
COMPRESSION BEHAVIOR OF A BIO-BASED POLYURETHANE FOAM REINFORCED WITH ALUMINUM HYDROXIDE

Enio Henrique Pires da Silva^a, Júlia Camargos Ferreira de Aguiar^b, Marcelo Leite Ribeiro^a, Volnei Tita^a, Romeu Rony Cavalcante da Costa^b

^aDepartment of Aeronautical Engineering, São Carlos School of Engineering, University of São Paulo
Av. João Dagnone 1100, 13563-120 São Carlos, SP, Brazil
eniopires@usp.br, malribei@usp.br, voltita@sc.usp.br

^bDepartment of Mechanical Engineering, Federal University of Technology – Parana (UTFPR)
Av. Alberto Carazzai 1640, 86300-000 Cornélio Procópio, PR, Brazil
juliacfaguiar18@gmail.com, romeu@utfpr.edu.br

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Abstract. *This work aims to evaluate the changes in compression behavior when a green PUF is reinforced by aluminum hydroxide (ATH), which is a well-known flame-retardant, in mass percentages of 10%, 20%, 30%, and 40%. The test was led by the ASTM D1621-16 standard for compression test in rigid cellular polymers. The ATH addition highly increased the compression yield strength of the tested specimens, with mean values for PUF (0.85 ± 0.14 MPa), PUF10ATH (1.22 ± 0.13 MPa), PUF20ATH (1.36 ± 0.10 MPa), PUF30ATH (1.43 ± 0.16 MPa), and PUF40ATH (1.71 ± 0.16 MPa). The compression yield strain did not show a noteworthy difference. The compression modulus increased with the ATH incorporation up to 20% of ATH mass addition, with values for PUF (15.40 ± 2.34 MPa), PUF10ATH (36.57 ± 2.63 MPa), and PUF20ATH (51.68 ± 2.57 MPa), presenting a slight decrement for PUF30ATH (42.16 ± 8.84 MPa) and PUF40ATH (41.45 ± 13.85 MPa). The ATH addition showed out as a good mechanical reinforcement under compression load, which may open new areas of application for bio-based PUFs since ATH is a good and inexpensive flame-retardant.*

1. INTRODUCTION

Polyurethane foams (PUFs) have a huge variety of application areas due to their many advantages such as light weight, inexpensive cost, excellent thermal and acoustic insulation, and simple manufacturability [1–3]. They are obtained by the reaction between a polyol and isocyanate, therefore, one of the main problems around PUFs nowadays is their oil-based raw materials, since the environmental impacts caused by polymers are growing in the last decades [4,5]. Another important concern over PUFs application is their high flammability, thus, many studies regarding the flammability reduction of bio-based PUFs have been done in the last years [6–8].

The addition of flame retardants, such as aluminum hydroxide (ATH), can reduce the high flammability that most polymers have. ATH is a halogen-free non-toxic additive flame retardant that liberates water in an endothermic reaction at an average temperature of 200 °C. It is a well know flame-retardant used in many polymers worldwide [9–12].

However, the presence of a particle inside the foam matrix may harm some of the important properties the PUF have, therefore, this work aims to evaluate the changes in compression behavior when a green PUF is reinforced by ATH. It may represent that new areas might be open for this green foam where flame security is required.

2. METHODS AND MATERIALS

The bio-based PUF raw materials were kindly supplied by Kehl Company and can be described as a blend of vegetable oils (reagents KT1106/KT1106-R). The ATH was provided by Alcoa Corporation. Thus, more details about the materials can be obtained directly from their cited companies.

Table 1 shows the amounts of reagents used in the PUF synthesis. First of all, polyol was poured into a plastic container over a precision scale, then, ATH was poured and mixed within the polyol (for the ATH added plates). The homogenization was done by a mechanic stirrer at 3000 RPM. After the polyol+ATH homogenization, isocyanate was poured into the mixture and mixed once again. Finally, the final mixture was poured into a mold with 125 x 125 x 25.4 mm³ and left for over an hour until the foam plate was rigid and ready for demolding.

