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EXPLORING THE IMPACT OF SALINE ENVIRONMENTS ON THE PROPERTIES OF EOS PA2200: A STUDY ON WEIGHT GAIN AND MECHANICAL CHARACTERISTICS

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Abstract

This study investigates the influence of saline environments, including conditions arising in the vicinity of roads with winter maintenance by de-icing salts, and exposure in other specific environments affected by chloride ion deposition, on the material properties of EOS PA2200 (PA12). The research focuses on assessing weight gain and mechanical properties using tensile testing. The experimental findings provide insights into the potential effects of saline environments on the performance and durability of PA2200, contributing to a better understanding of its suitability for marine applications. The results reveal significant variations in weight gain and mechanical properties under different exposure durations and concentrations of saline solution. Additionally, microscopic analysis offers valuable insights into the morphological changes occurring within the material structure due to saline water exposure. The implications of these findings are discussed in the context of material selection and design considerations for marine engineering applications. This research contributes to the broader understanding of material behavior in corrosive environments, offering valuable guidance for the development of more resilient and durable materials for marine applications.

Keywords:

Saline environment, EOS PA2200, Mechanical properties, Marine applications

1 INTRODUCTION

Polyamide-based materials (PAs), particularly PA12, are extensively used across various industrial sectors due to their excellent mechanical strength, wear resistance, and chemical stability [Salmoria 2012]. One of the most innovative approaches to manufacturing PA12 components is through additive manufacturing, specifically Selective Laser Sintering (SLS) technology [Kozior 2020]. The material can be recycled, making it a viable manufacturing option [Seidl 2023]. This production technology is increasingly utilized in applications requiring complex shapes and high levels of detail [Nguyen 2023, Marsalek 2020], effectively overcoming a certain number of constraints of the traditional manufacturing method [Gogolewski 2023].

However, a critical challenge in employing these materials is their resistance to environmental factors, which can significantly impact their mechanical properties and overall performance [Vacek 2022, Trindade 2022, Bochnia 2020]. Specifically, a year of exposure to the ambient climate, atmospheric pollution, and sea/salt spray can already downgrade the components [Bender 2022]. Saline environments are common not only in coastal regions but also in areas where de-icing salts are used for winter road maintenance. In such environments, moisture and chloride ion absorption can occur, potentially leading to material degradation [Krivy 2019].

Amstutz et al. investigated the mechanical properties of molded PA12 under the influence of ambient climate temperature for 4 months and water [Amstutz 2021]. It was found out that the increase in temperature and absorption time softens the material, leading to the reduction of Young's modulus and yield strength. The material however strengthens during the necking process. Because there is no apparent yield point after necking, the material exhibits higher loading capacity with stable neck growth. Paolucci et al. compared the performance of molded and sintered PA12 and reported that the significant difference in mechanical response can only be found at high strain rate testing condition [Paolucci 2019].

This study focuses on investigating the impact of saline environments on the properties of EOS PA2200 (a commercially available polyamide powder based on PA12) with a particular emphasis on weight gain and mechanical characteristics. The experimental section involves exposing PA2200 samples to a constant environment containing chloride ions for varying durations (up to 10 days), followed by tensile testing and microscopic analyses. As a highlight, we investigate the samples printed in different orientation. The findings provide crucial insights into how saline environments affect the structure and properties of this material, which is essential for its use in demanding applications, particularly in marine engineering.

The implications of these findings are discussed in the context of material selection and design considerations for environments affected by increased moisture and chloride ion deposition. This research contributes to a broader understanding of material behavior in corrosive environments, offering valuable guidance for developing more resilient and durable materials for marine applications and for applications in specific microclimatic conditions that arise in the vicinity of roads with intensive road traffic [Kubzova 2020].

2 MATERIALS AND METHODS

The geometry of the tensile specimen was prepared according to ČSN EN ISO 527-2 standard and is illustrated in **Figure 1**.

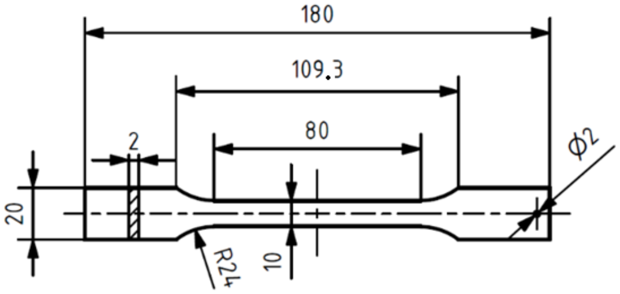

Fig. 1: Geometry of the tensile specimen.

