Effect Of Silica-Fume Microparticles On Rigid Polyurethane Foam Properties

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Abstract: This study investigated the effect of silica fume microparticles on the properties of polyurethane foam. Results show that the introduction of silica fume microparticles in the foam composition does not deteriorate the compression strength of the foam. Furthermore, the addition reduces the temperature that developed in the foaming process, slightly increases the density of the material, and reduces water absorption.

Keywords: Rigid polyurethane foam, Silica fume microparticles, Physical properties, Mechanical properties, Water absorption, Density, Foam composite

1. INTRODUCTION

Studies on the technology for producing polyurethane foam (PUF) and process development are currently abundant. The most important characteristics of these materials are their low thermal conductivity and low density. According to this indicator, the rigid PUF is superior to many other proofing materials (foam concrete, phenolic cellular plastic, and polymer concrete). However, one of the drawbacks of rigid PUF is a relatively minimal strength. Most related studies have focused on improving thermal insulation properties and retaining their excellent mechanical characteristics [1]. The production of foams reinforced by particles or fibers can increase the mechanical properties of the polymer matrix, which enhances its energy absorption ability [2, 3]. A range of particulate or fibrous fillers for cost saving or mechanical properties enhancement, among other benefits, have been stated in the literature, including such as: silica, glass fibers, glass wool, aluminum hydroxide, talc, CaSO4, \( \text{Ca}_3(\text{PO}_4)_2 \), and \( \text{CaCO}_3 \) as well as nanostuctured fillers, such as carbon nanotubes in addition to nano-clays [4–11]. However, the literature shows that the rigid PUF filled glass microparticles increases its strength properties with a slight increases in density, whereas the thermal conductivity of the modified material remains unchanged compared to the initial polymer and the reduced water absorption; furthermore, the modified hollow glass spheres foam is more resistant to high temperature [12,13]. In this paper we studied the effect of silica fume microparticles on the foam properties. In addition, the cost of silica fume microparticles are significantly below the glass, such that, the use of silica fume microparticles as fillers is very promising.

2. EXPERIMENTAL

2.1 Materials

Rigid polyurethane was obtained by free foaming using a two-component system, with the components A polyol and B isocyanate produced by the Baalbaki Chemical Industries. Components A and B were taken in the weight ratio 1:1 in the production of PUF system. Silica fume microparticles powder was provided by BASF Meyco MS 610® (Jordan).

<table>
<thead>
<tr>
<th>Property</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>2–5 μm &gt; 99%</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>-10–50 °C</td>
</tr>
<tr>
<td>Physiological effect</td>
<td>neutral</td>
</tr>
<tr>
<td>pH value</td>
<td>neutral</td>
</tr>
<tr>
<td>Bulk density</td>
<td>150–300 kg/m3</td>
</tr>
<tr>
<td>SiO2 content</td>
<td>&gt; 85%</td>
</tr>
<tr>
<td>Chloride content</td>
<td>&lt; 0.1%</td>
</tr>
<tr>
<td>Color</td>
<td>Gray</td>
</tr>
</tbody>
</table>

2.2 Composite preparation

Silica fume microparticles were introduced in the components and conducted in quantities of 2%, 4%, 6%, 8%, and 10% by weight based on the total weight of the resulting neat preform of the foam. Foam composite was prepared through the following method: in a sample of component A, a weighted sample of microparticles was added and mixed by hand until homogenizing. The resultant mixture was weighed, and component B was added. The resulting composition was stirred with a mixer at speed 1000 rev/min until homogeneous. The mixing time was 1 min. The stirred composition was poured into a restrictive free form for subsequent foaming and curing in a wooden mold lined with aluminum foil.

