23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

# EVALUATION COMPRESSIVE RESISTANCE OF THE RIGID POLYURETHANE FOAM FILLED WITH GLASS POWDER

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***Abstract.*** *The PU expansion may result in rigid PUR foam commonly applied as thermal insulation. Glass is a material that has the highest chemical stability and, as a ceramic material, has good properties as a thermal insulator. The commercialization of glass by thermopanes requires machining processes for the finishing of the product; implying generation glass particles, or tailings. This waste is not availed by the recycling industry. So some research looks for a use of this glassy residue applied as filler and/or reinforcement materials. Thus, the polyurethane composites filled with glass powder were applied to compose the new rigid foam specimens, which can be used as a thermal insulator. In this work were made PUR foams filled with 100 µm and 300 µm GP particle sizes. The PUR composites consisted of 5 %wt, 10 %wt and 20 %wt GP contents. The study aimed to evaluate the PUR composite specimens by compression test. Results showed the addition of GP in PUR composites was positive to compressive resistance, which values were greater than PUR-Pure. Therefore the PUR compressive resistances were improved by GP content and its GP particle size. This implies greater economy, environmental preservation and improvement of the mechanical performance of PUR.*

***Keywords:*** *polyurethane composites, thermal insulation, glass powder, compressive resistance*

## 1. INTRODUCTION

According to ABQUIM (2010), polyurethane (PU) is seen as an expensive product, despite its benefits and durability in the medium and long term mainly when it is compared with its competitors, for example, polystyrene (EPS). The increasing consumption of this material brought like consequence the concern with the final destination of the waste, parings and burrs, which are results from the industrial processes (Stramari and Siqueira, 2004). Due to the physicochemical properties of polyurethane, this material became very expensive for storage in landfill. This is justified by its large occupied volume (low density) and its long time of decomposition of ≈ 150 years (Fischer, 2002)

When the PU is dumped in unsuitable locations such as dumps, rivers and hillsides, it causes a much greater impact on the environment. This contributes to the proliferation of insects and it impairs also the quality of life of living beings that inhabit these places (Motta, 2011).

As raw material of polyurethane foam (PUR) comes from petroleum, the not recycling of foam also represents a waste of non-renewable natural resources (Mello *et al.*, 2006). Thus, companies have done a restriction on the concept of growth and began to introduce the ecological issue as a fundamental criterion of business activities. Therefore, the sustainability was introduced to protect the environment and also to become a function of administration.

The properties of PUR can be manipulated to understand the different requirements of its application as: flexible, rigid, plastic, elastic or thermoset solid or foam (Demharter, 1998). The PUR is very useful because of its wide range of good properties, mainly as structural materials (high mechanical strength and toughness) and thermal insulation. The properties of PUR are strongly influenced by the structure, geometry and density of the foam, as well as adding, size and shapes of the loads on the PUR (Thirumal *et al.*, 2007).

The most important characteristics for all highly porous materials are the compressive strength and thermal conductivity. Such materials include porous foams, which are influenced by the structure/morphology of the pores,

resulting in a low density. Usually, materials with high porosity and small structure of regular cellular pore present the best characteristics to obtain the foams (Vladimirov et al. 2011).

The glass is fragile, inert, thermally insulating and non-crystalline material. Their properties depend on the structural features, which are subject to the concentration, chemical composition, interaction between its constituents, and to lesser extent, to thermal history of the material. Santos (2009) defended the reuse of the glass of dumps, or other inorganic material as a material addition to the array of more expensive materials with the purpose of make it viable ecological and economically. According to him, the use discarded glass can offer an numerous advantages such as the increase economy, reduction of garbage collection costs, environmental pollution and environmental natural resources.

Thus, added fillers to a matrix of the material can be used to simply reduce the cost (fillers) and / or improve the mechanical properties of tensile, compressive and abrasion resistance (i.e., reinforcing fillers) [Ghosh (2002) *apud* Thirumal e*t al*. (2007)].

