase as seen in **Figure 2**.

We measured the width of the gap on an optical microscope. We etched the metallographic analysis samples with Kalling's reagent and observed them under an optical microscope and a scanning electron microscope (JEOL JSM-6500FR), where we also performed EDS analyses. We cut out the sample with the corrosion product and observed the surface without further preparation.

Figure 1 Corrosion on the steel–polymer bond

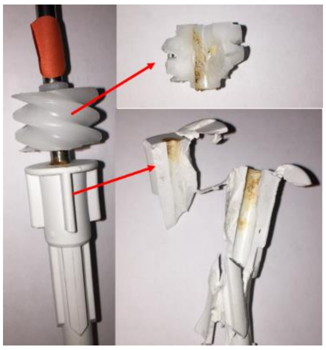

Figure 2 Visible corrosion under the polymer

No significant irregularities were detected in the microstructure. The microstructure of the 1.4016 stainless steel consisted of ferrite with precipitated chromium carbides. The grains were elongated in the direction of forming, with a length of about 100 µm and a width of 20 µm, as shown in **Figure 3**. The sample chemical composition is consistent with 1.4016, the specifications for chemical composition and the chemical analysis are given in **Table 1**.

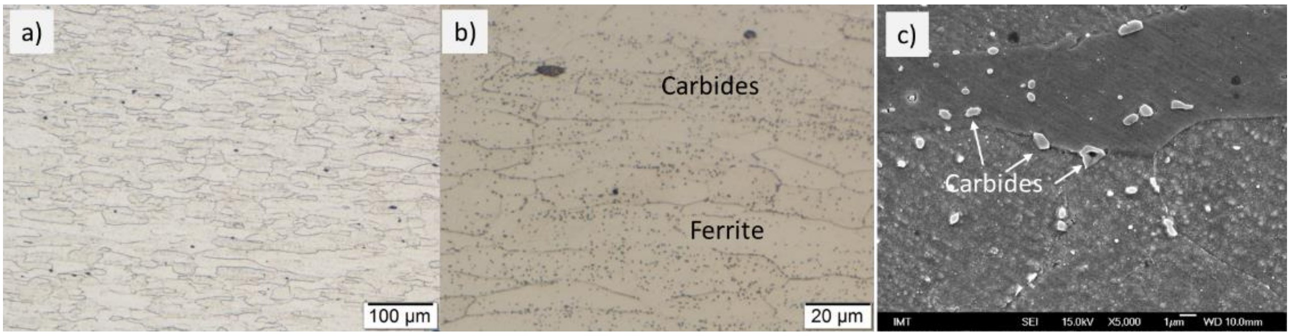

Figure 3 Microstructure of 1.4016, a) elongated ferritic grains, b) ferrite grains and carbides, c) Carbide precipitates along grain boundaries and within grains

Table 1 Chemical composition of sample 1.4016 in wt%

	C	**Si**	**Mn**	**S**	**Cr**
Specifications	Max. 0.08	Max. 1	Max. 1	Max. 0.02	16-18
Measured	0.021	0.73	0.85	0.016	16.9

The microstructure of the 1.4021 stainless steel consisted of tempered martensite with a high proportion of chromium carbides. The grains did not show a forming direction (typical for martensite) and were about 10 µm in size. The forming direction was evident from the bands of carbides and the elongated non-metallic inclusions -- manganese sulphides along which the carbides were precipitated, as shown in **Figure 4**. The sample chemical composition is consistent with 1.4016, the specifications for chemical composition and the chemical analysis are given in **Table 2**.

