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Application of Ground Rigid Polyurethane Waste as Filler in Production of Flexible Polyurethane Foam

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Abstract: *Incorporation of rigid polyurethane foam waste to pure polyol foam for the production of foams has been investigated. The polyurethane foam waste ranging between 1 and 10% was blended with the pure polyol. Subsequently, the blended mixture was cast into a metallic mould and mechanical tests were performed on the samples. Incorporation of polyurethane foam waste into pure polyol foam resulted in materials of satisfactory mechanical properties. Addition of the filler materials inhibited better density, compression set, hardness, load-bearing capacity and % elongation-at-break compared to the pure polyol. From the results of thermal conductivity of the blended foams, it was observed that thermal insulation property was improved. In addition, the particle sizes of the polyurethane foam waste played significant role on the mechanical properties of the blended foams - each of the mechanical properties improved as the filler size got smaller. The results of this study showed that polyurethane foam waste can be successfully used as filler materials to improve mechanical properties and reduce production cost of flexible polyurethane foam.*

Keywords: *Compression set, density, load bearing capacity, polyol, polyurethane foam waste.*

1. INTRODUCTION

Polyurethane foams are amazingly versatile and the ways to which we put them to use are limited only by human imagination. Flexible polyurethane foams affect our lives in many ways and new applications are rolling out on a regular basis. It is used in a wide variety of consumer and commercial products including furniture, carpet, transportation, bedding, packaging, textiles, insulation and fabrics. New developments in the production and uses of polyurethane foam means it will continue to offer design, safety and environmental benefits [1]. Despite the versatility and numerous uses which polyurethane foams are put, the management of wastes generated through their production processes has been a major challenge, which requires serious attention [2]. Figure 1 shows the statistics data from China Polyurethane Industry Association. The data have shown that polyurethane products yield grows rapidly, in 2000 the annual output was 1 million tons, 3.5 million tons in 2007 and 7.5 million tons in 2011 [3]. A large portion of these annual productions resulted to waste.

Waste management has been a major challenge in Nigeria and the World in general due to problems of increasing waste generation and poor management. There are mainly three types of disposal technology, landfill, incineration and recycling in the world. Day to day open incineration and landfill sites of wastes generated has caused pollution, which has brought about the depletion of the ozone layer because of greenhouse gas emission [4]. A recent case is the development at the Olusosun landfill site Ojota, Lagos, Nigeria where massive air pollution erupted [5]. This form of pollution resulting from poor waste management has been regarded as a major factor leading to climate changes all over the world [4]. It is therefore, pertinent to judiciously minimise the quantity of waste generated by either recycling or putting them to alternative uses.

Studies have been carried out on the uses of polyurethane foams. The effect of local fillers; rice husk and corn cob on some physico-mechanical properties flexible polyether foam has been investigated [6]. They demonstrated that the mechanical properties of the filled foams improved significantly. In a similar study by [7], coir fibres and tyre particles were used as fillers for the reinforcement of the flexible polyurethane. Rigid polyurethane foam composites with vegetable filler for application in the cosmetics industry has been developed [8]. The particle sizes and chemical structure of the vegetable filler played significant role on the mechanical properties of the biocomposite fabricated. [9] investigated the optimum calcium carbonate filler concentration required for the development of polyurethane foam composite.

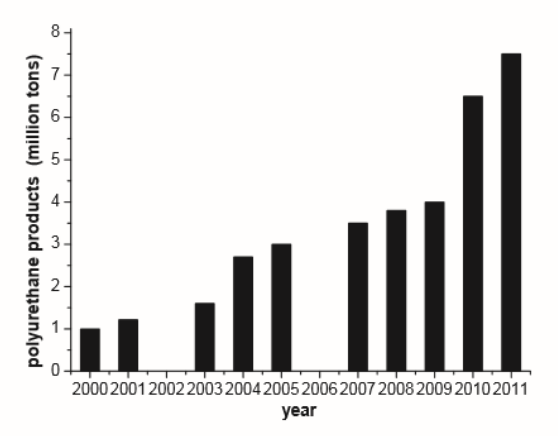

Figure 1: Annual production of polyurethane in China

(Yang *et al*., 2012)

They concluded that 20 wt% of calcium carbonate is sufficient to achieve 18.54% cost reduction of production. Physico-chemical analysis of flexible polyurethane foams containing commercial calcium carbonate was also studied. The foams are submitted to the morphological, mechanical and positron analyses to verify the alterations provoked by the progressive introduction of this filler [10]. Morphological, mechanical and thermal behaviour of foamed polyurethane composite reinforced with ash has been studied [11]. Results of the research show that fly ash can be used to enhance thermal properties in polyurethane foams, enhancing the economical aspect of the production through the decrease of material's density and incorporation of low cost filler.

