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Analysis on the Impact of Industrial Agents on 3D-printed Polymeric Materials in Soft Robotics

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Abstract: *The study investigates the effects of aggressive factors environments commonly found in industrial environments on the elastomeric material TPU 95 A, which is integrated into a multitude of soft robotics applications. Specimens made of TPU 95 A were subjected to aggressive liquid media - cooling oil, distilled water, and ultraviolet radiation (UV-C) to evaluate changes in their mechanical and elastic properties following uniaxial tensile tests. The research, carried out using additive manufacturing technology, highlights the importance of monitoring how the external factors impact elastic and mechanical characteristics of TPU 95 A material. The results obtained after the experimental tests proves to us that the aggressive media analyzed had a greater or lesser influence on the material. By uniaxial tensile tests, it was found that the liquid absorption had a very important impact on the tensile strength of the material. For example, at 1.02% absorption in distilled water, the maximum value of the ultimate strain decreased by 0.257 mm/mm, and at 3.06% absorption in cooling oil, the maximum value of the strain decreased by 0.672 mm/mm.*

Keywords*: soft robotics, industry, tensile tests, polymers, additive manufacturing*

1.Introduction

The field of soft robotics is a relatively new research area but has rapidly attracted the attention of researchers worldwide in recent years, a fact reflected in the impressive amount of scientific output [1]. The specific feature of this field is mainly based on the use of elastomeric materials with elastic modulus in the range of 10^4-10^9 Pa, characteristics comparable to those of biological organisms [2]. In the field of soft robotics, two technologies are predominantly used to make various robotic structures from soft elastomeric materials, these are molding and additive manufacturing (AM) using 3D printing [3]. The first technology uses two-component silicone materials with different hardnesses. This technology involves molding molds and a rigorous process to obtain a homogeneous material. This process, as a rule, involves a longer manufacturing time due to the need to cure the silicone. Also, molding technology involves molding molds which brings an additional cost and pushes the cost of making a soft robot quite a lot [4]. The second technology mainly uses commercially available elastomeric materials in filament or resin form, offering advantages in terms of achieving complex part geometries and speed compared to casting technology [5]. Currently, in the field of soft robotics, 3D printing is being addressed from three perspectives: 3D printing to produce molds, hybrid manufacturing, and fully additive manufacturing [6]. Applications in this field are varied, in areas of interest such as medical [7], services [8], or biologically inspired soft robots [9]. One of the concerns of the soft robotics community is to increase the range of applications of soft robots in the industrial field [10].

In industrial environments such as mechanical processing or assembly environments, various corrosive agents such as mineral or synthetic oils, degreasing or cleaning agents, water, ultraviolet radiation of various types (A, B, C), different temperatures, saline solutions or other various types depending on the specificity of the industry are often encountered. With a range of such aggressive agents, different soft robotic structures can come into contact and affect their functionality or shorten their lifetime. To identify the effects and behavior that these aggressive environments have on robotic

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structures made of soft materials by 3D printing technology, it is necessary to analyze the behavior of soft materials in contact with different aggressive environments identified in industrial environments. In our previous studies, we conducted an experimental analysis on Ecoflex 00-10 and 00-30 elastomeric silicone rubber-like materials that were exposed to a range of aggressive environments common in industrial environments. These silicone rubbers are bi-component rubbers that are based on the technology of making soft robotic structures by molding [11]. Other reviews identified in the literature address the influence of tempering on soft materials also made by molding technology [12].

The present study aims to identify the impact that a range of aggressive environments have on elastomeric materials used in making soft robotic structures by 3D printing additive manufacturing technology. The 3D printing technology on which our experimental study was based is that of Fused Deposition Modeling (FDM), using thermoplastic polyurethane elastomeric material (TPU with Shore hardness of 95 A). This analysis is based on a rigorous working methodology and on international standards that analyze several aspects related to the liquid absorption of plastics. The experimental determination of the impact that these aggressive environments have had on the elastomeric material is determined by experimental uniaxial tensile tests.

2. Materials and methods

The purpose of the experimental study is to find out the behavior of TPU 95A material in different environmental conditions. The main objective of the study is to see the changes in the mechanical characteristics and the elastic characteristics of the studied materials. A procedure for estimating the effect of a specific environment on one particular material is given in ISO-62:2008 [13] which provides a clear method for the moisture absorption determination of materials.

For the distilled water, cooling oil and UV-C media, the steps followed in preparing the test specimens for testing are shown in Figure 1. The specimens tested in ambient environment were not subjected to the drying process (the standard for environmental testing does not require samples to be dried before testing), they were tested under laboratory conditions according to ISO 527-1:2019, where the working temperature is 23 ± 2°C, and a humidity of 50 ± 5% for specimen preparation and testing.