2.3 Tests methods of Foam Composites

After obtaining the product and keeping them under room conditions for 24 h, product densities were determined using ISO 845 without removing the skin surface [14]. The foam product standard samples were mechanically cut for physical and mechanical tests. Samples for determining the static bending and impact test were cut perpendicular to the expansion direction. Samples for the mechanical...
performance properties in compression from the product were cut parallel the foaming direction. Both bending and compression were applied using the Trinius Olsen universal testing machine model H100KU. The compressive mechanical properties were determined on the samples in the cylinder diameter, 30 mm in height. The compression test with ASTM D1621 Pressing was conducted on the machine at a movement rate of the movable grip machine 2 mm/min. Automatic recording charts in the coordinates "stress-strain" were accomplished during the tests. The inspection was conducted through the sensors measuring system every 0.1 seconds [15]. Flexural testing was performed in accordance with ASTM D790 with a velocity relative movement of the tip loading and the 5 mm/min support. Static bending strength was determined on samples of bars with the 10 mm×15 mm× 120 mm dimensions. The testing machines used provide a measure of the load with an error of less than 1% of the measured value [16]. Impact tests were conducted in accordance with ASTM D4812 [17] on the pendulum 0.4 kg hammer impact velocity at 2.9 m/s. with the sample dimension of 10 mm× 10 mm× 55 mm. All tests were conducted at room temperature, 25 °C. At least five samples were prepared for the tests. The influence of silica fume microparticles on the temperature was studied. The developed significant amount of heat was released during foaming PUF upon receipt, such that, the foam material inside temperature rises significantly, reaching 140 °C. This high temperature achievement during fixation containers with economically or hazardous materials foaming heat can damage the container contents, which is highly undesirable. Therefore, the temperature when developing foaming is possible, and the PUF can be administered at lower values as silica fume microparticles are introduced as fillers. After mixing the foam ingredients and pouring it into a restrictive form, temperature was controlled and the process of free foaming and curing of the composition was carried out. For this purpose, using Aswar® in measuring temperature, probe (K type thermocouple) was installed to measure the temperature at the level of approximately half of the height of the mold. Water absorption was investigated using the method described in ASTM D570 on samples with 50 mm diameter and 5 mm thickness. At least five pieces of samples were selected. Prior to testing, the samples were conditioned for 24 h at (23 ± 2) °C. The mass of the samples with an accuracy of 0.001 g were then placed in a desiccator with water and a tight-fitting lid. The samples in the desiccator were maintained above water level and kept in the desiccator for 24 h before finally re-weighing them [18].

3. RESULTS AND DISCUSSION

3.1 Flexural Test

The flexural strength is practically dependent on the filling foam silica fume microparticles from 0 to 2 wt.% (0.59 MPa in pure PUF and 0.64 MPa in PUF filled with 2 wt.% of silica fume microparticles). When the concentration of microparticles was further increased to 10% by weight, the bending strength falls to 0.42 MPa as shown in Figure 1. This flexural strength decrease beyond 2 wt.% may be attributed to the non-wetting silica fume filler particles by the matrix and the non-uniform distribution of the silica fume microparticles in the foam matrix. The latter was a result of excessive and poorly dispersed microparticles in the foam, whereas the former may create stress concentrations in the polymer matrix and decrease flexural strength.

![Fig. 1. Dependence of the flexural strength of the rigid polyurethane foam on the content of the silica fume microparticles.](image1)

3.2 Impact strength

With increasing concentration of microparticles in the PUF from 0 to 10 wt.%, the specific foam toughness decreases from 0.46 to 0.11 kJ/m² as shown in Figure 2. This result is caused by the silica fume filler particles that serve as points for a localized stress concentration from which the failure begins or this is generally because of the elasticity reduction of the material with the silica fume filler addition. Thus, the deformability of rigid PUF matrix was reduced, which in turn affects the ductility in the foam surface. With this effect, the foam composite tends to form a weak structure and increase the concentration of silica fume filler, thus reducing the foam's energy absorption, resulting in reduced toughness and impact strength.

![Fig. 2. Dependence of impact strength of the rigid polyurethane foam on the content of silica fume microparticles.](image2)

3.3 Compressive strength

By increasing silica fume microparticles in PUF from 0 to 4 wt.%, the compressive strength increases from 0.38 to 0.43 MPa. With further increase in the concentration of microparticles to 10 wt.%, the compressive strength drops to 0.27 MPa, as shown in Figure 3. This finding may be related to the increased viscosity of the liquid when mixing high amounts of silica fume microparticles. The mixture produced difficulty in matrix fluidity and reduced aptitude to diffusion between fillers (increase in surface energy of foam resin) which in turn diminished filler wetting and adhesion.
between the rigid PUF matrix and silica fume fillers. As a result of the reduced wetting, numerous faults and gaps within the prepared foam composite material appeared. The above mentioned foundation will decrease compression strength at above 4 wt.% of silica fume filler.