Santos (2009) studied the use of glass in the production of new composite materials and he concluded, through his work on sintering of glass powder (GP), which, as the average particle size was reduced (98.6 μm; 30.7 μm; 14.9 μm), the greater was its chemical reactivity due to increased surface energy. From this analysis, it was also observed that the initial temperature of shrinkage during the sintering process was directly proportional to the size of these powders. Consequently, there was a reduction of energy consumption and environmental impact caused by gases generation.

Tsai et al. (2007) developed a PUR composite material with hollow fiber of polyester (PET) treated with flame retardant. In the preparation process of the composite, the PU reacted and expanded between two webs of polyester, conformed into a closed mold. Some studies evaluated the effect of adding fibers and / or fabrics PUR and concluded that, by finding ideal fiber content, the mechanical strength, the hardness and the impact resistance of the foam increased (Bledzki et al., 2001 cited Yang et al., 2004).

Knowing that the particle size and percentage of filler material can influence the mechanical properties of PUR, this work aimed to investigate through mechanical compression tests (NBR 8082 - 1983) the resistance of PUR filled with GP in the proportions by mass of 5 %wt, 10 %wt and 20 %wt with $D_{90}$ particle size of 50 μm and 320 μm.

## 2. MATERIALS AND METHODS

This work was accomplished through the development of seven types of PUR specimens filled and not filled with glass powder (GP) to investigate their resistance to compression. The minimum curing time was set at 40 hours, and the mixture PUR and GP was shaped in rectangular molds (10 *7 * 8 $cm^3$). Five specimens PUR pure (not filled GP or like reference standard) and filled with GP specimens were classified according to Tab. 1. It shows the mass percentage and GP particle sizes. To each type of specimen there were five replicates. The PU, originated petroleum, was purchased commercially while the GP, obtained from faceting of glass, was ceded by DVN Vidros LTDA of Natal / RN.

Table 1. Description of specimens of PUR filled with GP.

| Specimen | Description |
|---|---|
| PUR-Pure | PU foam filled without glass powder |
| PUR5-100 | PU foam filled with 5 %wt glass powder, particle diameter 100 μm |
| PUR5-300 | PU foam filled with 5 %wt glass powder, particle diameter 300 μm |
| PUR10-100 | PU foam filled with 10 %wt glass powder, particle diameter 100 μm |
| PUR10-300 | PU foam filled with 10 %wt glass powder, particle diameter 300 μm |
| PUR20-100 | PU foam filled with 20 %wt glass powder, particle diameter 100 μm |
| PUR20-300 | PU foam filled with 20 %wt glass powder, particle diameter 300 μm |

The mechanical resistance of these specimens were evaluated by compressive resistance tests using a universal testing machine SHIMADZU, model AUTOGRAPH AG-X 300KN, with compression capacity of 284 kN, available in the Laboratory of Mechanical Testing of NTI at the Federal University of Rio Grande do Norte (UFRN). The manufacturing process of specimens followed the following stages:

1 - Grinding of the waste glass with the aid of mortar and pistil.
2 - Using the ball mill with alumina balls to reduce the grain size.
3 - The hand sieving to obtain two particle sizes (small and large).
4 - Analysis and classification of the average particle size by laser granulometer.
5 - Preparation of rectangular molds (10 cm x 7 cm x 8 cm) for the fabrication of specimens.
6 - Weighing the reactants A-Polyol and B-Isocyanate (weight ratio 1:1), and the GP to obtain the specimens of the PUR filled with glass powder using a precision balance Bel Engineering, capacity maximum 1000 g ± 0.001 g, available on the LMF of NTI / UFRN.
7 - Removal of the specimens of the molds.

Figure 1 illustrated the process obtaining of GP and fabrication in lab of specimens, i.e. the obtaining of PUR filled with GP. The curing time was set in 48 hours (according to NBR 8082/83) before these specimens were evaluated by compression tests. After the sieving of GP, average particle sizes were measured using CILAS 1180 laser granulometer (0.04 μm – 2,500 μm).

Figure 1. Process fabrication steps of the specimens

### 2.1 Compression resistance test

The compressive resistance test followed the procedures of NBR 8082/83. After applying of 5 N pre-load, the speed of compressive load application was maintained at 0.25 cm/min. The criterion of final test was determined with a 10 %wt reduction in the PUR (and filled with GP) specimen during test, as shown in Fig. 2.