Considering that in most standards and technical documentation, the values of maximum stresses and maximum strains are given for tests performed in ambient environment (laboratory conditions), the samples that were tested in an ambient environment were considered as reference.

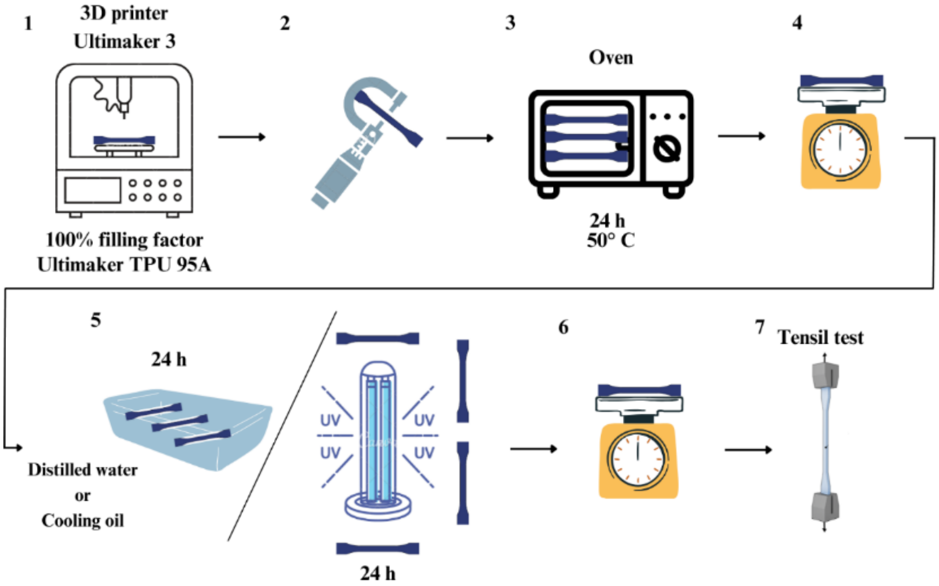

Figure 1. Steps to perform the analysis, 1 - specimen printing, 2 - specimen measurement, 3 - oven drying, 4 - weighing after drying, 5 - immersion/exposure to the medium of interest, 6 - absorption weighing, 7 - uniaxial tensile test

Based on this standard and on the ISO 527-2 [14] standard used to determine the tensile behavior of plastics, the impact that three specific industrial environment media (distilled water, mineral cooling oil, and UV rays) have on soft materials was analyzed. Ultimaker TPU 95A [15] elastomeric material with Shore 95 hardness was used in this analysis, specimens were made by additive manufacturing process with 100% infill factor using a 3D printer (Ultimaker 3). A white filament with a diameter of 2.85 mm was used and the nozzle and bed temperature were set at 235°C and 70°C, respectively, with a nozzle diameter of 0.4 mm. The zig-zag printing strategy was used as it is an optimal variation to achieve the best adhesion of the material layers. The successive steps required for the study have been shown graphically in Figure 1.

The printing parameters used to manufacture the test specimens for this research are presented in Table 1.

Table 1. FDM printing parameters

Parameter	**Value**
Nozzle diameter	0.4 mm
Primary layer height	0.2 mm
Layer height	0.1 mm
Infill density	100%
Infill pattern	Zig-Zag
Printing speed	25 mm/s
Nozzle temperature	235ºC
Bed temperature	70ºC

The shape and dimensions of the specimens used are shown in Figure 2a, according to ISO 527-2, which governs the uniaxial tensile testing of plastics. Figure 2b shows the strategy using for printing all the specimens tested in this research.

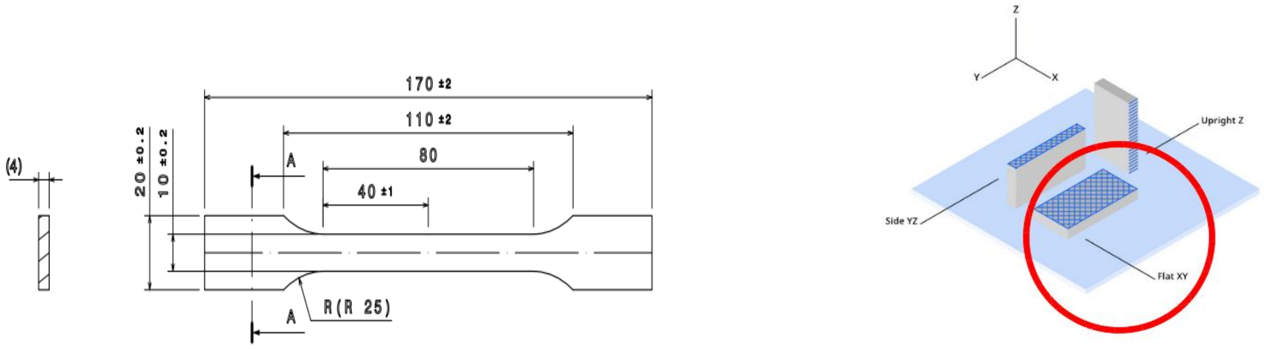

Figure 2. a. Specimen dimensions (in mm), **b.** Printing strategy of TPU 95A specimens

