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INFLUENCE OF 3D-PRINTING STRATEGIES ON THE COMPRESSIBILITY OF TPU 85A ELASTOMERIC MATERIAL

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Abstract: *The aim of the present work is to analyze by experimental methods the influence of printing strategies on the mechanical behavior of TPU 85A elastomeric material under compressive stress. We analyzed 3D printed specimens which were realized with three different printing strategies (circular, lines and zig-zag), the rest of the printing parameters remaining unchanged. The 3D printing was carried out using an Ultimaker 3 3D printer and the experimental tests were performed on a Galdabini Quasar 25 uniaxial testing machine with specimens of size 10x10 mm according to ISO 604:2002. The results of the experimental tests show that the specimens with the circular printing strategy obtained the lowest values of elastic deformation, and the compressive strength reached the highest value of the three analyzed variants. These experimental results can contribute to the development and improvement of the characteristics of actuators or soft robots realized by 3D printing technology.*

Key words: Elastomeric material, TPU 85A, compression test, soft robotics, additive manufacturing, spring back.

1. INTRODUCTION

A significant issue facing the soft robotics community today is the need to assess how various environments or stresses affect materials that are specifically used in soft robots [1], [2]. This understanding is crucial for facilitating the integration of soft robots into the manufacturing sector [3].

Currently, many of the applications of soft robots are focused on medical and service applications. In the medical field, where the field of soft robotics brings several advantages due to the silicone materials that are used, many applications deal with exoskeleton-type wearable devices for recovery or assistance of the upper limbs [4, 5]. Another significant part of the applications in this field are life-inspired locomotion systems [6, 7] as well as life-inspired grasping systems using different configurations of soft actuators [8, 9]. Some of these grasping systems are based on fluidic actuators [10] as well as smart materials [11, 12].

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The field of soft grippers represents a component that offers superior characteristics to one of the rigid materials, but it is necessary to analyze the characteristics of the material and the printing parameters of the gripper. Since it is necessary to determine the behavior of materials under different environmental conditions and loads, and to implement the findings from the service industry [13] to the industrial environment, the research question to be addressed in this study is, how various filling patterns affect the compressibility of materials. This in turn will affect the strength of various soft actuators made from soft rubber like material via the additive manufacturing process. This is one of the most commonly used methods in this field and has numerous implementations in various other fields as well [14], [15].

2. MATERIAL AND METHODS

To assess the compression characteristics of the plastic material with different infill patterns, the compression tests were conducted in accordance with the ISO 604:2002 standard [16] which provides a comprehensive method for determining the compression properties of materials. Figure 1 shows the main steps that were carried out in this analysis. It was chosen to test the elastomeric material under compressive stress due to the compressive stress found in grasping applications when the object is grasped, the compressive stress being between the jaws of the gripper and the object to be handled.

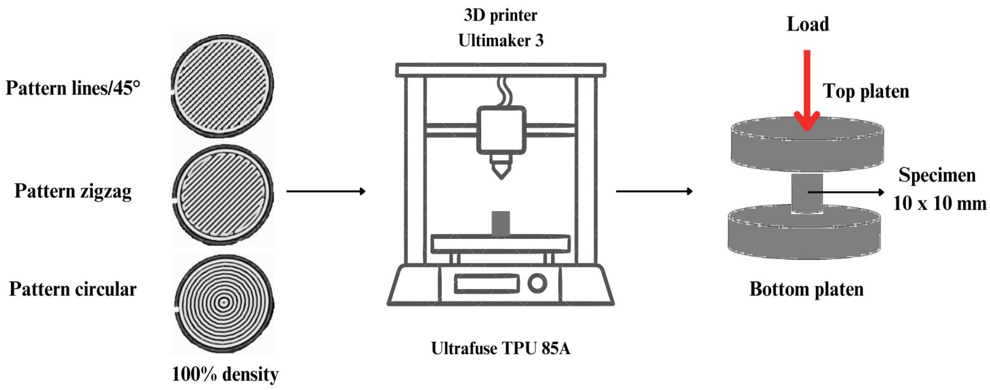
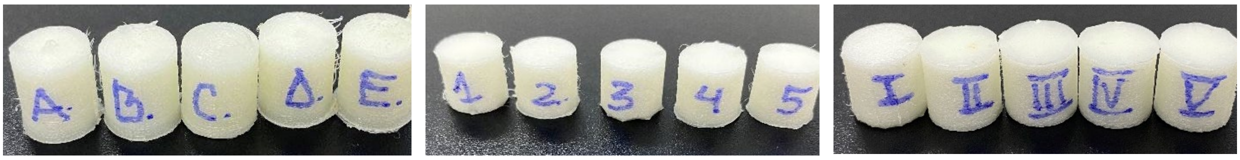


Figure 1: The steps for compression testing of 3D printed specimens.