For comparison, the specimens were printed in three different directions being 0°, 45°, and 90° degree as can be seen in **Figure 2**.

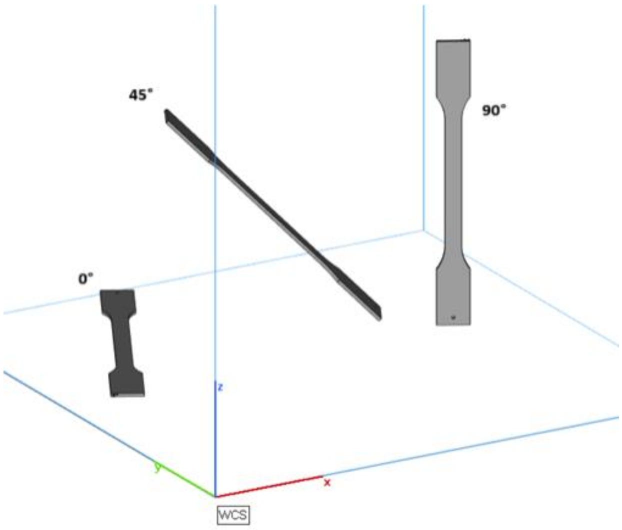

Fig. 2: Orientation of the tensile specimen.

The specimens were exposed in a saline environment for two different durations (one day and 10 days) in the salt spray chamber (Ascott S2000iS, **Figure 3**) and were compared with the as-built condition. Setup of the salt spray chamber is specified in the **Table 1.** For statistics purposes, five specimens were printed for each treatment setup (as-built, one day, 10 days) and angle (0°, 45°, 90°). Therefore, there are in total 45 specimens in the study. The arrangement of the specimens in the salt spray chamber is shown in **Figure 4**.

The SLS printer EOS P396 (EOS GmbH, Germany) was utilized for specimen fabrication. The associated printing parameters are listed below in **Table 2**.

Tab. 1: Setup of the salt spray chamber.

Salt spray chamber	Ascott S2000iS
Temperature inside the salt spray chamber [°C]	35
Temperature of the air humidifier [°C]	48
Salt concentration	5% NaCl solution
Standard	ISO 9227

Tab. 2: Printing parameters.

Laser power max [W]	70
Volume [mm^3]	340 × 340 × 620
Scan speed max [m.s^{-1}]	6
Beam offset [mm]	0.33
Layer height [mm]	120
Process temp. [°C]	171
Removal temp. [°C]	130
Material dependent scaling [%]	X 3.15 Y 3.23 Z_{min} 1.40 (0 mm) Z_{max} 2.55 (0 mm)

Fig. 3: Salt spray chamber Ascott S2000iS.

Fig. 4: Specimens in the salt spray chamber.

For tensile test, the used machine was EZ-LX tester (Shimadzu, USA) with load capacity of 5 kN. After the specimens were broken, we proceeded with inspection of the fracture profile and microstructure with Scanning Electron Microscopy/Energy Dispersive Spectroscopy (SEM/EDS) Explorer 4 Analyzer (ThermoFisher Scientific, USA). The SEM analysis was carried out using a backscattered electron detector, with an accelerating voltage of 15 keV and a beam current set to low values (spot = 40%). A narrow electron beam and voltage was chosen to avoid damaging the sample, as the specimens are plastic.

3 RESULTS AND DISCUSSION

3.1 Specimen fracture

The nylon PA12 is hygroscopic and is relatively resistant to hydrolysis. Therefore, the expose of tensile specimens in the salt spray chamber has introduced a distinct difference to the geometry of the tensile samples due to water absorption. The closed-up view on the fracture on 10-day specimens is reported in **Figure 5**.

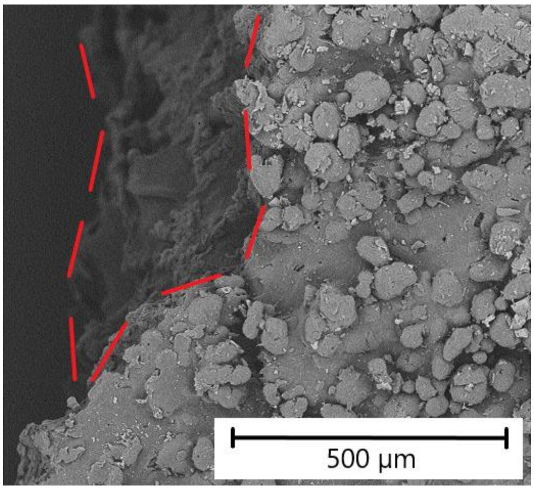

Fig. 5: Closed-up view on the fracture of a specimen after 10 days in salt water.

