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POLYURETHANE WASTE UTILIZATION

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ABSTRACT. Following the explosive development of industrial processes in recent decades, society began to feel more and more the need for efficient measures to prevent pollution on a global scale, or finding new, or alternative resources. Such a measure is to reuses as much material as possible, that we now consider waste or residue, to reduce the consumption of resources, especially non-renewable resources. In this regard, the paper presents a way to recycle polyurethane waste and obtaining a composite material by mixing it with a fresh polyurethane adhesive and quartz sand in different proportions. The polyurethane wastes thus become a substitute for pure polyurethane, and the obtained mixture may be used for manufacturing construction materials. The samples were studied in terms of physical properties and behavior under the action of some environmental factors.

Key words: *waste and polyurethane foams, polymeric composite materials, construction materials, insulation materials.*

INTRODUCTION

Polyurethanes (PU) are synthetic polymers produced by the polyaddition reaction of a diisocyanate or a polymeric isocyanate with a diol or polyol, in the presence of catalysts and additives. A virtually unlimited number of chemical structures can be obtained under the name of PU, the only condition being the presence of urethane group within the macromolecular chain at certain intervals. Urethane group is formed, usually by the reaction between the isocyanate and the hydroxyl group, although it may be formed from phosgene and di- or polyamines in some special cases (Sharmin and Zafar, 2012).

Due to the multitude of possible chemical structures and arrangement of molecules in the chain structure, PU is a good example of polymer with guided structure in order to obtain a wide range of materials with channeled physico-chemical properties (controlled structures). The properties of polyurethanes (thermoplastic or thermoset) depend largely on their macromolecular structure, i.e., the nature and macro functionality monomers constituents (Xu et al., 2008). PU can be obtained in a wide range of variations of the physico-chemical properties. The main types of PU are rigid polyurethane, flexible polyurethane (elastic PU), thermoplastic polyurethane and porous polyurethane (Kapps and Bushkamp, 2004).

This material is extremely versatile in structure and properties, combines the elasticity of rubber with the durability and strength of metals, which allows its use as a substitute for the long-term replacement of materials such as plastic, rubber or some metals, required in highly stressed environments. Due to the unique properties they possess such as tensile strength, tear, compression, high hardness, high elongation at break and a high elasticity modulus, polyurethanes are employed mainly as construction materials, thermal and acoustic insulation, for filling inoperative gaps, as adhesives, in textile industry, as material for packaging of sensitive and high-priced products, in footwear industry, in mining and ore processing, transport, paper and pulp processing, energy and sports equipment, (Goods et al., 1997; Kojio et al., 2010; Mounanga et al., 2008).

PU world consumption is steadily increasing due to their various use and advantageous economic properties, (Priscariu, 2011). Uses of PU is also reflected on their main components, especially isocyanates, polyols, auxiliary substances, catalysts, or substances used in producing rigid foams, fibers, paints and varnishes, elastomers, automotive applications in car body repair and as insulating building materials. Polyurethane "spray-on" type of products containing isocyanate, are used as protective coating for concrete, wood, fiberglass, steel and aluminum (Böer et al., 2014).

The increasing use of polyurethane products resulted in increased quantities of PU waste, which must be processed. Currently, there are three methods available for waste processing, respectively incineration, disposal to landfill and recycling or reuse. Of these, recycling and reusing materials offers the best solution in terms of the impact on the environment and human health, since there is no waste that cannot be salvaged or toxic gases after processing them. The most effective methods of recycling and destruction, both physical and chemical, must ensure not only compliance with safety and environmental pollution prevention, but also lowering the production costs of materials obtained from recycled PU (Howarth, 2003; Yang et al., 2012; Zevenhoven, 2004).

EXPERIMENTAL PART

The experimentation aimed to achieve a method in which polyurethane wastes are reprocessed by mixing them with fresh polyurethane adhesive and quartz sand, thus generating a new composite material that can be used as a substitute for pure polyurethane in the building materials industry. The method used for recycling the polyurethane waste involves, in a first phase, the modification of the size and shape of the material. Experimentally it has been observed that crushing and shredding wastes are effective methods to recycle and reuse thermosetting materials.