Considering the large quantity of rigid polyurethane foam wastes available in Nigeria, it is imperative to use it for other purposes not only to reduce waste and green house emission but also a way of cutting down the cost of production. The objective of this study therefore is the production of flexible polyurethane foams from the ground rigid polyurethane waste foams.

2.0 MATERIALS AND METHODS

2.1 Materials

The ground rigid polyurethane foam waste, conventional polyol (134.4 MT) and toluene diisocyanate (TDI 80/20 – 100MT NET) were obtained from Vital Foam Nigeria PLC Lagos, Nigeria. Table 1 shows the specification of these materials. Other procured materials are silicone oil, amide, water, methylene chloride and stannous octoate (tin catalyst).

Table 1: Specification of the materials used

Convectional Polyol 134.4MT			**Toluene Diisocyanate (TDI 80/20 – 100MT NET)**		
Property	Unit	Value	Property	Unit	Value
Hydroxyl valve	mg/g	48.00	Purity	%	99.90
Viscosity	CPS	525	Hydrolysable chloride	WT.PPM	29.40
Acid value	mg/m	0.01	2, 4 – Isomer	Wt (%)	79.79
Moisture content	%	0.03	Acidity or HCl	WT.PPM	2.90
Unsaturation	mg/g	0.03			
Appearance	-	Clear			

2.2 Equipment and apparatus

Beakers, reagent bottles, conical flasks, measuring cylinders, conical flasks, sieves of various sizes, IFD Foam Tester (Serial #2120074-1), plastic container, compression sets, tape rule, markers, weighing balance, plastic cups, automatics stirrer and metallic box container.

2.3 Samples preparation

Table 2 shows the foam formulation for the pure polyol (super soft) without the filler material (polyurethane foam waste) addition. Table 3 shows the foam formulation for the polyol with the addition of filler material. The obtained ground rigid polyurethane foam waste and pure polyol were sieved according to International Organisation for Standardisation (ISO) 13909-44:2001 specifications. The materials were measured with an electronic weighing balance and poured into a separate plastic container. Subsequently, pure polyol, methylene chloride, stannous octoate, water and amine were mixed with a stirrer. Finally, tolune diisocyanate was added and stirred for 5 seconds and then poured into metallic mould for solidification. Similar process was ensured for the preparation of foam with addition of polyurethane foam waste.

2.4 Mechanical testing

In this study, the mechanical properties of the foam samples were carried out using standard methods: density, compression set, indentation force deflection (hardness). The density of the sample was determined by dividing the mass of each the samples by their corresponding volume of the water displaced. The compression set test was conducted according to ASTM B3575. Hardness test was conducted by cutting a sample of foam 380 mm x 380 mm x 50 mm and testing it on the IFD Foam Tester (serial No 2120074-1). Three (3) measurements were taken for each sample and the mean hardness determined. Tensile test and thermal conductivity were performed according to ASTM T3575 and ASTM V3575 standard respectively.

Table 2: Foam formulation for pure sample (super soft)

Materials	Quantity (Parts per grams)
Polyol (134.4 MT)	100.00
Toluene diisocyanate	52.00
Amine	4.20
Silicone oil	0.30
Methylene Chloride	1.00
Water	5.00
Stannous octoate (tin catalyst)	0.16

Table 3: Foam Formulation using 300, 600 and 700 µm (other constituents were added in the same proportion as in Table 2)

	1 % powder	2 % powder	3 % powder	4 % powder	5 % powder	6 % powder	7 % powder	8 % powder	9 % powder	10 % powder
Polyol (±0.02)	495	490	485	480	475	470	465	460	455	450
Filler (±0.02)	5	10	15	20	25	30	35	40	45	50

3.0 RESULTS AND DISCUSSION

Figure 2 shows the responses of the densities to the filler addition. It can be observed that the density of the forms almost the same with the super soft (0% filler concentration) at 6 % filler addition. However, significant improvement in the density can be seen when filler addition was above 7 %. Similar trend was seen for the three sieve sizes of 300, 600 and 710 µm investigated. The improved density of the foam was due to the addition of the filler. This implies that addition of filler enhanced the collapsibility and market value of the foam greatly - since density is an indicator of the load bearing capacity and price-determining factor of the polyurethane foam. Thus, addition of the polyurethane foam waste to pure polyol foam improved the density and reduced the cost of production of the foams. This is in agreement with previous studies by [1, 9].

