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EVALUATING THE FLEXURAL PROPERTIES OF POLYOXYMETHYLENE UNDER AGGRESSIVE ENVIRONMENTAL CONDITIONS

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Abstract: *This study evaluates the four-point flexural behavior of polyoxymethylene (POM) specimens exposed to different environmental conditions. Ten specimens were tested, for each of which five different mediums were studied: ambient environment, distilled water, cooling oil, UV-C radiation, and saline solution. The main objective was to find the influence of these environments on maximum bending stress and compare the values obtained for all four aggressive mediums to the value for the ambient environment. The results showed that exposure to the three liquid media-distilled water, cooling oil, and salt solution-leads to a reduction in bending stress, underscoring the potential weakening effects of these media. In contrast, samples exposed to UV-C showed an increase in bending stress, suggesting an increase in material stiffness under these conditions. This study provides guidelines for the optimal use of POM in various applications and provides clear information on its mechanical performance in various industrial and environmental environments.*

Key words: Polyoxymethylene, four-point bending test, flexural properties, environmental conditions

1. INTRODUCTION

Four-point bending is a standard test of the bending behavior of materials, which provides insight into the deformation, stiffness, and ductility of materials, as well as the deformation of materials under a load. In contrast to three-point bending, in the four-point bending test, a load is exerted by two points, and there is a uniform time domain between them. This arrangement reduces deformation and allows further analysis of how the material behaves in bending and is particularly valuable for testing materials in bending in real applications. [1, 2].

High-performance engineering thermoplastic, polyoxymethylene (POM), is known for its top-notch mechanical characteristics such as high stiffness, dimensional stability and fatigue and wear resistance [3,4]. Because of these characteristics, it has become increasingly popular for use in fields like automotive, electronic, and consumer products [5]. Nonetheless, its performance can differ under various environmental and mechanical stress conditions, so there is a need to improve and clarify its behavior when exposed to flexural load [6, 7, 8]. In this study, polyoxymethylene was subjected to four-point bending tests to assess its flexural performance under both standard and aggressive environmental conditions [9].

This included environmental testing and post-deterioration testing under various adverse conditions, such as immersion in distilled water, cold oil and saline solutions, and UV-C radiation. The purpose of this study is to obtain useful information to predict performance in application programs and environments using instrumental analysis for these situations.

2. MATERIALS AND METHODS

The four-point flexural tests to polyoxymethylene (POM) in various environmental conditions (ambient environment, distilled water, cooling oil, UV-C radiation and saline solution) were performed according to ASTM D7264M-21 standard [10]. Using these standard outlines a demanding procedure for the characterization of the flexural properties of polymeric materials. The shapes and dimensions of

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specimens were observed in Figure 1.

ISO 62:2008 standard [11] that describes the flow for water absorption determination in plastic materials describes a standardized procedure for the scoring of water uptake in test specimens. The standard indicates that specimens are dried for 24 hours before being immersed in liquid and after that the specimens are placed in distilled water and stored for 24 hours. [3].

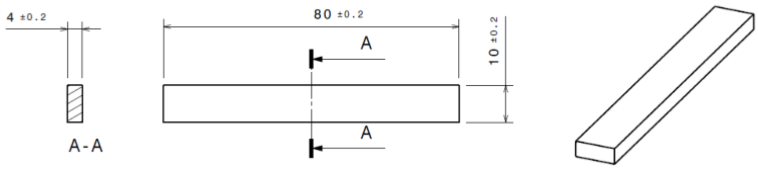

Figure 1: Specimen sizes (in mm).