For the next step, the working procedure consisted of physico-mechanical treatment of crushed PU wastes, by using a filling material, such as a polyurethane adhesive for binding the particles to each other, under continuous stirring to obtain the samples. The work stages are presented in the operating scheme (figure 1).

During experiments were used the following materials and equipment: polyurethane foam, polyurethane adhesive, quartz sand fraction 0.1 - 0.62 mm, plastic molds (petri dish), mold release agent, mixer with rotating blades, analytical balance and a heating oven.

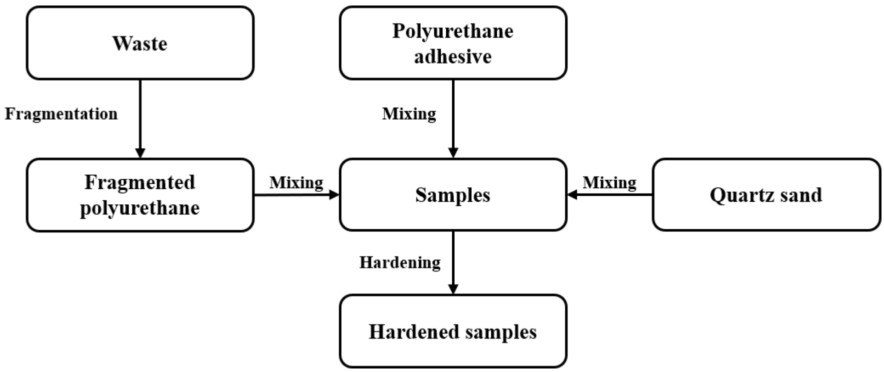

Fig. 1. *The operating scheme.*

The polyurethane waste (figure 2a) was fragmented with the aid of a cutting type mixer with rotating blades and speed control (figure 2b), after which it was mixed with a polyurethane adhesive (samples 1 - 5) and quartz sand (samples 6 - 10) in different proportions. The mixture was then poured into molds and held 4 days to cure at 32 - 35 °C, after which they were removed from the molds (figure 2 c - d).

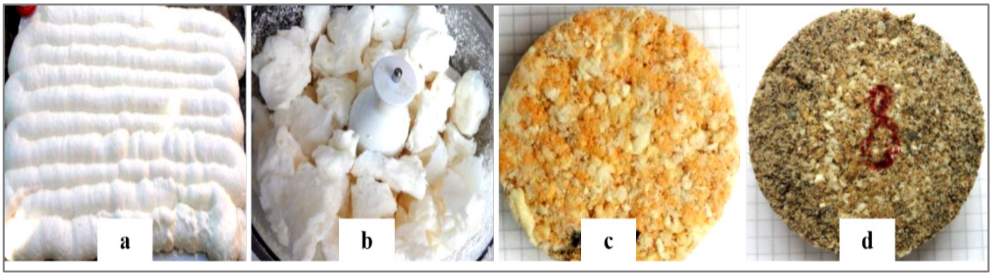

Fig. 2. *a. Waste from polyurethane foam. b. Material fragmentation. c. The hardened sample from the mixture of PU waste and PU adhesive. d. The hardened sample from the mixture of PU waste, PU adhesive and sand.*

To obtain the optimum mix of adhesive and fragmented polyurethane material, attempts were made to obtain a homogeneous mixture in a short time. The experiments have been carried out in three different modes by using the same amounts of material. In first method, the crushed material was added onto the adhesive and then the mixture has been stirred continuously, then during the second method, over the shredded material, the adhesive was poured out under continuous stirring, and last, the shredded material and the adhesive were simultaneously added while constantly mixing them together. The last method has provided the best results to get in a short time a homogenous material on a macroscopic scale.

For each sample, the apparent density was determined. All samples were immersed next in water and maintained immersed for 7 - 14 days to determine the liquid retention inside the material.