Figure 2. Application of (a) preload and (b) compressive load in the specimen

Test results were stored as stress-strain graphs and they were calculated according to Eq. 1 (Hook´s law):

$$R_C = \frac{F}{A} \tag{1}$$

where: $R_c$ = compressive resistance at 10 %wt deformation (Pa);
$F$ = maximum recorded load (N);
$A$ = cross-sectional specimen area (m²).

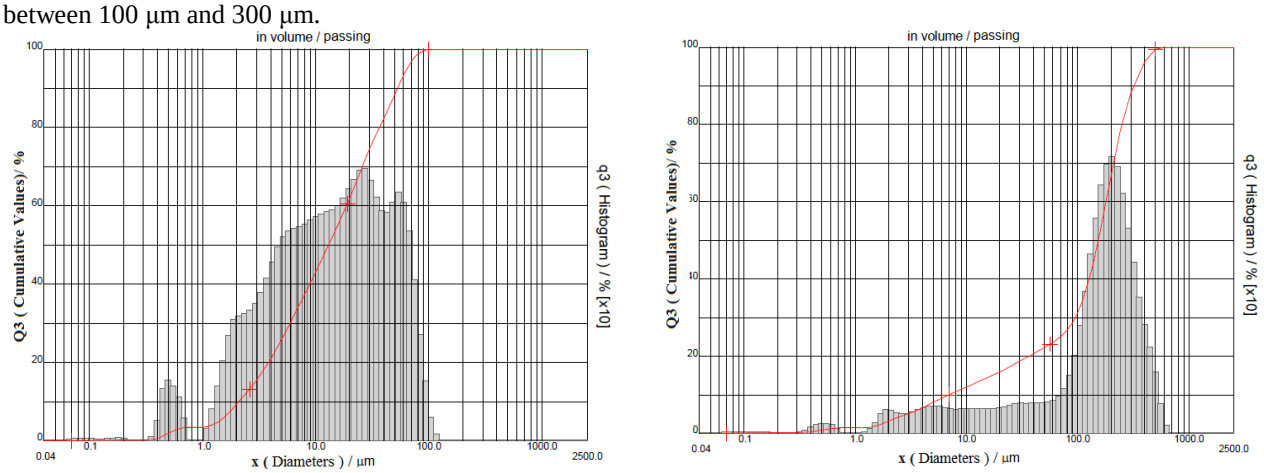
## 3. RESULTS AND DISCUSSION

### 3.1 Evaluation of medium GP size particle

The evaluation of the compressive resistance of PUR filled with GP was discussed considering the weight content (5 %, 10 % and 20 %) and size (100 μm and 300 μm) of the GP particles. Figure 3 shows two graphs generated by laser granulometer to evaluate the small and large GP particles.

The GP particles were classified according to average diameters obtained at 10 %, 50 % and 90 % of cumulative values, which are represented by $D_{10}$, $D_{50}$ and $D_{90}$ respectively. Thus, the measured $D_{90}$ diameter value was 52.80 μm (small particles) and 320.45 μm (large particles).

It is noted that there is a greater dispersion between the values obtained for small particles. This occurred because the sieving was selected for particles < 100 µm whereas in the case of large particles, they were retained in a range between 100 µm and 300 µm.




(a) small particle (b) large particles

Figure 3. Histograms of cumulative values to the (a) small and (b) large particles

### 3.2 Compressive resistance results

The test of resistance to compression is useful to estimate the maximum mechanical resistance of the specimens while applying a compressive axial load. Figures 4 and 5 show the stress-strain graphs for the 35 specimens that were analyzed according to their GP weight content (0 %, 5 %, 10 % and 20 %).