Figure 3 shows the responses of the compression set to the filler addition. It was observed that increase in filler load enhanced the compression strength of the foam samples. Similar trend can be seen for all the seive sizes studied. This is attributed to the ability of the filler to fill the voids presence in the polyol foam and thus promote an increase in resistance of the foam to compression load and increase ability to regain its position [12]. The ability of the form to resist compression load which enhance the durability and prevent easy collapsibity during service improved with filler addition. This is also in agreement with previous studies [9].

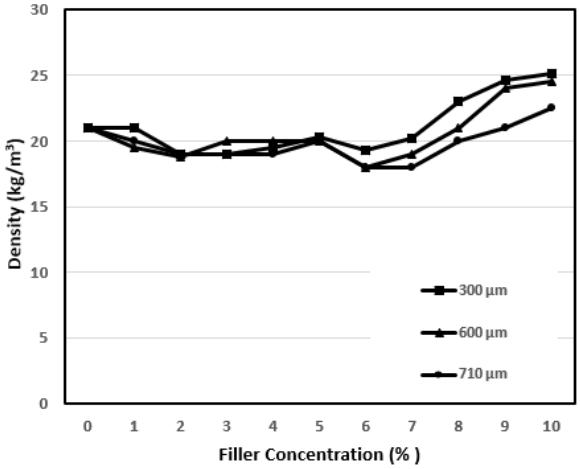

Figure 2: Responses of foam density to the filler concentration addition

There is an agreement between the results of the density and the compression set, as shown in Figures 2 and 3 respectively. As can be seen, there is a better performance of the filler with the range of 6 % to 10 % filler addition.

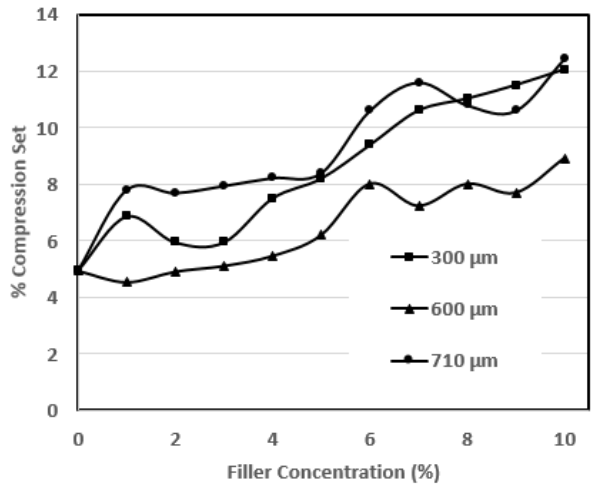

Figure 3: Responses of foam compression set (%) to the filler concentration addition

The steadfastness of every foam is measured by their resistance to indentation force deflection (IFD) [12]. Addition of filler to the pure polyol was seen to be beneficiary, as shown in Figure 4. The hardness values of the reinforced foams were seen to be higher than that of the control sample (0 % filler addition). This implies that addition of filler to the polyol foam will enhance the hardness property of the foam positively. The developed foam will possess load carrying ability without failure in service.

Figure 5 shows the responses of the tensile strength of the foams to the filler addition. Below 4 % filler addition, it can be seen that the tensile strength increased as the filler material increased. However, above 5 % filler addition, there is a slight reduction in the tensile strength property of the foam. In general, filler addition enhanced the tensile strength property of the foam due to good wetting that occurred between the filler, reinforcement phase and polyol, matrix phase. In addition, the particle size of the filler is another important factor that may enhance the tensile strength of the foam. Material with large particle sizes is more rigid than small particle size of the same volume. This could be the reason for higher tensile strength seen for the foams of 710 µm.

Figure 6 shows the % elongation at break with addition of filler materials. At filler addition less than 5 %, the % elongation increased. A decrease in the % elongation-at-break was observed as the filler material increased above 5 %. The initial increase in % elongation-at-break was due to homogeous distribution of the filler, especially at 300 µm. When the quantity of the reinforcement phase is relatively low and uniformaly distributed, there is a greater tendency of matrix phase (polyol) to elongate. Thus, the influence of filler material on the polyol to reduce % elongation-at-break was not seen. However, with a higher filler ratio than polyol ratio, the effect of fller became significant.