RESULTS AND DISCUSSIONS

The recycling method is simple and easy to implement, and the costs are relatively low. The best results regarding the hardening of the adhesive and the quality of the final material were obtained at a temperature between 32 - 35 °C for 4 days, (table 1). Before pouring the mixture into the molds, they were covered with the release agent to prevent the samples from sticking to them.

Samples 1 - 5 were prepared by making homogenous mixture of PU waste material and freshly PU adhesive in different proportions (table 1). The samples were left to harden in plastic molds inside the oven at 32 °C for 4 days. It has been observed that the polyurethane material was cured completely into the mold. Samples 6 - 10 were prepared by mixing the crushed PU waste material in plastic molds with fresh PU adhesive and sand in varying proportions (table 1) to obtain a homogenous mixture. All samples were kept in the oven to harden at 35 °C for 4 days. Adding sand to the mixture made the mixing process more difficult due to the high density and small grain size. In addition, the sand tends to flow preferentially towards the bottom of the container during mixing.

In the samples in which the adhesive was first poured, then the crushed PU waste and sand were added, even with continuous mixing, as a result a strong agglomeration of sand in the mixture was observed. By simultaneous addition of shredded material, sand and the adhesive under constant stirring, we obtained the best results in terms of homogeneity of the material, the strength of the material and the ease of sample detaching from the molds.

Table 1. *The quantities of material and parameters used experimentally.*

Sample	PU waste (g)	PU adhesive (g)	Quartz sand (g)
Sample composition: PU waste, PU adhesive Curing temperature: 32°C; Duration of hardening: 4 days			
1	1	4	0
2	3	4	0
3	5	5	0
4	7	5	0
5	10	6	0
Sample composition: PU waste, PU adhesive, quartz sand Curing temperature: 35°C; Duration of hardening: 4 days			
6	2	3	5
7	3	3	7
8	5	4	9
9	6	6	10
10	7	6	11

After removing the hardened samples from the molds, from each sample a small amount of material of about 1 cm^3 was removed and their apparent density were determined (table 2). Next, the samples were immersed in water and kept for 7 and 14 days, to determine the liquid retention (table 2). It was found that with the increase in the amount of waste that was added to the composition, the apparent density also increased. This effect was also assumed to be due to the higher density of the adhesive. Water retention after 7 days is higher for samples with a higher percentage of waste, which is acceptable considering the higher porosity of the material. As expected, the water retention after 14 days is even higher, due to the water-soaking phenomenon of the porous material. After the 14 days, the water retention in the samples becomes insignificant.

Table 2. *Apparent density of samples and water retention.*

Sample	Density (g/cm^3)	Water retention after 7 days (g)	Water retention after 14 days (g)
Sample composition: PU waste, PU adhesive			
1	0.041	0.11	0.19
2	0.065	0.14	0.29
3	0.092	0.27	0.45
4	0.121	0.45	0.55
5	0.158	0.54	0.58
Sample composition: PU waste, PU adhesive, quartz sand			
6	0.258	0.22	0.56
7	0.297	0.33	0.80
8	0.324	0.41	0.84
9	0.407	0.55	0.83
10	0.469	0.62	0.86

CONCLUSIONS

The experimental study proposed the implementation of a practical solution regarding the recovery of polyurethane waste and its reuse trough physical-mechanical methods to obtain a composite material that could be used as an insulating material in constructions. Experimentally, various proportions of materials were used to create samples: PU waste, PU adhesive and quartz sand. The best results were obtained for the samples in which the simultaneous addition of the shredded PU waste and PU adhesive was carried out, under continuous mixing. Samples 3 – 5, which contain a mixture of PU waste and PU adhesive, are similar in appearance, uniformly hardened and homogenous. In samples containing sand, as the amount of sand increases, the homogeneity of the samples decreases. The samples that contain a larger amount of quartz sand show a higher brittleness (samples 9-10).

From an economic point of view, it is preferable to use the mixture of PU waste and fresh PU adhesive instead of fresh PU foam. The mix can use a large amount of PU waste, which can serve as a substitute for fresh PU foam, but requires the addition of PU adhesive, which has a lower cost comparing to PU foams and as a result, the raw material costs decrease considerably.

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