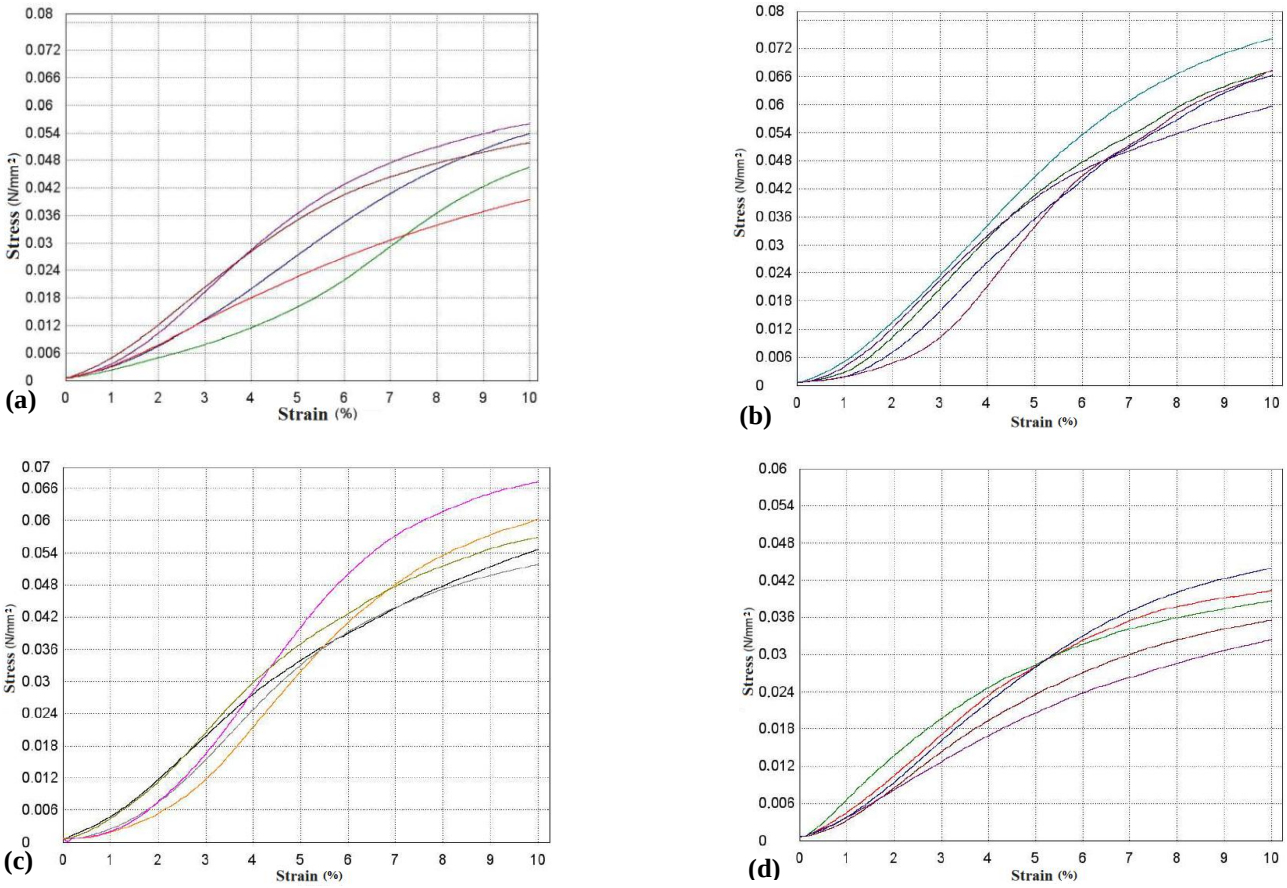



Figure 4. Graphs of stress-strain of the specimens of (a) PUR-Pure and PUR filled with GP ($D_{90}$ 52.80 µm) at (b) 5 %wt, (c) 10 %wt and (d) 20 %wt