Table 1 – Mass fractions of the materials in the synthesis of the foams

Material	Polyol (g)	Isocyanate (g)	ATH (g)	ATH mass fraction (%)
PUF	50.3	41.9	0	0
PUF10ATH	50.3	41.9	9.22	10
PUF20ATH	50.3	41.9	18.44	20
PUF30ATH	50.3	41.9	27.66	30
PUF40ATH	50.3	41.9	36.88	40

The chosen ATH mass fractions were based in some papers available in the literature, such as the works of Akdogan, et al. [9] and Pham, et al. [10]. As shown in Table 1, the tested ATH mass fractions were 0% (pure foam), 10%, 20%, 30%, and 40%.

The test followed the ASTM D1621-16 [13] standard, which provides the parameters for the specimen dimensions and test speed. Therefore, five samples were cut from two separate foam plates for each ATH mass fraction. The final sample dimensions were 50.8±0.4 x 50.8±0.4 x 25.4±0.1 mm³. Therefore, as the standard specifies, the test speed was set to 10% of the specimen thickness, or 2.5 mm/min in this case.

Digital image correlation (DIC) technique was used via software GOM Correlate, moreover, the software requires a pattern area over the whole sample surface with noticeable points standing out from the background. This pattern was created by applying a layer of black paint (background) followed by sprinkled white paint. The camera used in the tests was a Canon Rebel 5 positioned around 50 cm away from the specimen.

3. RESULTS

The compression test results are shown in Table 2, where the compression yield strength, compression modulus, and Poisson ratio are given by σ_c , E_c , and ν respectively. The yield strain for all the tested materials was around 0.04 mm/mm.

Table 2 - Compression test results

Material	σ_c (MPa)	E_c (MPa)	ν
PUF	0.85 ± 0.14	15.40 ± 2.34	0.12 ± 0.02
PUF10ATH	1.22 ± 0.13	36.57 ± 2.63	0.09 ± 0.03
PUF20ATH	1.36 ± 0.10	51.68 ± 2.57	0.18 ± 0.04
PUF30ATH	1.43 ± 0.16	42.16 ± 8.84	0.28 ± 0.03
PUF40ATH	1.71 ± 0.16	41.45 ± 13.85	0.27 ± 0.05

The compression yield strength presented a significant raise when ATH was added into the PUF matrix, showing that besides increasing the flame resistance of the foam, it also raises the foam elastic resistance under compression load. The increment in σ_c was more than 100% for the 40% compared to the pure PUF. Furthermore, the compression modulus also presented high numbers for the ATH added foams than the pure one. However, unlike the σ_c , the compression modulus value increased up to 20% added ATH mass fraction. The PUF30ATH and PUF40ATH showed high standard deviation values in the elastic zone, it may be explained by the strain fields shown in Fig. 1.