The methodology begins with oven-drying the test specimens at 50 °C for 24 hours (Step 1), followed by weighing them with a precision balance (Step 2). In Step 3, the specimens are submerged in a glass container to avoid interference with the test quality and left in the designated medium for 24 hours. The media used in this study included distilled water, supplied by the Simplu Quality Products brand for the immersion of the test specimens, which is used in various industrial applications such as diluting antifreeze and windshield washer fluids, topping up the electrolyte level in electric batteries, as a spray liquid for electric irons, cooling internal combustion engines, cooling oil, supplied by the brand Azur-Cut 602.01 M-15. It is a combination of mineral oil and additives specifically designed to operate at high pressures and to cope with the intense machining regimes encountered in mechanical machining with material removal. The oil has a viscosity of 15 mm^2/s at 40 °C and is a synthetic coolant oil for industrial applications. The next medium is UV-C radiation, with wavelengths between 100 and 280 nanometers, and is known for its ability to degrade polymeric materials by photochemical processes and the last medium is 25% saline solution with pH = 2.162 and the immersion water temperature is 0.5^{o}C. This approach ensures consistent and accurate evaluation of the material's absorption properties under varying environmental conditions [3]. In step 4, after drying, the specimens were re-weighed to calculate the quantity of liquid absorbed. To calculate liquid uptake, the formula was used:

$$c = \frac{m_2 - m_1}{m_1} \, x \, 100\% \quad (1)$$

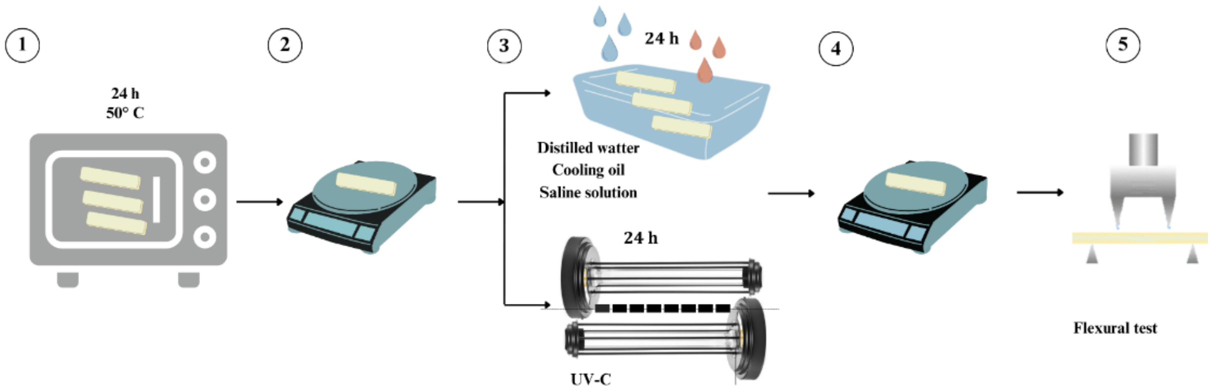

Figure 2: The steps for flexural testing of POM specimens.

In the final stage, the specimens were tested for four-point bending on the Galdabini Quasar 25 universal testing apparatus shown in Figure 3. The testing speed for all bending tests was equal to 5 mm/min and the maximum displacement on force direction (vertical direction) was set to 10 mm. To ensure the best possible reproducibility of the results, ten specimens per medium were tested.

Figure 3: The bending device mounted on Galdabini Quasar 25 testing machine.

3. RESULTS

Based on the experimental results, for each of the ten sets of tests, a characteristic curve of engineering stress vs. engineering strain was plotted for specific environments, as shown in Figure 4, to better see the differences between them.