From **Figure 5**, there are two distinct regions, that is, the fracture (highlighted with discontinuous line) and the surface of the specimen (characterized with particles). The two regions illustrate typical characteristics of the SLS-ed components. The surface of the specimen is scattered with several powder particles (grey and large size) and there as well exist some salt particles (white and smaller size). From the fracture profile, we can obtain the clear brittle fracture with pores. The pores are left when the sintered PA12 powder particles are removed, whose details are shown in **Figure 6**.

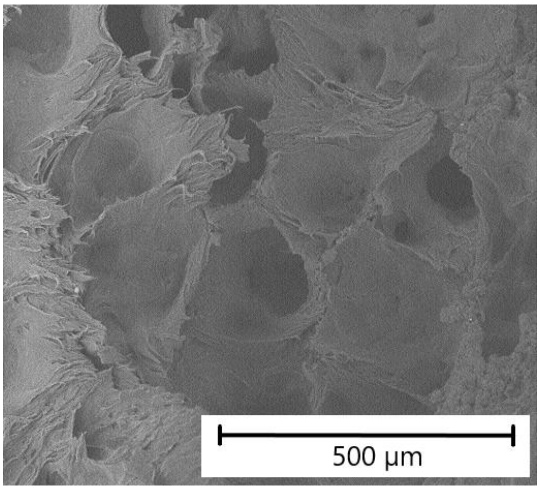

Fig. 6: Direct view in the fracture of the specimen after 10 days in salt water.

From **Figure 6**, the circular pores can be clearly observed, indicating the complete separation of the powder particles. It should be noted that there is a significant elongation of the surrounding material on the circumference of the pores, explaining the remarkable increase in strain of the specimens exposed in the salt spray chamber in comparison with the as-built condition. This aligns with the finding in [Amstutz 2021] that even though the material is softened, it exhibits higher loading capacity with stable neck growth and significant improvement in the ductility. The effect of this phenomenon on the stress-strain behavior is further discussed in the next subsection.

3.2 Stress-strain and weight results

The results from specimen evaluation are numerically reported in **Table 3**, **Table 4**, and **Table 5**. The reported results are the cross-sectional area (A), the Young's modulus (E), the ultimate strength (σ_u), the maximum elongation (ΔL_{max}), and the water absorption weight gain of the specimens. The three conditions (as-built, in salt spray chamber for one day, and in salt spray chamber for 10 days) are separated for easier reading. In addition, the stress-strain curves are illustrated in **Figure 7**.

In general, it can be observed that specimens printed in 0 degree orientation has higher cross-sectional area in comparison with the other two printing directions. Remarkably, all of them are higher than the measures from the drawing (20 mm^2). This is due to the combined effect of scaling in **Table 1**, the expansion and distortion of specimens that have larger cross-sectional area, and the printing direction.

Examining the three tables separately, we can see that all the specimens have relatively the same Young's modulus and ultimate strength. However, the maximum elongation is highest for specimens printed in the 0-degree orientation. This can be explained by the way the layers are stacked. Specifically, for the 45-degree and 90-degree specimens, the gauge length section of the specimens is printed with much smaller cross-sections oriented in a direction that is (almost) perpendicular to the tensile loading direction, causing them to perform relatively poorly because the layers can be easily separated under tension. This is evident from the decreasing tendency of the maximum elongation. In addition, the weight of the specimens increases with the length of exposure to saline water. After 10 days of exposure, the weight of the samples increased by approximately 3 % due to water absorption.

When analyzing the three tables together, it can be observed that Young's modulus tends to decrease the longer the specimens are exposed in the salt spray chamber. This is closely related to the increase of maximum elongation that the specimens can withstand. The elongation can be up to 35% (as-built condition versus 10 days in the salt spray chamber). The result is that the tensile curve is with lower initial slope (elastic region), and longer maximum strain as can be clearly observed in **Figure 7**. The absorption of water indeed plasticized the nylon, making the specimens softer and more flexible.

A significant decrease in ultimate strength was also observed with increasing wetting time of the specimens. A decrease in ultimate strength of approximately 18% was observed for samples exposed for 10 days in the salt spray chamber.

4 CONCLUSIONS

Experimental measurements show that an environment with increased moisture and chlorides affects PA12 products, due to their internal structure. Significant changes in physical and mechanical properties were observed for specimens exposed in the salt spray chamber compared to as-built specimens. While the ductility of the samples increased with longer exposure time, a significant decrease was observed in the modulus of elasticity and ultimate strength compared to as-built samples. We can observe the effects of printing orientation as well on the mechanical response of the material.