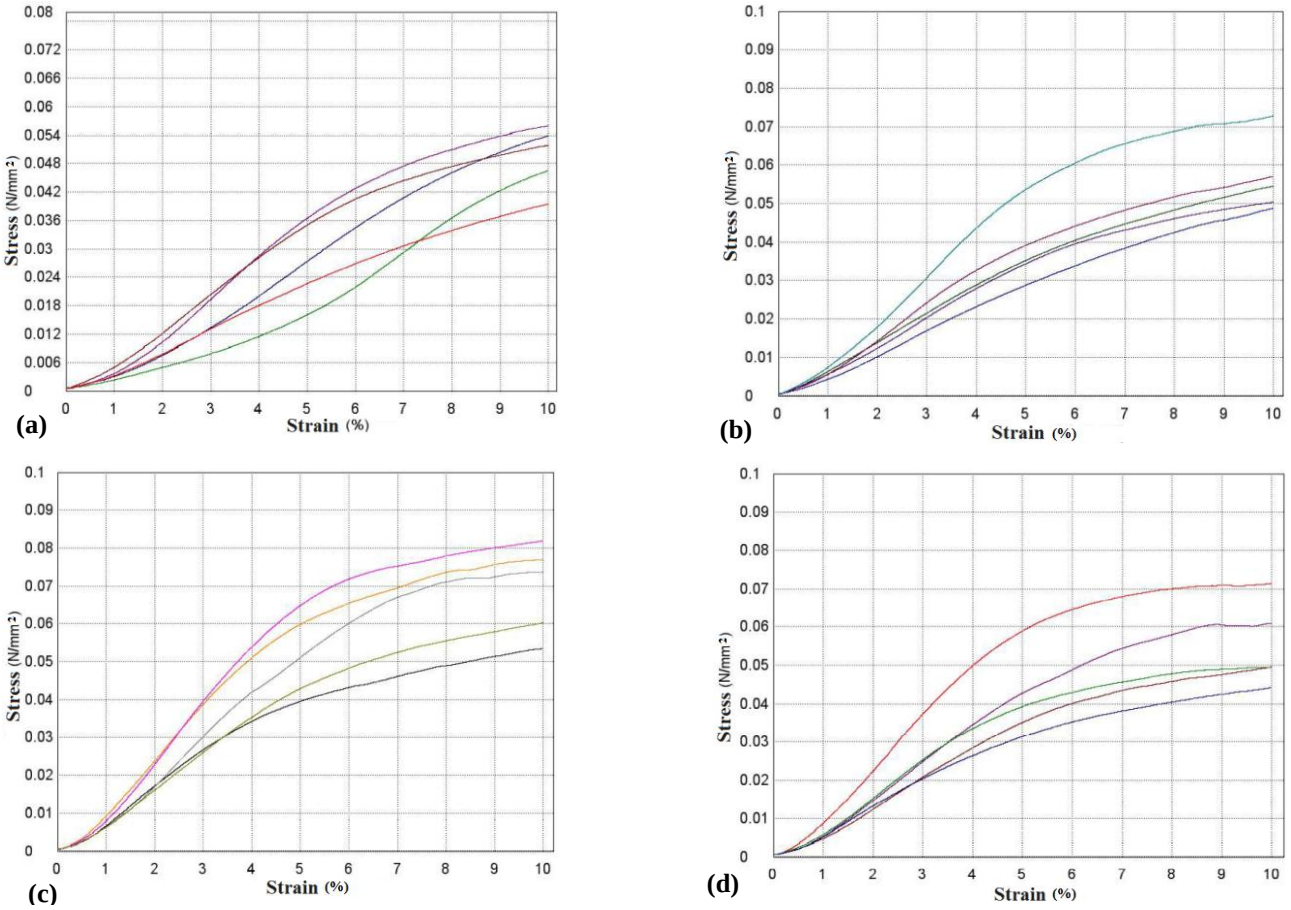



Figure 5. Graphs of stress-strain of the specimens of (a) PUR-Pure and PUR filled with GP (D90 320.45 µm) at (b) 5 %wt, (c) 10 %wt and (d) 20 %wt

Figure 4 presents the results of compressive resistance to the PUR specimens filled with GP ($D_{90}$) 52.80 µm. Figure 5 shows the PUR specimens filled with GP ($D_{90}$) 320.45 µm. The graphics in the Fig. 4 (a) and Fig. 5 (a) are equal and refer to the stress-strain curves for the PUR-Pure specimens (reference standard). Saha *et al.* (2008) studied the effects on thermal and mechanical performance of PUR, derived petroleum, caused by the addition of three types of nanoparticles ($TiO_2$, nanoclay and carbon nanofiber - CNF). They found that PUR filled with CNF showed the best results, and PUR/$TiO_2$, the worst results in all tests. The addition of only 1 % CNF promoted an increase of 86 % in the storage modulus, 40 % in the compressive resistance and 45 % in flexion resistance, besides increased the decomposition temperature of 18 °C.

