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Investigation of The Combustion Characteristics of Rigid Polyurethane Foam With Added Natural Filler Powder

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ABSTRACT

Objective: *This study aims to investigate the combustion characteristics of rigid polyurethane foam (RPUF) composites with the addition of natural filler powder, specifically perlite stone powder, to evaluate its effect on fire resistance.* ***Method:*** *RPUF composites were prepared with varying weight percentages of perlite stone powder (0%, 5%, 10%, 15%, 25%, and 35% w/w) with particle sizes ≤ 125 µm. Combustion performance was assessed by measuring the average burning time (ATB) and the percentage of time burning under controlled conditions.* ***Results:*** *The results revealed that the average burning time significantly decreased as the perlite filler content increased. While the composite without filler (0%) exhibited the highest ATB, a notable reduction in combustion duration was observed with increasing filler content, reaching approximately 20 seconds at 35% perlite. This indicates an inverse relationship between filler content and combustion duration, suggesting improved fire resistance with higher filler concentrations.* ***Novelty:*** *This study provides new insights into the fire-retardant potential of natural fillers like perlite stone powder in RPUF composites, highlighting their effectiveness in enhancing thermal stability and reducing flammability, which has promising implications for safer material applications in construction and insulation industries.*

INTRODUCTION

Polyurethane is one of the important polymers in many applications and Tritosil Polyurethane is one component with Highly resistant to seawater-diluted acids and alkalis, odorless, Non-sag, -moisture-cure polyurethane sealant designed to skin and cure rapidly, outstanding UV resistance and long term durability [1]. Polyurethane is widely used in several industries, including construction, packaging, and furniture. The remainder of the polyol chain, which is flexible, and hydrogen bonds, which are rigid, make up polyurethane [2]. Since the Inflexible PU foam's hardness rises with density, foam with better properties is produced. More specifically, an increase in density of (1000 g/cm3) suggests an increase in hardness of approximately (100 Pa) [3]. Adding materials (fillers) to polymers is a rapid and inexpensive approach to changing the properties of basic materials; as a result, the mixture (polymers with fillers) was and still is of interest to interest of researchers in the field of scientific research, particularly in the industry [4]. When certain fillers are added to polymers or a mixture of similar polymers to form a new polymer, a new system is formed that differs in its attributes and characteristics in terms of performance and has an appropriate and relatively low cost, but when chemically different polymers are mixed, the final product lacks integration and compatibility and does not have good characteristics [5-7]. Fillers are solid materials added to polymers to improve mechanical properties and reduce cost, and they have the opposite effect of plasticizers in that they minimize ductility and elongation rate while increasing tensile strength and Young modulus, or know that they are organic or inorganic materials added to the polymer. It can either be used to increase the volume of the plastic material, lowering the cost of usage (inert fillers), or it can be used to improve mechanical qualities (effective fillers) [8-10]. This research aims to make polyurethane composite polymers with the addition of perlite stone powder. This additive is unique in that it is widely available, and has no economic cost.

RESEARCH METHOD

The trimethylamine (TEA) was used as a catalyst in the reaction of 1:1 weight percent isocyanate and (polyol) provided by Sigma-Aldrich Company. Polyurethane was prepared, also added drops of water to release carbon dioxide, which worked to generate cellular gaps inside the mass of the mixture. As filler, perlite stone was used. Large perlite stone pieces were initially collected and then cut into smaller pieces. Then, using an electric grinder of French origin, the small stone pieces were ground into a powder. The powder was put through a wire sieve (an American company, ATM Corp.'s Allen-Bradley Sonic Sifter Model L3P), producing a fine-grained, ultrafine powder with particle sizes of about (125 µm). The perlite stone is shown in Fig. 1.

Figure 1. Perlite stone

The Polyurethane samples were prepared with perlite stone powder at laboratory temperature. Then, we have been added different weight ratios (5, 10, 15, 25, and 35) wt% of perlite stone powder to the polymer mixture. The mixing procedure was continued for the mixture was evenly distributed, then, the final product was poured into a cylinder mold, circular and rectangular. Fig.2 shows the Tensile, thermal conductivity and compressive strength test samples.