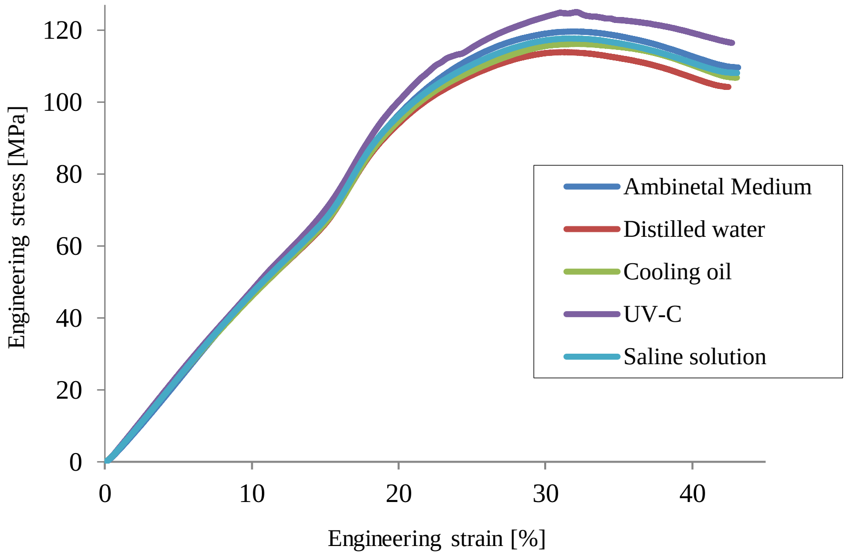

Figure 4: Mean specific stress-strain curves for the bending test of POM material in five different mediums.

Comparing the results of these tests, the mechanical and elastic properties of the material did not undergo any major changes in the samples kept in liquid mediums, whereas, in specimens subjected to ultraviolet radiation (UV-C), there is an unexpected increase in bending stress.

Table 1: The mechanical and elastic characteristics of POM specimens tested at four-points bending after storage in the five mediums.

Specimen no.	σ_{max} [MPa]	E [GPa]	σ_{max} [MPa]	E [GPa]	σ_{max} [MPa]	E [GPa]	σ_{max} [MPa]	E [GPa]	σ_{max} [MPa]	E [GPa]
	Ambiental		***Distilled water***		***Cooling oil***		***UV-C***		***Saline solution***	
#1	121.35	0.45	113.32	0.49	115.50	0.49	125.55	0.48	116.44	0.48
#2	121.09	0.46	113.32	0.48	114.45	0.48	120.11	0.50	116.25	0.47
#3	121.05	0.45	113.96	0.48	115.09	0.48	123.79	0.50	116.59	0.48
#4	120.60	0.46	114.04	0.49	115.84	0.48	125.74	0.50	117.34	0.49
#5	116.32	0.48	113.62	0.47	115.95	0.48	128.21	0.49	117.71	0.49
#6	121.05	0.46	114.41	0.48	116.44	0.47	128.36	0.50	114.86	0.49
#7	119.17	0.48	114.15	0.48	117.00	0.48	127.46	0.50	119.21	0.47
#8	116.44	0.48	113.36	0.48	117.00	0.48	129.11	0.50	119.62	0.48
#9	119.89	0.49	114.00	0.48	117.49	0.48	130.27	0.50	119.32	0.48
#10	119.55	0.47	114.60	0.48	117.19	0.48	124.72	0.51	119.47	0.47

Mean	***119.65***	***0.47***	***113.87***	***0.48***	***116.19***	***0.48***	***126.32***	***0.50***	***117.68***	***0.48***
Median	***120.24***	***0.47***	***113.98***	***0.48***	***116.19***	***0.48***	***126.6***	***0.50***	***117.52***	***0.48***
Standard	***1.87***	***0.01***	***0.45***	***0.01***	***0.99***	***0.01***	***2.99***	***0.01***	***1.66***	***0.01***
Minimum	***116.32***	***0.45***	***113.32***	***0.47***	***114.45***	***0.47***	***120.11***	***0.48***	***114.86***	***0.47***
Maximum	***121.35***	***0.49***	***114.6***	***0.49***	***117.49***	***0.49***	***130.27***	***0.51***	***119.62***	***0.49***
KS Value	***0.20***	***0.22***	***0.17***	***0.37***	***0.19***	***0.40***	***0.15***	***0.40***	***0.22***	***0.20***
p Value	***0.15***	***0.15***	***0.15***	***0.15***	***0.15***	***0.15***	***0.15***	***0.15***	***0.15***	***0.15***
Grubbs	***1.78***	***1.57***	***1.58***	***1.94***	***1.75***	***2.12***	***2.08***	***2.28***	***1.70***	***1.22***
p Value	***0.53***	***1.00***	***0.96***	***0.30***	***0.58***	***0.13***	***0.17***	***0.05***	***0.68***	***1.00***