Table 2 summarizes the average values of compressive resistance to the tested specimens. As is noted, the PUR20-100 showed the worst performance of mechanical resistance. The other kinds of specimens showed greater resistance than the PUR-Pure to both $D_{90}$ sizes (52.80 µm and 320.00 µm). However, the resistance values obtained for all the specimens are almost a same range (50 kPa – 69 kPa). Thirumal *et al.* (2008) studied the addition of expandable particle graphite (EG) on the PUR matrix at concentrations of 5 to 50 %wt, whose particles measured between 180 and 300 µm. They found that, with increasing proportions of EG, decreased compressive resistance. The PUR filled with large EG particles obtained better results. Thus, the small particles were poorly dispersed and formed aggregates, which led to a heterogeneous cell structure, resulting in low mechanical properties.

Table 2. Compressive resistance values of PUR filled with GP.

| Specimens | Values (kPa) |
|---|---|
| PUR-Pure | 50±7 |
| PUR5-100 | 67±5 |
| PUR5-300 | 57±10 |
| PUR10-100 | 58±6 |
| PUR10-300 | 69±12 |
| PUR20-100 | 38±4 |
| PUR20-300 | 55±11 |

In their work, Thirumal et al. (2010) added alumina trihydrate (ATH) and triphenylphosphate (TPP) on PUR. The compressive resistance of PUR increased only filled with 50% ATH, but when it was filled with 50 % ATH and 10 % TPP, this property decreased due the plasticizing effect of TPP with ATH. Those literatures show that the interaction between the matrix and filled charges is not always positive. So in this study, PUR20-100 presented a decreased of compressive resistance at least 24 % in relative to PUR-Pure. It is noted that when was used PUR filled with GP specimens at $D_{90}$ 52.80 μm, the increasing of GP content favored a decrease of compressive resistance. So the use of only GP 5 %wt showed the highest mechanical resistance of all the PUR. In the group of GP $D_{90}$ 320.45 μm, addition of GP 10 %wt in the PUR contributed to rising of compressive resistance, whereas PUR filled with GP 5 % to 20 % promoted a lower increasing of compressive resistance.

In general, these results infer that 5 %, 10 % and 20 % GP weight contents on PUR matrix increased the compressive resistance of these specimens. Thus, these charges acted as much charges as much reinforcing. Therefore, this justice using GP with polyurethane to reduce the final cost of PUR applied for the purpose of thermal insulation.

## 4. CONCLUSION

1. 1. When comparing the results obtained with the compression test, the PUR specimens filled with GP exhibited a higher compressive resistance compared to PUR-Pure specimens. Thus, the GP addition of 5 %wt, 10 %wt and 20 %wt GP contents resulted in increased compressive resistance of PUR, thus the glass powder acted as filler as reinforcing material.
2. The particle size of GP influenced to the mechanical resistance; so the larger particles provided highest compressive resistance of the PUR specimens, except of PUR5-300.
3. Among the percentage studied, the 10 %wt GP content was that it contributed more to the increase in the resistance of the PUR specimens, which the values were 58 kPa (PUR10-100) and 69 kPa (PUR10-300). When used 20 %wt GP content, its compressive resistance had a less reduction, especially for PUR20-100 whose value was lower than the PUR-Pure specimens.
4. Concluded that the glass powder addition on rigid polyurethane foam was viable and satisfactory to the increase of the compressive resistance of the PUR composites. This can help to reduce the costs and the environmental impacts arising of PU feedstock, since the using of glass powder waste can be reused, and could spare more polyurethane.

## 5. ACKNOWLEDGEMENTS

We would like to thank the CAPES (Coordination for the Improvement of Higher Education Personnel), DVN Vidros LTDA, LMF (Mechanic of Fluids) and Mechanical Tests laboratories of Federal University of the Rio Grande do Norte.

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