These findings may have significant implications for the mechanical resistance and stability of structural elements made of PA12 that are exposed to direct environmental influences. Based on the results of the study, it can be concluded that the application of PA12 material requires increased attention to the external environmental effects. In addition to the effects of moisture and chloride ions, future research work will also focus on the effects of cyclic changes of temperature and moisture. The applicability of the material will also be verified by long-term exposure of samples placed in an external environment.

The future works will be also focused on the boosting effect of salt for water absorption, the roughening effect (change of surface roughness), the chemical degradation due to direct/indirect contact with metal components that is degraded and release ions in salt water. Additionally, we consider conducting in-situ exposure near selected roads and in direct sunlight or under shelter. Time of exposure will be discussed according to future research/results of cyclic test in salt spray chamber with cycles of freezing (i.e. without the influence of sun/UV radiation). Fatigue, impact, and creep tests are as well among the material characterization tests that can be realized.

5 ACKNOWLEDGMENTS

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Tab. 3: Properties of as-built specimens.

Angle [°]	A [mm²]	E [MPa]	σ_u [MPa]	ΔL_{max} [%]	Water absorbtion weight gain [%]
0	23 ± 0	1065 ± 26	44 ± 1	26 ± 5	-
45	21 ± 0	1056 ± 31	42 ± 1	15 ± 2	-
90	21 ± 0	1048 ± 44	41 ± 3	16 ± 2	-

Tab. 4: Properties of specimens in salt spray chamber for one day.

Angle [°]	A [mm²]	E [MPa]	σ_u [MPa]	ΔL_{max} [%]	Water absorbtion weight gain [%]
0	23 ± 1	870 ± 42	40 ± 0	25 ± 2	0.5 ± 0,1
45	21 ± 1	909 ± 61	38 ± 2	16 ± 4	1.2 ± 0.4
90	20 ± 1	851 ± 60	38 ± 3	14 ± 4	0.8 ± 0.2

Tab. 5: Properties of specimens in salt spray chamber for 10 days.

Angle [°]	A [mm²]	E [MPa]	σ_u [MPa]	ΔL_{max} [%]	Water absorption weight gain [%]
0	23 ± 1	733 ± 79	36 ± 2	37 ± 4	3.2 ± 0.4
45	21 ± 0	713 ± 36	36 ± 1	22 ± 1	2.8 ± 0.7
90	21 ± 0	742 ± 69	34 ± 3	14 ± 6	3.6 ± 0.5

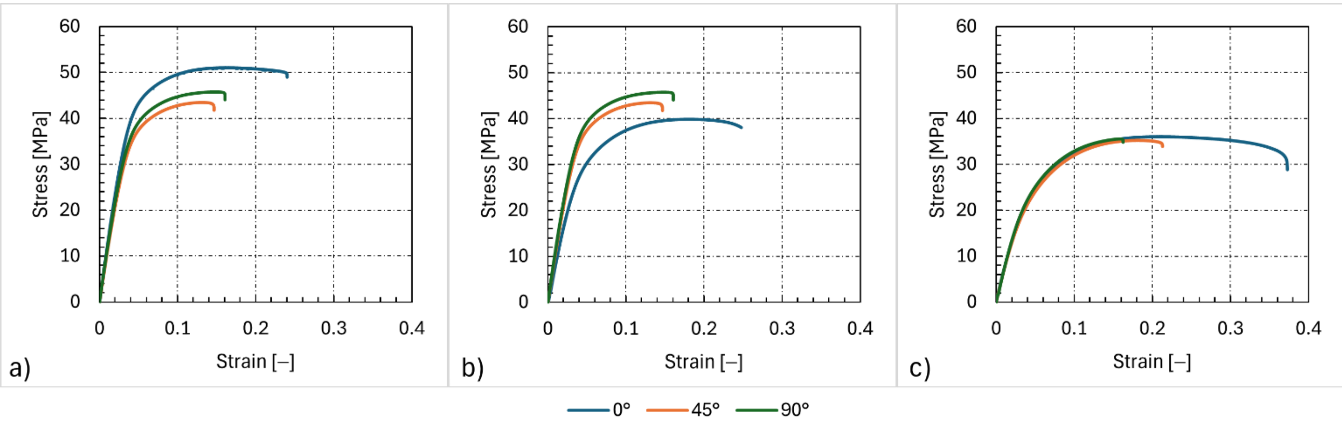

Fig. 7: Summary of the stress-strain curve results a) as-built, b) one day, and c) 10 days. They are representative curves selected to illustrate the changes by the saline-water treatment.