After printing the specimens, we conducted a test method using the GraphWork software, which is equipped with the Galdabini testing machine, model Quasar 25. In this method, the following were defined: geometrical dimensions of the test specimens, and test speed of 5 mm/min. All the specimens were measured thus excluding possible errors, into the process, after they were dried in an oven at a constant temperature of 50ºC for 24 h according to the standard ISO-62:2008 [13]. After drying, the specimens were weighed using a precision scale with two decimal places after the decimal point and the data were noted in an Excel table, then several specimens were immersed in different environments (distilled water, cooling oil) and other specimens were exposed to UV rays for 24 h. The UV rays came from a radiation source with a power of 36 W, emitting C-type radiation with a wavelength of 253.7 nm. The specimens were positioned approximately 50 mm away from the radiation source. All the specimens immersed in distilled water and cooling oil, were again weighed in order to determine, according to ISO-62:2008, the amount of absorbed fluid. The level of absorption (c) was calculated using expression (1):

$$c = \frac{m_2 - m_1}{m_1} \cdot 100\ [\%] \qquad (1)$$

where: m_1 - the mass before immersion, and m_2 - the mass after immersion. Finally, uniaxial tensile tests were performed, with a test speed of 20 mm/min at ambient temperature, until the until the samples break.

Excess liquid was removed using absorbent wipes. The process was carefully carried out until the liquid was completely removed from the specimens, so that the specimens did not slip into the grips of the testing machine. The determination of the degree of absorption of liquids (water and oil) in the tested specimens was based on the ISO 62:2008 standard, which establishes the procedure necessary for this determination.

In the next stage, the specimens were subjected to uniaxial tensile tests using the Galdabini Quasar 25 universal testing machine at room temperature, and from these tests, we obtained precise data on the changes in strength and elasticity of the materials. The analysis of the results obtained will provide essential information for understanding the material behavior under various conditions, with significant implications for materials research and the development of products with improved mechanical properties.

Uniaxial tensile tests under laboratory conditions are fundamental to polymeric materials for several reasons. First, they allow the determination of mechanical properties necessary to compare results from different working environments. Through these tests direct comparisons can be made between different polymeric materials or polymer formulations, which is essential for engineers in selecting the optimal material for specific applications. The results obtained for tests carried out in the ambient environment shall be taken as the baseline for all other environments used.

The second test medium is distilled water. For the immersion of the test specimens, we used distilled water supplied by the Simple Quality Products brand, which is used in various industrial applications such as dilution of antifreeze and windshield washer fluids, topping up the electrolyte level in electric batteries, as a spray liquid for electric irons, cooling of internal combustion engines. The distilled water used had a *p*H between 6 - 7.5 and a density of 1 g/cm^3 at 20°C.

The third test medium chosen for this study is the cooling oil supplied by Azur-Cut brand 602.01 M-15. This is a combination of mineral oil and additives; the oil has a viscosity of 15 mm²/s at 40°C and is a synthetic coolant oil for industrial uses.

The fourth test medium used was ultraviolet C (UV-C) radiation. Testing polymeric materials to UV-C radiation is essential to assess their durability and resistance under conditions of intense exposure to UV-C radiation. UV-C radiation, which has a wavelength between 100 and 280 nm, is known for its ability to degrade polymeric materials by photochemical processes. These tests allow the identification of potential modification in the physical and mechanical properties of polymers, such as embrittlement, loss of elasticity, discoloration or decrease in mechanical strength. By exposing materials to UV-C, we can determine the lifetime and performance of various polymeric materials in applications where they are subjected to such intense UV radiation, thus ensuring the reliability and safety of the final products.

3. Results and discussions

The results of the tests carried out, in terms of absorption levels and uniaxial tensile strength, are presented in the following section. To ensure the quality of the tests, we opted to include five test specimens. Subsequently, the results from these four sets of five test specimens were analyzed and presented as their mean values.

Table 2 shows the maximum values for engineering stress ($\sigma_{eng\ max}$), engineering strain ($\varepsilon_{eng\ max}$), and tensile modulus (E). We ran a statistical analysis on the experimental data to spot any outliers. After performing these tensile tests, the resulting data were statistically analyzed using Minitab 18, from two perspectives: the Outliers test and the Normality test, two tests being applied: the Anderson-Darling test to check the normal distribution of data and the Grubbs test to eliminate outliers. Based on the above,

Table 2 includes the measured values and the results of the statistical analysis for the two tests (Anderson-Darling and Grubbs) applied on the five specimens made of TPU95. Thus, in addition to the mean, median, standard deviation, AD and G indicators, Table 2 shows the p-values for the two statistical tests. Note that these statistical tests were performed for all test means of the test specimens made of TPU95.