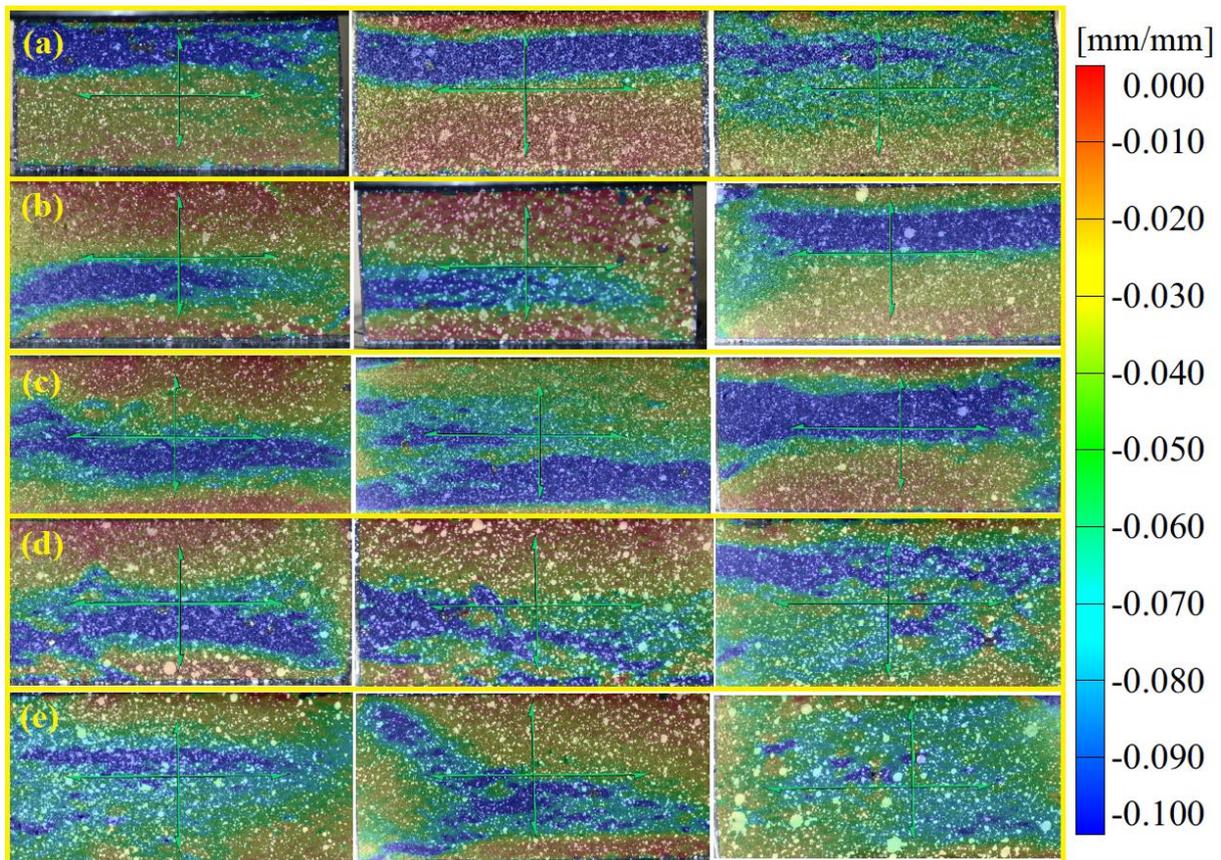


Figure 1 – Strain fields obtained from DIC for (a) PUF, (b) PUF10ATH, (c) PUF20ATH, (d) PUF30ATH, (e) PUF40ATH

Figure 1 brings three strain fields for each mixture. As it can be seen, the lesser was the amount of ATH added into the foam, the more the strain was concentrated in a layer. This may explain the smaller standard deviation for the lesser amounts of ATH added foams, since the materials with higher amounts of ATH presented strain fields with random behaviors. These random behaviors can be attributed to the arbitrary distribution of ATH inside the foam matrix.

CONCLUSIONS

Researches regarding bio-based PUFs are of great interest to the scientific academy, seeking to replace oil-based materials with environmentally friendly ones. The bio-based PUF used in this study showed good mechanical response under compression load when ATH was added into its polyol. The compression strength gain was over 100% for the PUF40ATH in relation to the pure PUF. The yield compression strain did not show a noteworthy change and the compression modulus was increased in the foam with up to 20% of ATH. The foams with the higher amounts of flame retardant presented compression modulus with relatively high standard deviations. This behavior was attributed to the

random distribution of ATH inside the matrix as it can be observed by the differences in the strain field between the foams with lesser amounts of ATH and the foams with higher amounts. Therefore, the ATH addition showed out as a good mechanical reinforcement under compression load, which may open new areas of application for bio-based PUFs since ATH is a good and inexpensive flame-retardant.

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