![Figure 3](image-url)  
*Fig. 3 Dependence of the compressive strength of the rigid polyurethane foam on the content of silica fume microparticles.*

Figure 4 shows that by increasing the silica fume microparticles content from 0 to 10 wt.%, the compression modulus of the composite foam slightly increases from 10.2 to 13.9 MPa. The increased compression modulus may be attributed to the high elastic modulus of the silica fume filler material compared with that of the rigid PUF material.

![Figure 4](image-url)  
*Fig. 4. Dependence of the compressing modulus of the rigid polyurethane foam on the content of silica fume microparticles.*

3.4 Foaming Temperature

The dependence of the maximum temperature on the process of developing foam PUF of the microsphere content is presented in Figure 5. The highest temperature during foaming developed inside the composite foam material was reduced from 136.7 °C for pure PUF to 112.8 °C for PUF filled with 10 wt.% silica fume microparticles. This decrease in foaming temperature can be related to the foaming process of rigid PUF heat transfer to the silica fume particles, as well as in accordance to the effect of lumped capacitance of silica fume particle, where the net rate of heat transfer into the solid silica fume particles through its boundaries are equal to the increase rate of the internal energy of the solid silica fume particles. Thus, silica fume particles were absorbed because of the heat generated from the foaming reaction, which results in the reduced foaming temperature.

![Figure 5](image-url)  
*Fig. 5. Dependence of the foaming temperature of the rigid polyurethane foam on the content of silica fume microparticles.*

3.5 Density

The results of measuring the product density are shown in Figure 6. The figure shows that as the content of microparticles increases from 0 to 10 wt.%, the density of composite foam slightly increases from 59.83 to 82.9 kg/m³. This increase in density can be related to the density of silica fume microparticle according to the law of mixture. Furthermore, the silica fume may reduce cell size during the foaming process of rigid PUF, which results in increased density.

![Figure 6](image-url)  
*Fig. 6. Dependence of the density of the rigid polyurethane foam on the content of silica fume microparticles.*

3.6 Water Absorption

The data shows that the water absorption of PUF decreases with increasing concentration of microparticles in the composite material in Figure 7. This finding is caused by the reduced proportion of open pores in the rigid PUFs. An open cell contains air and matches the microparticles filler particles in size. Therefore, as water absorption depends on the number of communicating open connected cells, filling the open pores with microparticles reduces the water absorption.
**Fig. 7.** Dependence of the water absorption of the rigid polyurethane foam on the content of silica fume microparticles.

### 4. CONCLUSIONS

This work on filling foam silica fume microparticles established the following conclusions. The upper concentration limits filled with PUF microparticles were determined by technological limitations. When introducing the microparticles into the foam composition, its viscosity increases, and at high degrees of filling, the casting process becomes impossible. Furthermore, we found the highest concentration of microparticles in the composition, where it turned into a pasty mass at 12% by weight. The maximum temperature during foaming inside the material was reduced from 136.7 °C (in pure PUF) to 112.8 °C for PUF filled with 10 wt.% silica fume microparticles. The density of the material increases slightly from 59.83 kg/m³ for neat PUF to 82.9 kg/m³ for the PUF filled with 10 wt.% silica fume microparticles. At the maximum filling foam 2 wt.% silica fume microparticles its flexural strength decreases. With increasing concentrations of the specific microparticles, the toughness PUF decreased from 0.46 to 0.11 kJ/m². When the concentration of microparticles were from 0 to 4 wt.%, the compressive strength of PUF rises from 0.38 to 0.43 MPa. The subsequent increase in the microparticle concentration reduces compressive strength to 0.27 MPa. Moreover, the compression modulus of composite foam slightly increases from 10.2 to 13.9 MPa with increasing silica fume microparticles content from 0% to 10%. With the increased microparticles in the PUF material the water absorption was reduced by the practice (1.261% for the neat foam to 0.616% for PUF filled with 10% by weight of silica fume microparticles). Thus, the introduction of silica fume microparticles in the foam composition does not impair the compressive strength PUF. Furthermore, it reduces the temperature that develops during the foaming process, significantly increases the material density, and reduces water absorption. The results show that the PUF filled with silica fume microparticles can be used as a fixing material to repair damaged containers with environmentally hazardous materials.

### REFERENCES