After performing these flexural tests, the data thus obtained were statistically analyzed using Minitab 18, from two perspectives: elimination of outliers (Kolmogorov-Smirnov) and verification of the normal distribution of the data (Normality test), two tests were applied in this respect: the Kolmogorov-Smirnov test to verify the normal distribution of the data, data that are close together and tend towards a concentrated distribution and the Grubbs test to eliminate outliers.

Based on the above, Table 1, includes the measured values and the results of the statistical analysis for the two tests (Kolmogorov-Smirnov and Grubbs) applied on the ten specimens made of POM. Thus, Table 1 shows, in addition to the maximum, minimum, median, mean, standard deviation, KS and G indicators, as well as p-values for the two statistical tests. I mention that these statistical tests were performed for all test means of the test specimens made of POM, all this confirming that for the obtained results there is a normal distribution. This is also evident by the fact that in all cases, p values are greater than 0.05.

It can be seen from this graph that, based on the results obtained when the specimens were tested in ambient environment without any external factor, for all the other four cases where the specimens were previously tested with an external factor (distilled water, cooling oil, UV-C radiation and saline) the maximum normal stress decreases, and for UV-C radiation an increase is evident. Thus, in the case of specimens immersed in distilled water there is a decrease in this maximum normal stress of 5.08%, in the case of specimens immersed in saline solution the decrease is 1.67%, in the case of specimens immersed in cooling oil the decrease is somewhat more pronounced, being 2.98%, and in the case of specimens subjected to UV-C radiation, the increase is 5.28%, as shown in Figure 5.

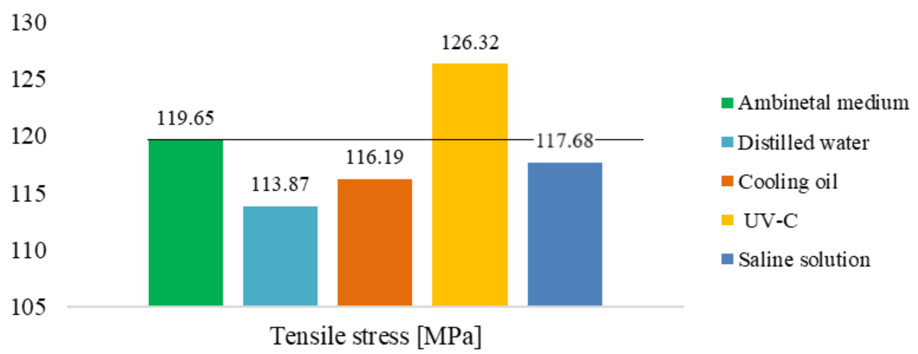

Figure 5: Mean values of the maximum bending stress for POM specimens obtained for the five studied environments.

It can be seen from Figure 6 that, based on the results obtained when the specimens were tested in an ambient environment without any external factor, for all the other four cases where the specimens were previously tested with an external factor (distilled water, cooling oil, UV-C radiation, and saline), the modulus of the elasticity increases, and for UV-C radiation, the highest percentage increase is evident. Thus, for specimens immersed in distilled water, cooling oil, and saline solution, an increase in elastic modulus of 2.08% is observed, while for specimens subjected to UV-C radiation, the increase is 6%.