Three different fill pattern configurations (circular, 45º lines and zig-zag) were utilized for samples printing. The 3D printed using for printing the compression sample is a Ultimaker 3 with Ultrafuse TPU 85A material with Shore 85 hardness and 100% fill factor. The dimensions of the specimens, in accordance with the standard, are 10 mm diameter and 10 mm high. All the tests were done using a universal testing machine Quasar 25 produced by Galdabini company, and the maximum displacement of the upper grip was limited at 7 mm.

3. RESULTS

For each of the printing strategies, five compression samples were created, which were then labeled as shown in Figure 2.



(a) (b) (c)

Figure 2: Compression specimens
(a) Circular printing strategy, (b) Lines printing strategy, (c) Zig-zag printing strategy.

The average curve force versus deformation, obtained from the experimental results, is presented for each of the five specimens across three sets, corresponding to the specified printing strategies, as illustrated in Figure. 3.

The analysis reveals that the specimens realized using a circular printing strategy exhibits the greatest compressive force, (F_{mean} = 2587.00 N). In contrast, for the specimens realized using a line printing strategies we find the smaller compressive forces (F_{mean} = 1314.68 N). Regarding the specimens printed using the zig-zag strategies the compressive forces are between the minimum and maximum values previously specified (F_{mean} = 1758.62 N). Of course, the same trend can be observed in the case of maximum compression stress. Thus, for specimens obtained using circular printing strategy, $\sigma_{max, mean}$ = 32.93 MPa, for specimens obtained using lines printing strategy, $\sigma_{max, mean}$ = 16.73 MPa and for specimens obtain using zig-zag printing strategy $\sigma_{max, mean}$ = 22.39 MPa.

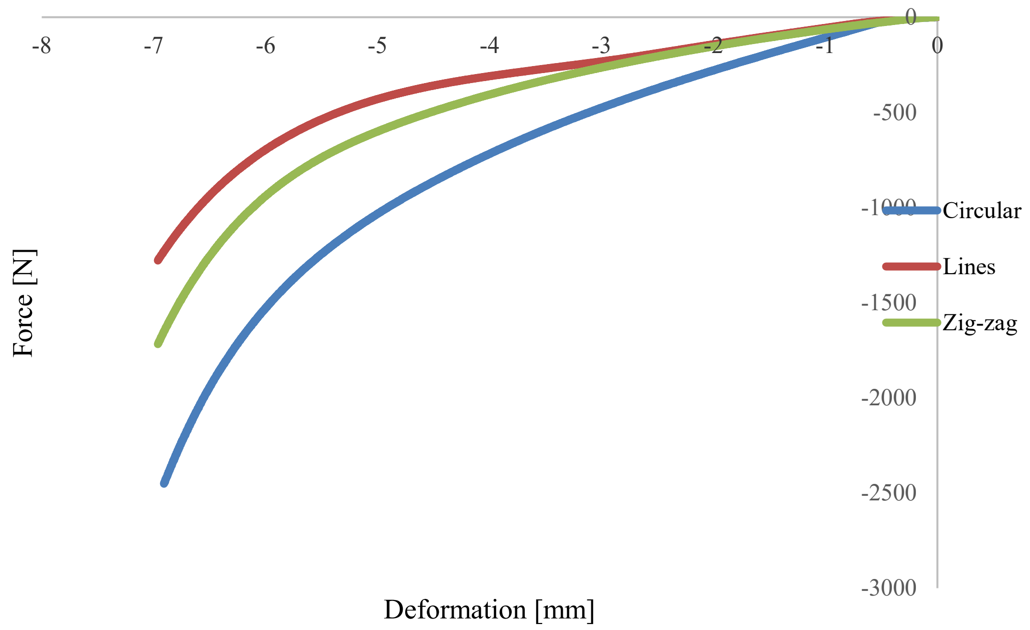


Figure. 3. Force vs. deformation curves for TPU85A for all three printing strategies studied.

Table 1: Spring back of the specimens after compression.