In many industrial applications it is important to know these mechanical and elastic characteristics of the materials, so that these materials can be used according to these properties, thus avoiding their use to overstressing, which could lead to the functional failure of the parts made of this material. The determination of the maximum stresses and the maximum deformations that the specimens made of the studied material can withstand can help in the correct design (dimensioning calculations, maximum loading capacity calculations) of the various components found in different industrial assemblies that interact with aggressive environments.

Table 2. Maximum values of the mechanical and elastic characteristics for TPU 95 A material tested at uniaxial tension

Specimen no.	**Specimen dimensions**		$\sigma_{eng\ max}$	$\varepsilon_{eng\ max}$	**E**
	b [mm]	**t [mm]**	**[MPa]**	**[mm/mm]**	**[MPa]**
Ambient medium					
#1	10	4	31.92	7.275	31.713
#2	10	4	31.19	7.188	31.729
#3	10	4	31.82	7.138	27.07
#4	10	4	31.41	7.275	29.667
#5	10	4	33.76	7.138	32.689
Average value			**32.02**	**7.202**	**32.689**
Standard variation			**1.017**	**0.069**	**2.247**
Sample variance			**1.034**	**0.004**	**5.051**
AD value (AD test)			**0.53**	**0.47**	**0.37**
p value (AD test			**0.09**	**0.13**	**0.26**
Grubbs value (Grubbs test)			**1.71**	**1.05**	**1.56**
p value (Grubbs test)			**0.06**	**1**	**0.27**
UV-C					
#1	10	4	28.27	6.925	27.39
#2	10	4	28.09	7.3	30.696
#3	10	4	27.17	6.9	28.364
#4	10	4	26.28	6.3	30.245
#5	10	4	26.578	6.828	31.567
Average value			**27.277**	**6.850**	**29.652**
Standard variation			**0.886**	**0.358**	**1.723**
Sample variance			**0.758**	**0.128**	**2.97**
AD value (AD test)			**0.28**	**0.35**	**0.25**
p value (AD test			**0.47**	**0.3**	**0.56**
Grubbs value (Grubbs test)			**1.13**	**1.54**	**1.31**
p value (Grubbs test)			**1**	**0.31**	**0.79**
Distilled water					

#1	10	4	22.68	7.125	21.077
#2	10	4	22.43	6.888	22.254
#3	10	4	22	6.825	21.249
#4	10	4	20.99	6.613	21.768
#5	10	4	23.22	7.275	25.323
Average value			**22.264**	**6.945**	**22.334**
Standard variation			**0.837**	**0.259**	**1.733**
Sample variance			**0.701**	**0.067**	**3.004**
AD value (AD test)			**0.21**	**0.18**	**0.85**
p value (AD test			**0.72**	**0.83**	**0.06**
Grubbs value (Grubbs test)			**1.52**	**1.28**	**1.72**
p value (Grubbs test)			**0.34**	**0.87**	**0.05**
Cooling oil					
#1	10	4	27.79	6.513	30.341
#2	10	4	25.42	6.075	29.337
#3	10	4	25.22	6.363	30.057
#4	10	4	25.72	7.288	31.637
#5	10	4	26.72	6.413	27.583
Average value			**26.174**	**6.530**	**29.791**
Standard variation			**1.071**	**0.453**	**1.483**
Sample variance			**1.148**	**0.205**	**2.215**
AD value (AD test)			**0.34**	**0.45**	**0.21**
p value (AD test			**0.33**	**0.15**	**0.73**
Grubbs value (Grubbs test)			**1.51**	**1.67**	**1.48**
p value (Grubbs test)			**0.37**	**0.1**	**0.41**

It can be observed that in the case of the AD test, the values of AD and p for σ_{max}, ε_{max}, and E for ambient environment fall in the range 0.32 - 0.53, respectively 0.09 - 0.36, and in the case of the Grubbs test, the values of G and p for for σ_{max}, ε_{max}, and E fall in the range 1.05 -1.71, respectively 0.06 -1.00. For UV-C, the values of AD and p for σ_{max}, ε_{max} and E falls under 0.17-0.35, respectively 0.30-0.84, and in the case of the Grubbs test, the values of G and p for for σ_{max}, ε_{max} and E fall in the range 1.13 -1.54, respectively 0.31 -1.00. For distilled water the values of AD and p for σ_{max}, ε_{max} and E falls under 0.15-0.21, respectively 0.83-0.90, and in the case of the Grubbs test, the values of G and p for for σ_{max}, ε_{max}, and E fall in the range 1.28 -1.52, respectively 0.34 -0.87 and for cooling oil, the values of AD and p for σ_{max}, ε_{max} and E falls under 0.31-0.45, respectively 0.15-0.39, and in the case of the Grubbs test, the values of G and p for for σ_{max}, ε_{max} and E fall in the range 1.44 -1.67, respectively 0.10 -0.49, all of which confirm that for the results obtained there is a normal distribution of the results. This being also evident by the fact that in all cases, the p values are greater than 0.05.