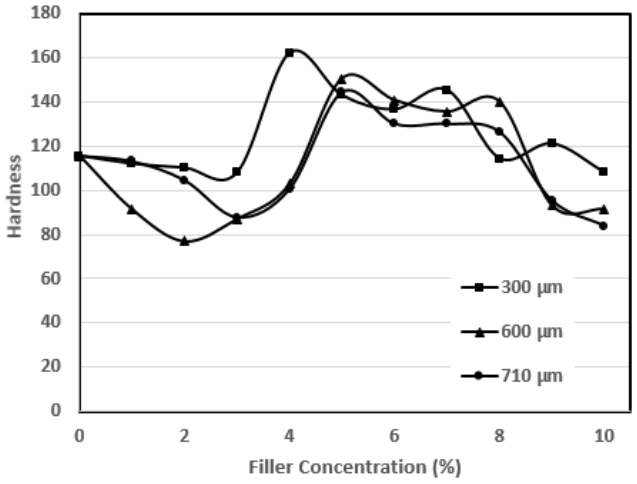

Figure 4: Responses of foam hardness to the filler concentration addition

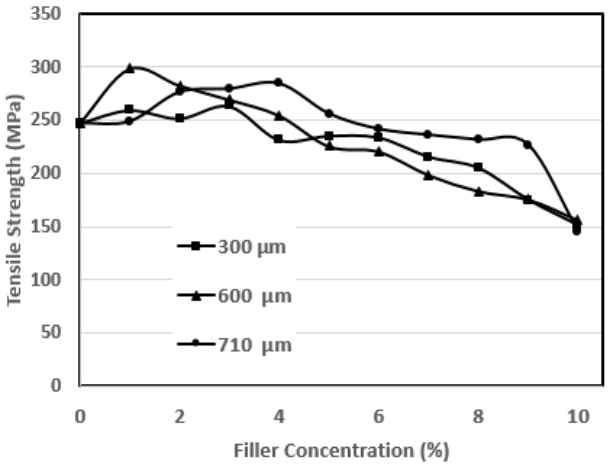

Figure 5: Responses of foam tensile strength to the filler concentration addition

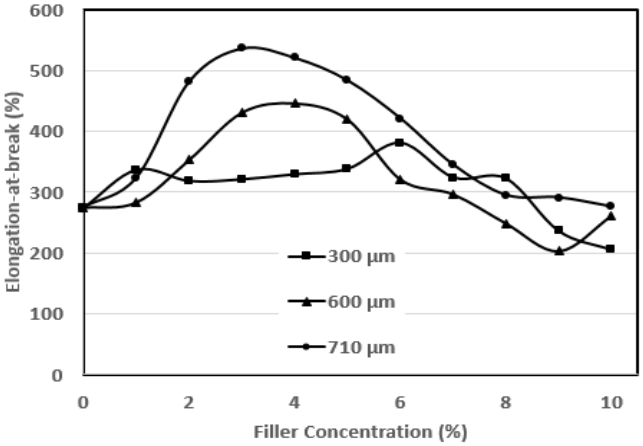

Figure 6: Responses of foam elongation at break to the filler concentration addition

Thermal conductivity of foams indicate the level of ignition that can be achieved. Figure 7 shows the dependence of the thermal conductivity on the filler. Thermal conductivity of the foams decrease with increasing filler concentration. This trend was achieved independent of the filler particle sizes. This implies that the fire resistance of the foams produced is higher than the pure polyol. Therefore, the foam produced cannot be easily flammable and/or will not support combustion.

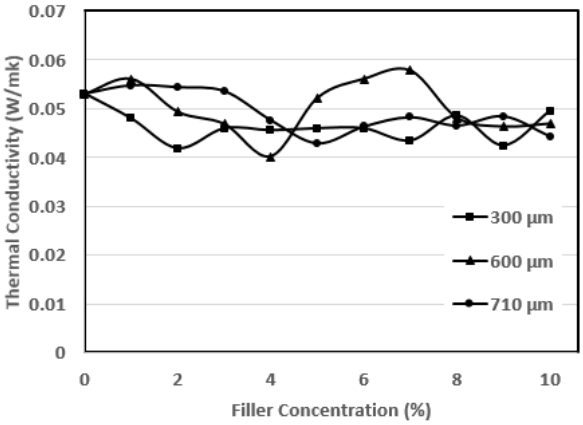

Figure 7: Responses of foam thermal conductivity to the filler concentration addition

4.0 CONCLUSIONS

The following conclusions were drawn from this study:

- Ground rigid polyurethane foam waste can be used as filler in the production of flexible polyurethane foam
- The mechanical properties of the foams produced improved with filler addition and decreasing particle size except for the tensile strength and elongation at break.
- Some reduction in the cost of production of flexible polyurethane foam can be achieved if ground rigid polyurethane waste foam is used to partly replace the more expensive polyol

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