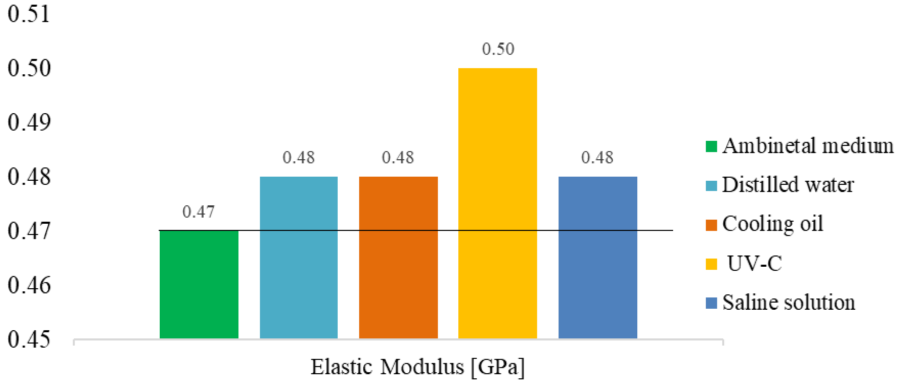

Figure 6: The mean values of the maximum bending elastic modulus for the POM specimens obtained for the five studied environments.

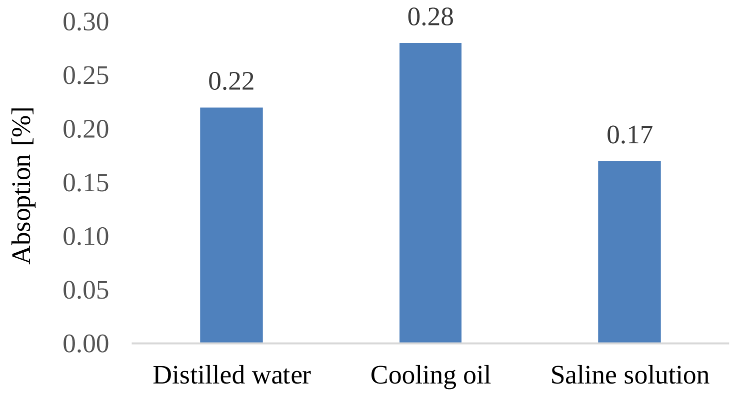

Figure 7: Mean absorption level in POM specimens for the three liquid media studied.

It can therefore be concluded that all four mediums (distilled water, cooling oil, UV-C radiation and saline solution) have a negative influence on the tensile strength of POM specimens, with UV-C radiation having the greatest influence and distilled water the least. Cooling oil has the highest absorption fence in the material among all the three liquid media studied, as can be seen in the graph in Figure 7.

4. CONCLUSIONS

Specimens exposed to liquid media, including distilled water, cooling oil and saline, exhibited reductions in maximum bending stress and increases in modulus of elasticity. In comparison with the results obtained for specimens tested in ambient environment, the decreases in maximum bending stress were 5.08% for distilled water, 2.98% for cooling oil and 1.67% for saline. Exposure to UV-C radiation uniquely caused a 5.28% increase in the maximum bending stress, indicating a potential stiffening effect of prolonged UV exposure.

Although the maximum bending stress of POM is reduced by the liquid medium, POM also kept its high elastic properties, reflecting its robustness in less harsh environment. Concerning elastic modulus, a marginal augmentation of the modulus of elasticity is found in case of liquid media, and the highest one in case of UV-C,´6% of that of the ambient medium. The UV-C induced maximum bending stress enhancement indicates that UV-C irradiation can increase surface mechanical stiffness, but the potential risks of long-term degradation may be involved. Of the liquid media studied, cooling oil showed the highest absorption into the material, which may correlate with a more pronounced mechanical weakening.

Observed alterations (e.g., decrease of stress/absorption levels) emphasize the necessity for environmental aspects in applications of POM. These results contribute useful information toward understanding the environmental robustness of POM, which can be used to help select POM for industrial uses, where mechanical properties and exposure to hostile environments are key considerations.

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