The experimental results were used to plot a characteristic engineering stress - strain curve for each of the four test sets conducted in specific environments, as depicted in Figure 3.

After the analysis of the experimental results, it was found that the materials underwent changes in their characteristics. As far as the specimens kept under ultraviolet ray's type C are concerned, a decrease of 17.39% of the tensile strength can be observed compared to the specimens tested in an ambient environment and a decrease of elongation at break of 5.14% and the tensile modulus decreased by 10.24%.

For the specimens immersed in distilled water, a decrease of 43.82% in breaking strength and 3.70% in elongation at break was observed. Additionally, the tensile modulus decreased by 9.73%. Conversely, for specimens stored in cooling oil, there was an 22.34% decrease in breaking strength, a 10.29% decrease in elongation at break, and an 46.36% decrease in tensile modulus.

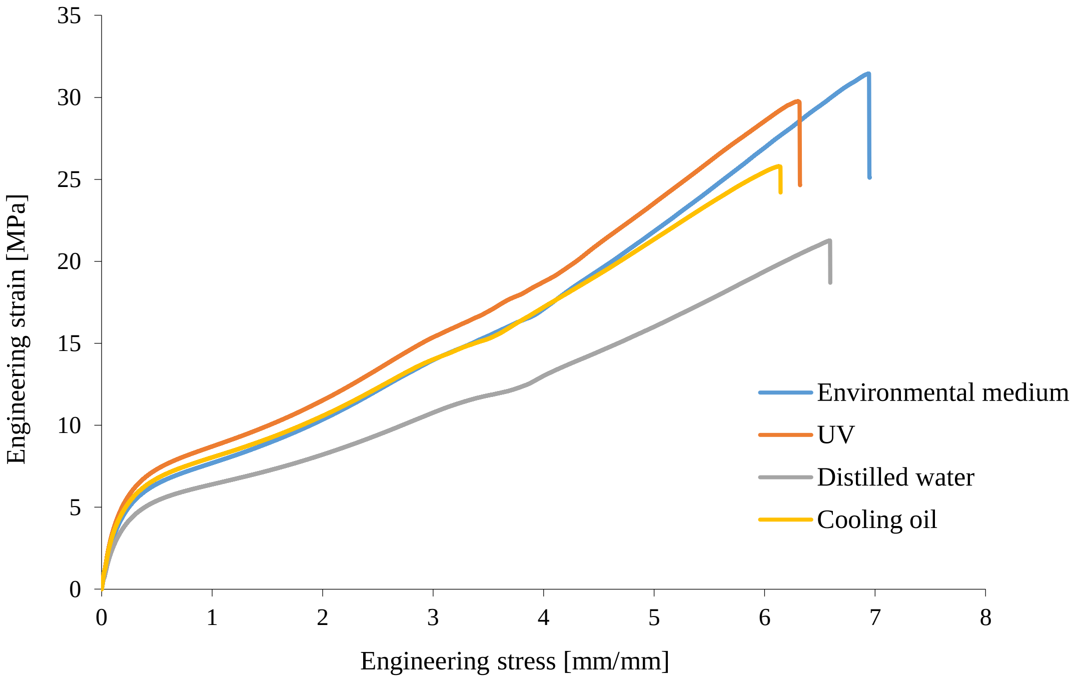

Figure 3. Engineering stress - strain curves for TPU 95A in four different environments studied

To determine how liquid absorption in the tested material influences the mechanical and elastic characteristics of this, was determinate absorption level of the two liquids studied in the TPU 95A material, and the results being presented in Tables 3 and 4 below.

Table 3. Distilled water absorption level of TPU 95A specimens

No. specimen	Mass after drying [g]	Mass after 24 hours in distilled water [g]	Absorption [%]
#1	10.4375	10.5261	0.8489
#2	10.4432	10.5581	1.1002
#3	10.6954	10.8024	1.0004
#4	10.6285	10.7498	1.1413
#5	10.6623	10.7765	1.0711
Average value			**1.0324**

Table 4. Cooling oil absorption level of TPU 95A specimens

No. specimen	Mass after drying [g]	Mass after 24 hours in distilled water [g]	Absorption [%]
#1	10.3725	10.6418	2.5963
#2	10.6912	11.0035	2.9211
#3	10.6328	11.0053	3.5033
#4	10.6053	10.9045	2.8212
#5	10.3763	10.7316	3.4241
Average value			**3.0532**

Tables 3 and 4 display the absorption values, measured in grams, before and after a 24h immersion in the distilled water and cooling oil for each of the five representative specimens. Additionally, the average absorbance quantity was determined for both types of liquid.