Figure 2. Combustion characteristic test sample rectangular slab

Average Time of Burning ATB.

Using a combustion rate measurement apparatus, the average burning duration (Average Time of Burning ATB) and burning rate for each of the samples manufactured were determined using the standard technique 81 ASTM D635 - [11]. The time it took to burn the model to a distance of (75 mm) was computed, and the measurement was repeated three times for each sample, after which the average results were obtained. Using the following mathematical equations [12], calculate the Average Time of Burning (ATB) and Average Extent of Burning (AEB). the schematic diagram of the combustion time rate meter measurement apparatus is shown in Figure 3.

Average Time of Burning (ATB) = $\frac{\Sigma\,(t-30\ s)}{number\ of\ \ specimens}$

Average Extent of Burning (AEB) = $\frac{\Sigma\,(100\ mm-unburned\ lenght)}{number\ of\ \ specimens}$

The rate of burning (RB) can be calculated using the following equation:

Rate of Burning (RB) = $\frac{Average\ Extent\ of\ \ Burning\ (AEB)}{Average\ Time\ of\ \ Burning\ (ATB)}\ \frac{cm}{\min.}$

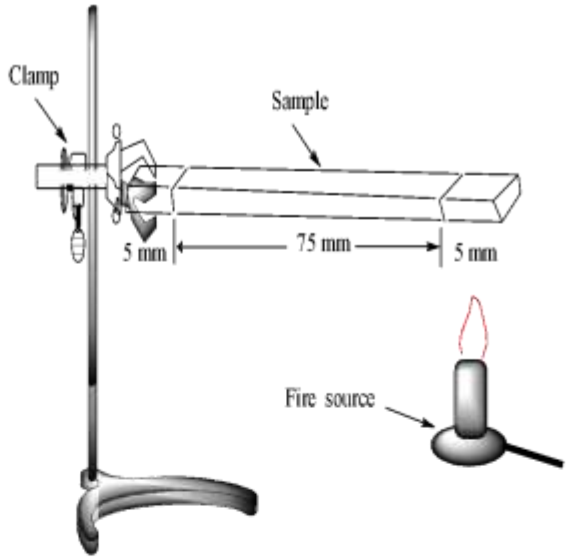

Figure 3. The schematic diagram of the combustion time rate meter

RESULTS AND DISCUSSION

Combustion resistors are used to prevent or stop polymer combustion, and their popularity has recently grown, particularly in the field of applied polymers. The physical and chemical mechanisms of operation of combustion resistors are the most common. The influence of perlite stone powder fillers on polyurethane combustion characteristics (Average Time of Burning) was investigated for this purpose. The relationship between the average burning time and the percentages of the heavy additives for the perlite stone powder fillers is shown in Figure (4). The behavior of the polymer with fillers starts with a strong effect at the percentage (0 %), as its value rises to (57 sec.) until it reaches the lowest value, which is (20 sec.) at the percentage (35%). Then the behavior starts to decrease with the increase in the weight percentages of the additive, which indicates that increasing the percentage of wasted perlite stone powder improves the ignition resistance and limits the spread of heat within the polymer chains, thus reducing the rate of combustion and self-extinguishing, as we get the lowest value at the percentage (35%) which is (20 seconds), while at the percentage (5%) of the additive, perhaps due to the lack of strong homogeneity of the additive with the polymer chains or perhaps because the molten wasted tire powder formed as a result of thermal decomposition did not appear as a thermal insulator on the surface and did not form a solid protective layer, which prevents the spread of flame on the polymer, which led to the abnormality of the polymer.