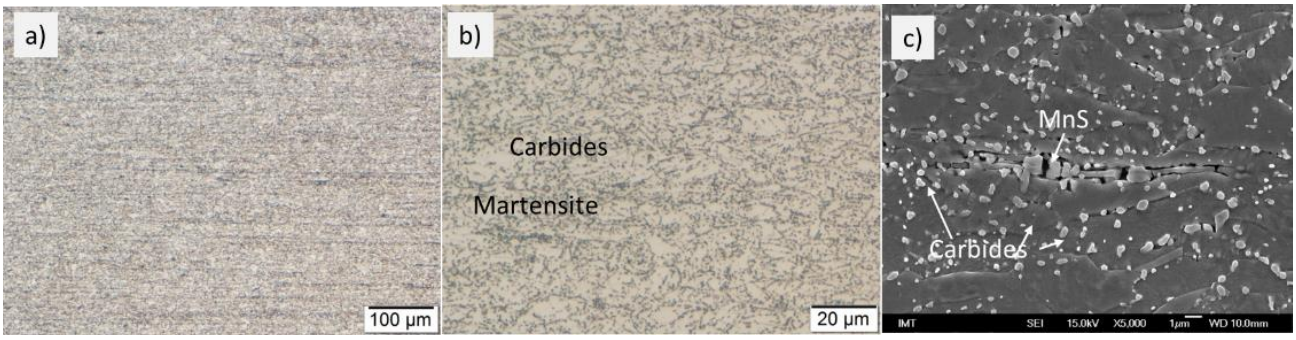

Figure 4 Microstructure of 1.4021, a) Martensite with elongated non-metallic inclusions, b) martensite matrix with carbides, c) Carbide precipitates along grain boundaries and within grains, MnS non-metallic inclusions with carbide precipitates

Table 2 Chemical composition of sample 1.4021 in weight %

	C	**Si**	**Mn**	**S**	**Cr**
Specifications	0.16-0.25	Max. 1	Max.1.5	Max. 0.03	12-14
Measured	0.22	0.54	1.10	0.010	12.20

The gap width between the plastic and steel was 9-10 µm in both cases, as shown in **Figure 5**.

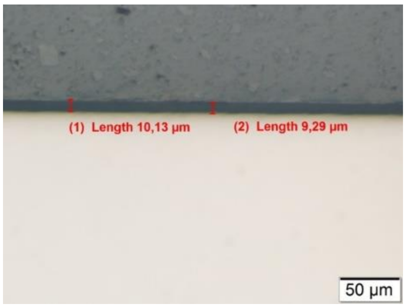

Figure 5 Gap between the steel and polymer

EDS analysis of the corrosion product (1.4021) in **Figure 6** showed an increased content of chlorine and sodium (**Table 3**), which is typical for crevice corrosion. The oxides also contained a lot of iron, which is why the product was reddish in colour. For comparison of microchemical EDS analysis and surface morphology, a non-corroded 1.4021 surface on the same mixer head is shown (**Figure 7** and analysis in **Table 4**). The SEM-

EDS analysis of the surface deviates from the bulk chemical analysis, showing higher Cr and lower Si and Mn, we also included O in the analysis to show a normally passivated surface.

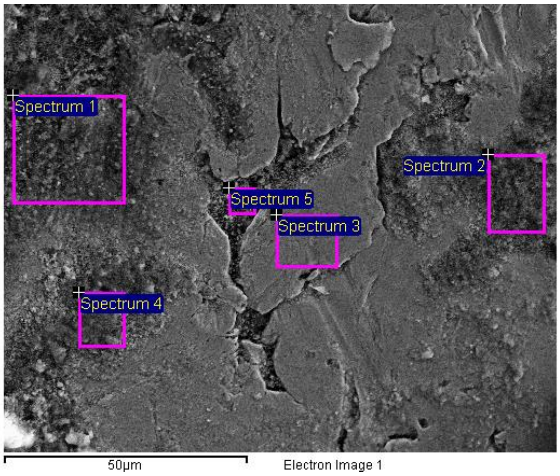

Figure 6 SEM-EDS analysis of corrosion product on steel 1.4021

Table 3 EDS analysis of corrosion product on steel 1.4021 from **Figure 6** in wt%

Spectrum	O	Na	Si	Cl	Ca	Cr	Mn	Fe	Total
Spectrum 1	32.0	1.6	0.6	3.0	/	18.2	0.9	43.6	100.0
Spectrum 2	38.9	4.4	0.8	4.7	0.6	4.0	/	46.6	100.0
Spectrum 3	2.7	/	0.6	/	/	13.5	/	83.3	100.0
Spectrum 4	41.7	1.2	0.7	2.5	/	4.4	/	49.4	100.0
Spectrum 5	22.0	0.7	0.8	0.9	/	9.4	/	66.1	100.0