Based on Figure 4, which graphically presents the absorption process of the two media, it is obvious that cooling oil exhibits the most substantial absorption, with distilled water following closely behind. Specifically, the absorption of cooling oil is approximately triple that of distilled water.

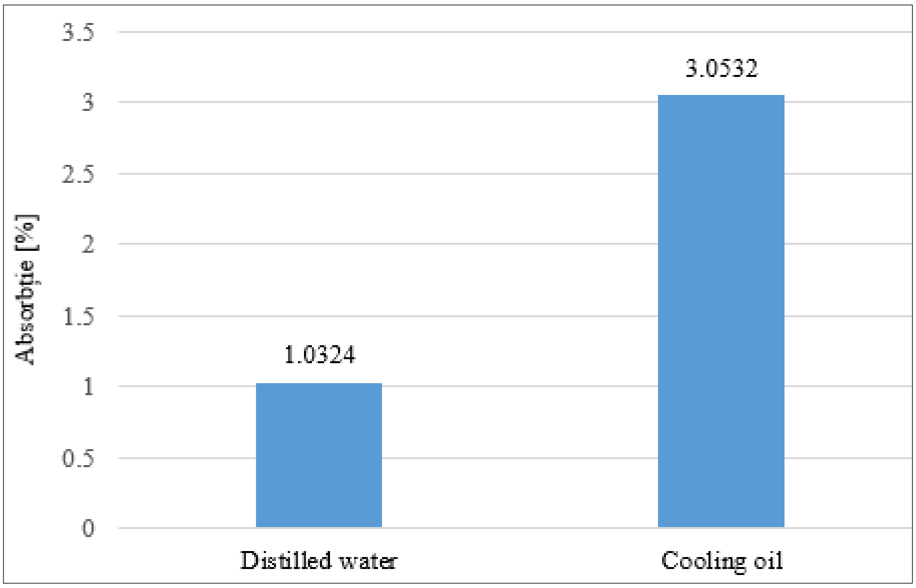

Figure 4. Average liquid absorption percentage in TPU 95A specimens

Figure 5 illustrates the comparisons of the maximum tensile stress values for the three environments (distilled water, cooling oil, UV-C) against the values of the averages of the specimens tested in the ambient environment. The reference value in the figure below is 32.02 MPa, representing the maximum value of tensile stress for the specimens tested in the ambient environment.

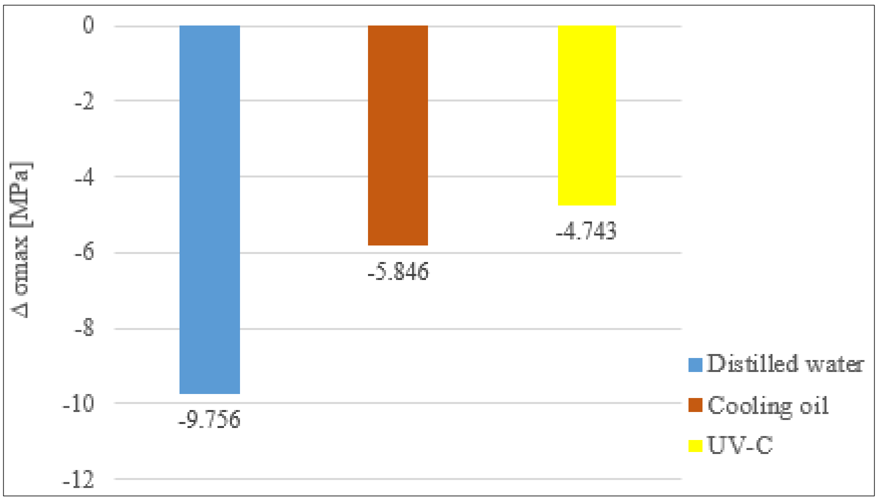

Figure 5. The average of maximum values of tensile stress for TPU 95A specimens for each medium

Observations reveal that in the instance of distilled water, with an absorption of 1.0324%, the maximum tensile stress at which the specimen fractures decrease by an absolute value of 9.756 MPa, compared to the stresses and deformations related to the ambient medium. Similarly, for cooling oil, at an absorption of 3.0532%, the maximum tensile stress diminishes by an absolute value of 5.846 MPa, and for UV-C, the maximum tensile stress decrease by an absolute value of 4.743 MPa.

Figure 6 illustrates comparisons of the maximum values of tensile strain for the three environments (distilled water, cooling oil, UV-C) against the values of the averages of the specimens tested in the ambient environment. The reference value in the figure below is 7.202 mm/mm, representing the maximum value of tensile strain for the specimens tested in the ambient environment.

