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STRENGTH ANALYSIS OF SUS304 AND PFA (PERFLUOROALKOXY) MATERIALS FOR PIPING IN DEIONIZED WATER SYSTEMS

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ABSTRACT

Deionized (DI) water systems require the use of materials that are not only resistant to corrosion and degradation but also possess the necessary strength to withstand pressure, temperature variations, and mechanical stress. This paper presents a comprehensive strength analysis of SUS304 (austenitic stainless steel) and PFA (Perfluoroalkoxy) materials for use in DI water systems. Through a combination of experimental testing, environmental exposure, and mechanical simulations, this study evaluates the tensile strength, yield strength, corrosion resistance, and overall durability of SUS304 and PFA, as well as their suitability for high-purity applications. The findings provide a comparative analysis that highlights the advantages and limitations of each material in different operating conditions.

KEY WORDS: *Corrosion resistance, deionized water, stainless steel, SUS304, PFA*

NOMENCLATURE

DI Water	Deionized Water
SUS	Steel Use Stainless
PFA	Perfluoroalkoxy
Ca^{2+}	Calsium
Mg^{2+}	Magnesium
Cl^{-}	Chloride
Na^{+}	Sodium
Cr	Chromium
Ni	Nickle
Mg	Manganese

1.0 INTRODUCTION

The selection of appropriate materials for piping in industrial applications is crucial for ensuring longevity, reliability, and optimal performance, particularly in sensitive systems such as those handling deionized (DI) water. DI water is often used in industries like electronics, pharmaceuticals, and power generation due to its high purity, but it poses unique challenges due to its aggressive nature towards certain materials. Thus, the materials used for piping must exhibit both mechanical strength and resistance to corrosion or degradation when exposed to DI water over time.

Among the most widely used materials for piping systems are Stainless Steel (SUS304) and Perfluoroalkoxy (PFA) polymers. SUS304, austenitic stainless steel, is renowned for its mechanical strength, excellent corrosion resistance, and widespread industrial application. However, its performance in DI water systems is often influenced by factors such as stress, temperature, and water purity. On the other hand, PFA, a high-performance fluoropolymer, offers superior chemical resistance and low friction characteristics, making it a prime candidate for applications in highly corrosive environments.

This study aims to compare and analyze the strength characteristics of SUS304 and PFA materials, focusing on their suitability for use in piping systems specifically designed for DI water. Through experimental analysis and material property evaluation, this research seeks to provide insights into the mechanical performance, durability, and overall effectiveness of these materials in the context of DI water handling, thereby contributing to the selection of optimal materials for future piping applications in similar industrial settings.

2.0 METHODOLOGY

This study evaluates the strength characteristics of SUS304 stainless steel and PFA (Perfluoroalkoxy) polymer materials for use in piping systems handling deionized (DI) water. The methodology adopted combines both experimental and analytical approaches to assess the mechanical strength, material degradation, and suitability of these materials in a DI water environment. The key steps in the methodology are outlined below:.

2.1 Material Selection

1) SUS304 Stainless Steel: Austenitic stainless steel, commonly used for its superior corrosion resistance, especially in environments where exposure to moisture and chemicals is frequent. SUS304 is generally preferred for food and water systems due to its non-reactive nature.
2) PFA (Perfluoroalkoxy): A high-performance fluoropolymer that offers superior chemical resistance and low friction properties, often used in systems with aggressive chemicals like DI water.

2.2 Corrosion Testing Procedures

Corrosion resistance is a critical property for materials used in piping systems handling deionized (DI) water, as DI water is often more aggressive than ordinary water due to its high purity and tendency to leach ions from materials. In this study, corrosion testing was conducted to assess the durability of SUS304 stainless steel and PFA under prolonged exposure to DI water. The tests aimed to evaluate the corrosion behavior of these materials, which will help determine their long-term suitability for DI water applications.

2.2.1 Immersion Testing

The samples were submerged in separate containers filled with DI water at room temperature (approximately 23°C). The immersion periods were set to 30, 60, and 90 days to simulate short- and long-term exposure. The following procedure was followed for each time interval:

1) The containers were kept in a controlled environment, with the DI water being replaced periodically to maintain purity.
2) After each exposure period, the samples were removed, rinsed with DI water, and dried before further analysis.