Specimen no.	**Specimen dimensions after compression h [mm]**	**Spring back [%]**	**Specimen dimensions after compression h [mm]**	**Spring back [%]**	**Specimen dimensions after compression h [mm]**	**Spring back [%]**
	Circular printing strategy		**Lines printing strategy**		**Ziz-Zag printing**	
#1	9.35	311.67	9.75	325.00	9.52	317.33
#2	9.38	312.67	9.71	323.67	9.53	317.67
#3	9.31	310.33	9.77	325.67	9.56	318.67
#4	9.41	313.67	9.83	327.67	9.50	316.67
#5	9.46	315.33	9.74	324.67	9.62	320.67
Average		***312.73***		***325.33***		***318.20***

Table 1 reveals that the spring-back behavior of specimens varies significantly depending on the printing strategy. Specimens fabricated using the circular printing strategy exhibit the lowest average spring-back value, recorded at 312.73%. Conversely, those produced with the line printing strategy demonstrate the highest average spring-back value, measured at 325.33%. Specimens printed with the zig-zag strategy display an intermediate average spring-back value of 318.20%, situated between the circular and line strategies. These results underscore the influence of the printing pattern on the mechanical response of the specimens under compression.

Table 2: Statistical analysis of experimental data.

Specimen no.	F_{max} [N]		
	Circular printing strategy	Lines printing strategy	Ziz-Zag printing strategy
#1	-2773.5	-1218.38	-1854.75
#2	-2679.13	-1691.25	-1800.88
#3	-2552.25	-1360.38	-1549.13
#4	-2541.75	-1110.63	-2285.13
#5	-2388.38	-1192.75	-1303.25
Mean	***-2587.00***	***-1314.68***	***-1758.62***
Median	***-2552.25***	***-1218.38***	***-1800.88***
Standard	***146.60***	***228.94***	***367.25***
Minimum	***-2773.50***	***-1691.25***	***-2285.13***
Maximum	***-2388.38***	***-1110.63***	***-8793.14***
AD value	***0.20***	***0.40***	***1.18***
p value	***0.74***	***0.20***	***0.79***
G value	***1.35***	***1.64***	***1.43***
p value	***0.69***	***0.14***	***0.51***

Table 2 provides a detailed summary of the maximum force values for the three sets of five specimens, accompanied by the results of statistical evaluations using the Anderson-Darling and Grubbs tests. The table includes critical statistical parameters such as the maximum, minimum, median, mean, and standard deviation, as well as the test statistics (AD and G) and their associated p-values. These results offer a rigorous characterization of the data distribution and facilitate the identification of potential outliers.

After performing these compression 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.

It can be observed that in the case of the AD test, the values of AD and p for Fmax for all three strategies fall in the ranges 0.20-1.18, respectively 0.20-0.79 and in the case of the Grubbs test, the values of G and p fall in the range 1.35-1.64, respectively 0.14-0.69, all of which confirm that there is a normal distribution for the results obtained. This being also evident by the fact that in all cases, the p values are greater than 0.05.

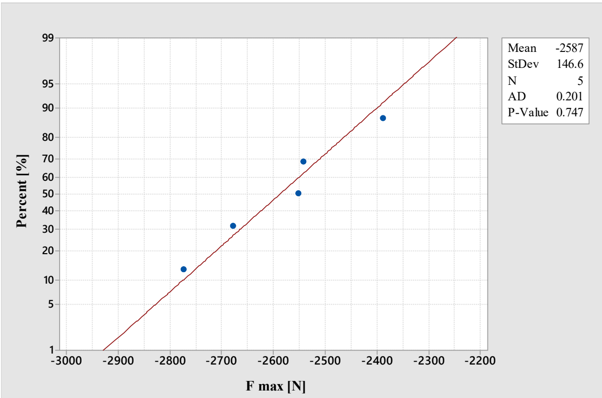


Figure. 4. Normal distribution plot for maximum compressive force for circular strategy