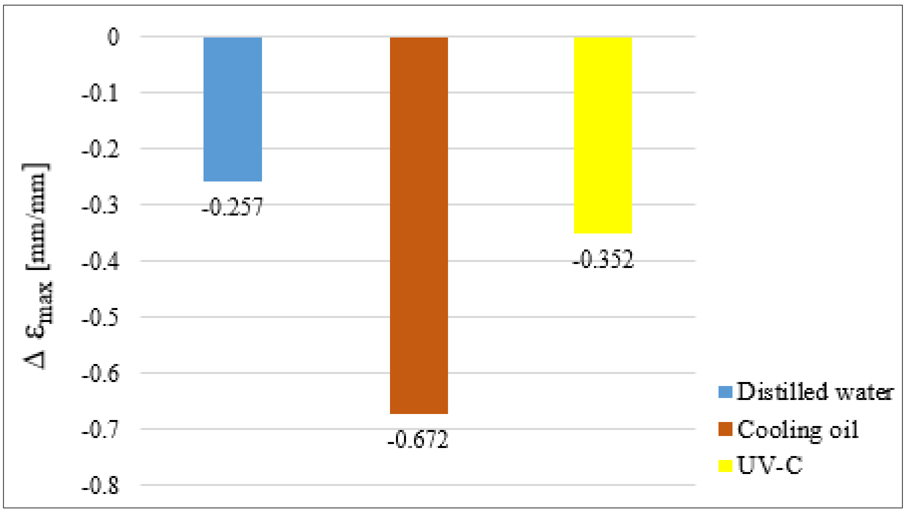

Figure 6. The average of maximum values of tensile strain for TPU 95A specimens for each medium

Based on the results of the experimental analysis on the absorption concerning the characteristics of the material, it is found that the cooling oil with an absorption of 3.0532% was able to reduce the tensile strain by 0.672 mm/mm, compared to distilled water which had an absorption of 1.0324% and a reduction in tensile stress of 0.257 mm/mm and for UV-C, the maximum tensile strain decreases by an absolute value of 0.352 mm/mm.

At first glance, there is no correlation between the two quantities, but some arguments can be made regarding the chemical composition of the aggressive medium, which requires further detailed environmental analysis.

Figure 7 illustrates comparisons of the maximum values of elastic modulus for the three environments (distilled water, cooling oil, UV-C) against the values of the averages of the specimens tested in the ambient environment. The reference value in the figure below is 29.791 MPa, representing the maximum value of elastic modulus for the specimens tested in the ambient environment

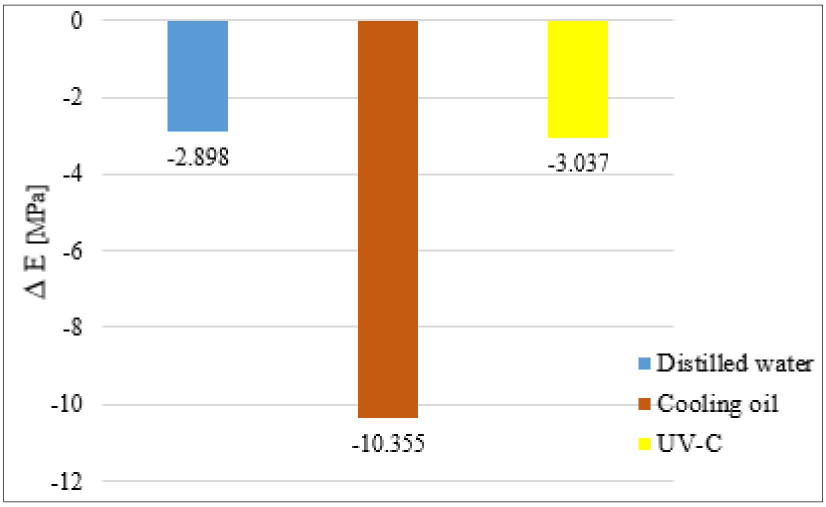

Figure 7. The average of maximum values of elastic modulus for TPU 95A specimens for each medium

Based on the results of the experimental absorption analysis on the material characteristics, it is found that the cooling oil with an absorption of 3.0532% was able to reduce the modulus of elasticity by 10.355 compared to distilled water which had an absorption of 1.0324% and a reduction in the modulus of elasticity of 2.898, and for UV-C, the modulus of elasticity decreases with an absolute value of 3.037.