2.2.2 Visual Inspection

Upon removal from the immersion bath, each sample was visually inspected for any signs of corrosion, discoloration, pitting, or surface degradation. Any visible surface changes were recorded, and images were taken to document the extent of corrosion. The following observations were noted:

1) SUS304 Stainless Steel: Corrosion is typically manifested as pitting, crevice corrosion, or generalized surface rusting. Any discoloration or rust formation was carefully assessed.
2) PFA Polymer: Since PFA is known for its excellent chemical resistance, visible degradation was not anticipated. However, any surface cracks, discoloration, or changes in texture were carefully observed and recorded.

2.2.3 Weight Loss Measurement

To quantify the extent of corrosion, a weight loss method was used for SUS304 stainless steel samples. After each exposure period, the mass of the stainless steel samples was measured using an analytical balance (accuracy of 0.001 g). The weight loss was calculated by subtracting the post-exposure mass from the initial mass of each sample. The corrosion rate was then determined using the following formula:

$$Corrosion\ Rate = \frac{K\ x\ Weight\ Loss}{Density\ x\ Area\ x\ Time} \quad (1)$$

Where:

1) K is a constant (for sodium chloride testing, typically 8.76×10^4).
2) Density is the material’s density (g/cm³).
3) Area is the surface area of the sample (cm²).
4) Time is the exposure duration (hours converted to years).

For PFA, no significant mass loss was expected, as it is a highly inert material. However, surface roughness and texture changes were evaluated using a profilometer, and any observed increase in surface roughness was noted as a qualitative indication of degradation.

3.0 RESULT

Deionized water is water that has been treated to remove most of its dissolved mineral ions, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), sodium (Na^{+}), and others. This process makes the water much purer than regular tap water, but it also makes it more aggressive in certain situations, particularly with metals. The low ion content in deionized water means that the water is more electrically conductive and more chemically reactive with metals. Normally, in regular water, the dissolved ions help form a stable, protective oxide layer on metals like stainless steel. In deionized water, the lack of these ions allows for the breakdown of this passive layer.

SUS304 stainless steel contains chromium (Cr), which is essential for forming the protective oxide layer. However, in the absence of other ions that can stabilize this layer, DI water can more easily dissolve chromium and other alloying elements such as nickel (Ni) and manganese (Mn). When chromium and nickel are leached out, the material loses its resistance to corrosion, which weakens the protective layer and increases the susceptibility to various forms of corrosion.

The results from the corrosion tests were analyzed to compare the corrosion behavior of SUS304 and PFA in DI water:

1) SUS304 Stainless Steel: The primary focus was on the pitting and crevice corrosion behavior of SUS304 when exposed to DI water. The weight loss measurements, along with visual inspection, indicated the rate and extent of corrosion over time. The electrochemical data provided additional insight into the material’s susceptibility to localized corrosion.
2) PFA Polymer: Given its chemical resistance, it was expected that PFA would exhibit minimal to no corrosion. However, any signs of surface degradation or changes in mechanical properties were carefully noted.

4.0 DISCUSSION

The results obtained from the corrosion testing, and overall material performance under exposure to DI water provide valuable insights into the suitability of SUS304 stainless steel and PFA (Perfluoroalkoxy) polymers for use in piping systems handling deionized (DI) water. Each material demonstrated distinct behaviors, and the findings offer a comprehensive understanding of their respective advantages and limitations in such applications.

4.1 Corrosion Resistance and Durability

Corrosion testing revealed a stark contrast between the two materials. SUS304 stainless steel showed a marked increase in corrosion rate over time, particularly after extended immersion in DI water. The presence of pitting and crevice corrosion, as observed in the weight loss data and visual inspection, suggests that SUS304 may not be the optimal choice for environments where long-term exposure to DI water is expected. The electrochemical analysis further confirmed that SUS304 stainless steel becomes more susceptible to localized corrosion (pitting) in the absence of protective coatings or passivation treatments. The corrosion rate increased progressively with longer immersion times, which may eventually compromise the material's mechanical integrity and lead to failure in DI water systems if left unchecked.