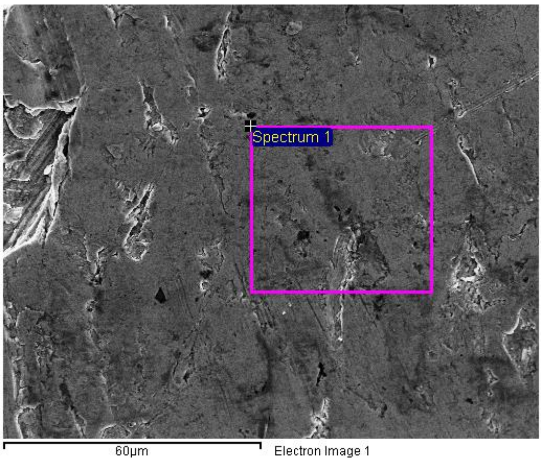

Figure 7 SEM-EDS analysis of an uncorroded surface on the mixer head

Table 4 EDS analysis of steel 1.4021 surface from **Figure 7** in wt%

Spectrum	O	Si	Cr	Mn	Fe	Total
Spectrum 1	3.6	0.5	13.5	0.9	82.1	100.0

3. INSTRUCTIONS FOR BULLETS AND NUMBERING

Crevice corrosion leads to the breakdown of the passive film in the localized shielded areas. Stainless steels depend on their surface oxide film for corrosion resistance and are particularly prone to crevice corrosion, especially in environments that contain chloride ions [6]. The gap defining the crevice is large enough to get the liquid in but too small to permit a steady flow. The schematic presentation of crevice corrosion is shown in **Figure 8**. When the attack begins it quickly progresses. The anodic and cathodic reactions are established, where the anodic reaction is characterized by metal dissolution and the cathodic by oxygen reduction as seen in **Figure 8**. As the reactions proceed, the dissolved oxygen in the small volume of stagnated solution inside the crevice is consumed, thus preventing the formation of the passive chromium oxide film. The electrons travel through the steel outside the crevice, where plenty of oxygen is available for reduction (oxygen acts as a depolarizer). When chloride ions are present, the situation is further aggravated [4,5,7,8].

The accumulated cations inside the crevice attract the negatively charged chloride anions from the surrounding aqueous solution. Hydroxide anions also migrate, but they are less mobile than chloride ions. Metal chlorides are formed inside the crevice, which are also less mobile. Furthermore, the metal chlorides hydrolyse to produce metal hydroxide and hydrochloric acid as shown in equation 1.

$$MCl + H_2O \rightarrow MOH + HCl \qquad (1)$$

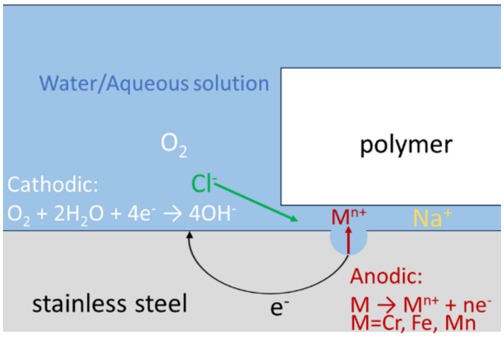

Figure 8 Schematic representation of crevice corrosion

The hydrochloric acid destroys the passive film (chloride attack) and accelerates the dissolution of the metal inside the crevice. Meanwhile, the cathodic reduction remains restricted to the areas outside the crevice that remain protected. **Figure 8** shows schematic crevice corrosion.

To assess the resistance to crevice corrosion, we use the PREN (pitting corrosion resistance equivalent number) value, which is calculated using the following equation 2.

$$PREN = Cr + 3.3Mo + 16N \qquad (2)$$

For the ferritic stainless steel 1.4016, this means a PREN in the range of 16 – 18, in our case 16.9. For the martensitic stainless steel 1.4021, the number is smaller in the range 12 – 14, in our case 12.2. The higher the PREN number, the more resistant the steel is to be pitting and crevice corrosion. However, even a high PREN number is no guarantee that this phenomenon. Standard austenitic stainless steels like AISI 304 and AISI 316 have PREN in the range 19-23, and 28-32 respectively.

The higher the PREN number, the more resistant the steel is to be pitting and crevice corrosion. However, even a high PREN number is no guarantee that this phenomenon

4. CONCLUSION

The corroded mixer heads were made from ferritic stainless steel 1.4016 and martensitic stainless steel 1.4021. The aforementioned steels had appropriate microstructures and chemical compositions.

The corrosion occurred only on the polymer-steel interphase.

Based on the performed analyses, we can confirm that crevice corrosion has occurred. The gap between the polymer and the stainless steel provided the conditions for crevice corrosion. The gap width of 10 μm is sufficient for corrosion to occur.

To assess the resistance to crevice corrosion, we use the PREN (pitting corrosion resistance equivalent number) value.

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