4. Conclusions

This study employed a well-defined methodology to examine the effects of various aggressive environments commonly found in industrial settings on the elastomeric material TPU 95 A. Specimens crafted from this material were fabricated using additive manufacturing technologies, a primary method for creating soft robots. The impact of aggressive environments was evaluated by assessing changes in the mechanical and elastic properties of the analyzed material through uniaxial tensile testing. TPU 95 A, frequently utilized in soft robot construction, underwent exposure to aggressive liquid media (distilled water and cooling oil) as well as radiation (ultraviolet radiation - UV - C). Additionally, the absorption level of the liquid media was scrutinized in accordance with specific standards. According to the test results of the experiments performed on the TPU 95A material in the three analyzed environments, they had impact on the mechanical and elastic characteristics by decreasing them. The aggressive media that had the most significant impact by decreasing the characteristics was distilled water followed by mineral cooling oil and then UV-C radiation which had the lowest impact.

The relatively new field of 'Soft robotics' offers opportunities and requires further research. Therefore, in terms of future research directions, to provide a comprehensive understanding of the influence of various media types on the interaction with the TPU 95 A material, it is necessary to monitor the influence of external factors on its compression and twisting properties.

Another aspect that warrants further study is the consideration of other types of media prevalent in the industry, as they can impact not only the mechanical characteristics but also the elastic properties of TPU 95 A material. Additionally, research on materials within the same class but possessing different elastic properties is essential. This allows for a comparative analysis of material behavior and facilitates the establishment of the influence that industrial factors have on materials utilized in the field of 'Soft robotics'.

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References

1.RUSU, D.-M., MÂNDRU, S.-D., BIRIȘ, C.-M., PETRAȘCU, O.-L., MORARIU, F., IANOSI-ANDREEVA-DIMITROVA, A. Soft Robotics: A Systematic Review and Bibliometric Analysis. *Micromachines* 2023, 14, 359.
2.RUS, D., TOLLEY, M., Design, fabrication and control of soft robots. *Nature* 2015, 521, 467–475 https://doi.org/10.1038/nature14543.
3.SCHMITT F., PICCIN O., BARBÉ L., BAYLE B., (2018), *"Soft Robots Manufacturing: A Review"*. Front. Robot. AI 5:84. doi: 10.3389/frobt.2018.00084.
4.MAZZEO, A. D., HARDT, D. E., (2013), Centrifugal casting of microfluidic components with PDMS. J. Micro Nano Manufactur. 1:021001. doi: 10.1115/1.4023754.
5.GUL J.Z., SAJID M., REHMAN M.M., SIDDIQUI G.U., SHAH I, KIM K.H., LEE J.W., CHOI K.H., 3D printing for soft robotics - a review. Sci Technol Adv Mater. 2018 Mar 8;19(1):243-262. doi: 10.1080/14686996.2018.1431862. PMID: 29707065; PMCID: PMC5917433.
6.GIANNI STANO, GIANLUCA PERCOCO, *"Additive manufacturing aimed to soft robots fabrication: A review"*, Extreme Mechanics Letters, Volume 42, 2021, 101079, ISSN 2352-4316, https://doi.org/10.1016/j.eml.2020.101079.

7.NAM C., RONG W, LI W., CHEUNG C., NGAI W., CHEUNG T., PANG M., LI L., HU J., WAI H., HU X., An Exoneuromusculoskeleton for Self-Help Upper Limb Rehabilitation After Stroke. *Soft Robot* 2022, Feb; 9 (1): 14-35.
8.GONG Z., FANG X., CHEN X., et al. A soft manipulator for efficient delicate grasping in shallow water: Modeling, control, and real-world experiments. *The International Journal of Robotics Research* 2021, 40(1):449-469.
9.JIZHUANG F., QILONG D., QINGGUO Y., YI W., JIAMING Q., YANHE Z., Biologically inspired swimming robotic frog based on pneumatic soft actuators. *Bioinspir Biomim* 2020 May 27; 15(4):046006.
10.Rossiter, J.M.; Hauser, H. Soft Robotics - The Next Industrial Revolution? *IEEE Robot. Autom. Mag.* 2016, *23*, 17–20.
11.RUSU, D.-M., PETRAȘCU, O.L., PASCU, A.M., MÂNDRU, S.D., The Influence of Industrial Environmental Factors on Soft Robot Materials. *Materials 2023, 16*, 2948.
12.LIAO, Z., HOSSAIN, M., YAO, X., NAVARATNE, R., CHAGNON, G., A comprehensive thermo-viscoelastic experimental investigation of Ecoflex polymer. *Polym. Test. 2020, 86*, 106478.
13.***ISO 62:2008 Plastics - Determination of water absorption, Accessed May 4, 2023.
14.***ISO 527-2:2012 Plastics - Determination of tensile properties - Part 2: Test conditions for moulding and extrusion plastics, Accessed May 5, 2023.
15.***Ultrafuse TPU 95A, https://forward-am.com/material-portfolio/ultrafuse-filaments-for-fused-filaments-fabrication-fff/flexible-filaments/ultrafuse-tpu-95a/, Accessed in 31.03.2024.

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