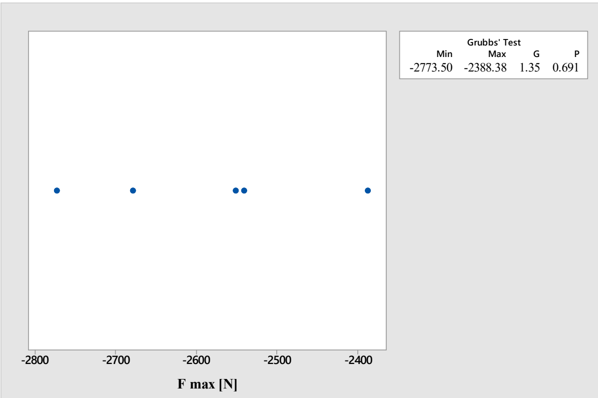
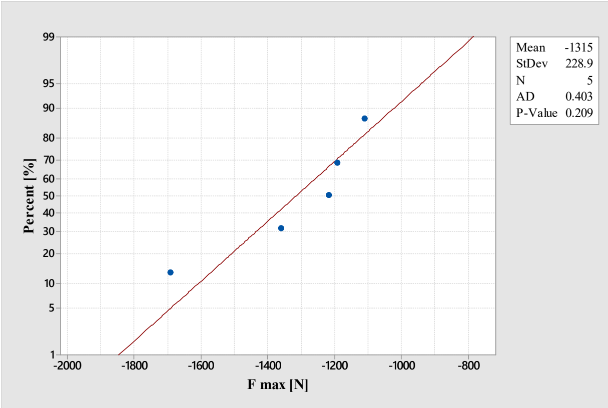


Figure. 5. Outlier plot for maximum compressive force for circular strategy



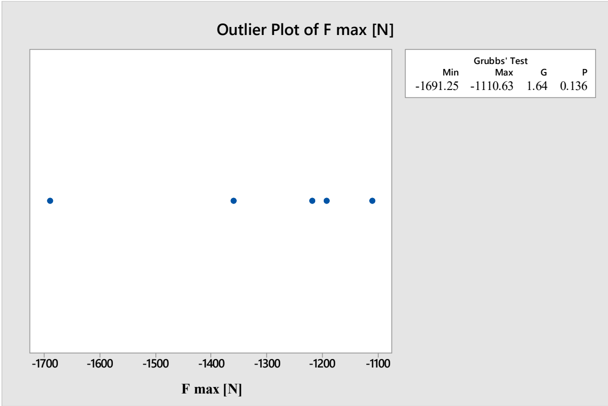
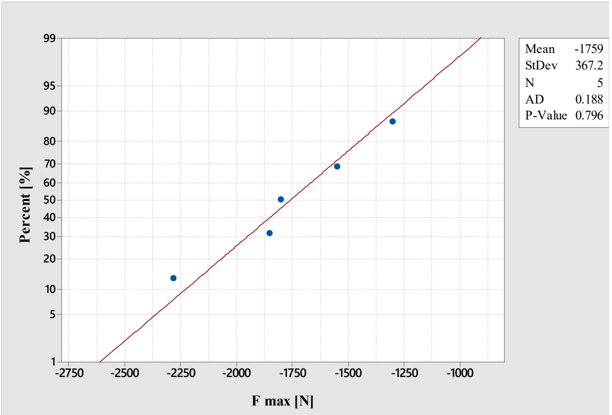


Figure. 6. Normal distribution plot for maximum compressive force for lines strategy

Figure. 7. Outlier plot for maximum compressive force for lines strategy



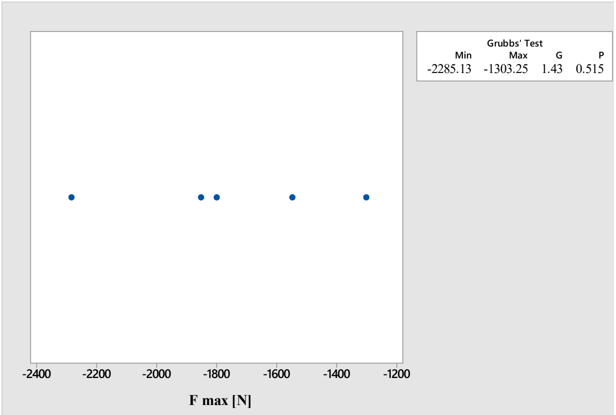


Figure. 8. Normal distribution plot for maximum compressive force for zig-zag strategy

Figure. 9. Outlier plot for maximum compressive force for zig-zag strategy

4. CONCLUSIONS

The analysis indicates that specimens produced using the circular printing strategy demonstrated the lowest spring-back values while achieving the highest compression force and highest maximum compression stress. In contrast, specimens fabricated with the line printing strategy exhibited the highest spring-back values and the lowest compression force and lowest maximum compression stress. Notably, all specimens, regardless of the printing strategy, exhibited exceptionally high spring-back behavior, reflecting the material's inherent high elastic properties.

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