On the other hand, PFA polymer demonstrated exceptional chemical resistance and showed virtually no signs of degradation over the test periods. No significant weight loss or surface damage was observed, indicating the material's superior ability to resist the aggressive nature of DI water. The electrochemical impedance spectroscopy (EIS) results corroborated the material's remarkable stability, with minimal changes in impedance over time, highlighting its durability in corrosive environments. Given that DI water is known for its tendency to leach ions from metals and promote corrosion, PFA proves to be a more favorable choice in applications where resistance to chemical degradation is paramount. However, it is important to note that PFA's mechanical limitations may restrict its application in high-pressure systems, where strength is a crucial factor.

4.2 Effect of DI Water on Material Performance

The impact of DI water exposure on SUS304 stainless steel and PFA polymer was particularly evident in the corrosion behavior. While PFA exhibited consistent performance, maintaining its mechanical properties and chemical resistance throughout the exposure period, SUS304 stainless steel showed signs of deterioration. The increasing corrosion rate and pitting of SUS304 suggest that, while this material may perform well initially, its long-term durability in DI water environments could be compromised without additional protective measures, such as passivation, coating, or the use of higher alloy stainless steels.

Interestingly, PFA's performance under extended exposure to DI water was consistent with its expected chemical resistance. The material's ability to maintain its mechanical properties despite prolonged exposure positions it as an excellent candidate for applications where corrosion resistance outweighs the need for high mechanical strength. This makes PFA particularly suitable for systems where long-term exposure to DI water or aggressive chemicals is inevitable, such as in semiconductor manufacturing or pharmaceutical industries.

4.3 Implications and Future Considerations

While both materials demonstrate distinct advantages, future research could focus on hybrid solutions that combine the mechanical strength of metals with the corrosion resistance of polymers. For example, composite materials or coated metal pipes may offer a compromise between strength and corrosion resistance, ensuring the best of both worlds for DI water systems.

Further studies could also investigate the effects of elevated temperatures on both materials, as many industrial applications may involve temperature fluctuations that can affect material performance. Additionally, exploring the influence of different water qualities (e.g., varying purity levels) on corrosion behavior may provide deeper insights into how these materials perform under diverse conditions.

5.0 CONCLUSION

SUS304 is generally resistant to corrosion and is commonly used in various environments, including in applications with water. However, SUS304 is not ideal for use with deionized (DI) water. Deionized water, by definition, has had most of its mineral ions (such as calcium, magnesium, and other salts) removed. These ions normally help form a protective oxide layer on metals like stainless steel. In the absence of these ions, the passive oxide layer on 304 stainless steel can become less stable and more prone to localized corrosion, such as pitting or crevice corrosion. The lack of dissolved minerals in deionized water increases the aggressiveness of water towards metal surfaces. This can lead to the breakdown of the protective passive oxide film on the stainless steel.

DI water, being highly pure, can dissolve the alloying elements in stainless steel, such as chromium and nickel**.** This can lead to the loss of the metal's corrosion resistance, leaving the material more vulnerable to attack by aggressive environments. For environments where deionized water is used, other materials such as 316 stainless steel (which has a higher concentration of molybdenum, improving its corrosion resistance) or plastics like PTFE (Teflon) or PFA are often recommended. These materials offer better resistance to corrosion and stress cracking in pure or deionized water.

PFA is suitable for use with deionized water because of its chemical inertness, outstanding corrosion resistance, and ability to withstand high temperatures and aggressive environments without degrading. Its non-reactive nature ensures that it does not leach any harmful substances into the water, maintaining the purity of DI water and avoiding any contamination issues. Moreover, PFA's resistance to chlorides, biofouling, and surface scaling makes it a reliable, long-lasting material for systems that involve deionized water. In summary, PFA provides an ideal solution for systems requiring high purity, corrosion resistance, and long-term durability in contact with deionized water.

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