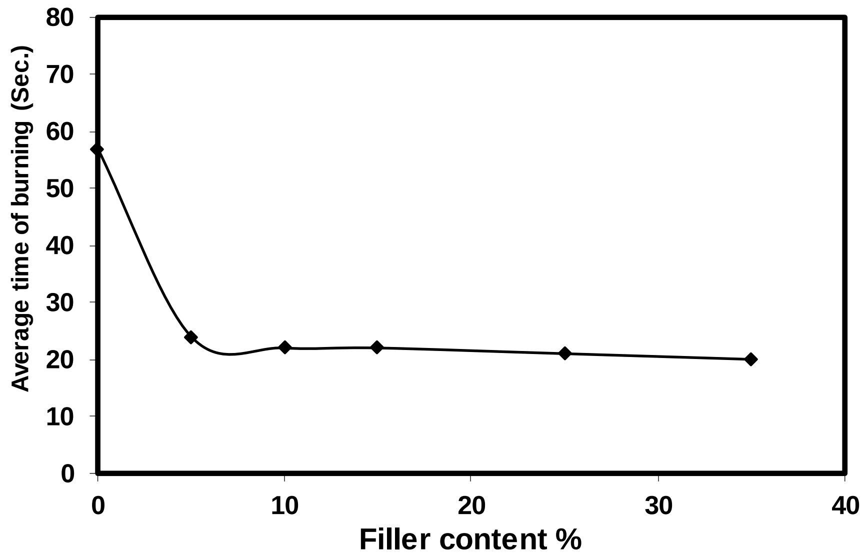

Figure 4. The relationship between the average of burning time and the concentration of the additive for the polyurethane polymer

Figure (5), which was calculated by dividing the difference between its values for the two impure states (polymer with waste tire powder) and pure (polymer without any addition) by their value when in the impure state (polymer with waste tire powder), shows the change in the percentage of combustion time as a function of the percentage of the added weight of the waste tire powder. The pure state is given by the equation:

Percentage for time of burning = $\frac{A-B}{B}\times 100\%$

Where,

A: The fillers' weight in relation to the polymer's, B: The polymer's weight ratio in its purest form.

Figure (5) shows that all negative values for the percentages are (5-35)%, which indicates that the percentages are all negative as a result of the burning time values for the percentages being less than the pure polymer value, and thus the fillers have the benefit of preventing the spread of flame within the polymer chains and thus self-extinguishing.

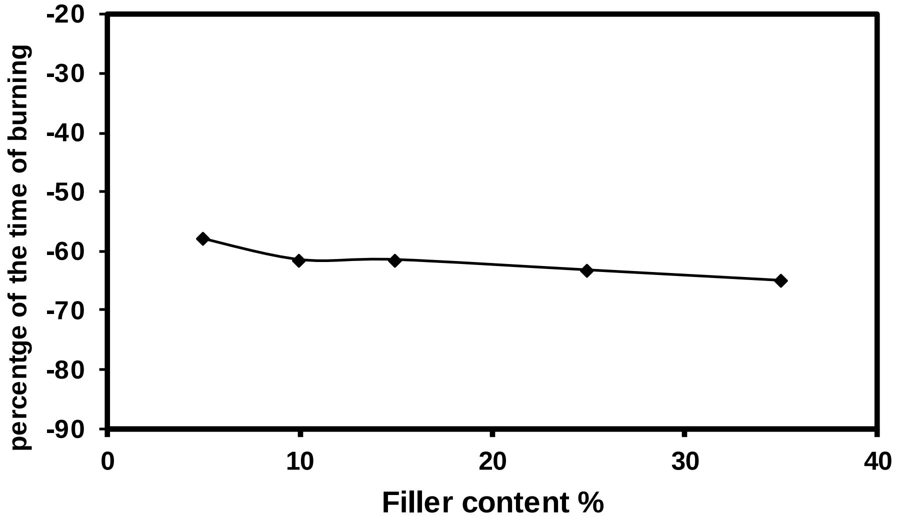

Figure 5. The relationship between the percentage of burning time and the concentration of the additive for the polyurethane polymer

CONCLUSION

Fundamental Finding: This study concludes that the incorporation of perlite stone powder as a natural filler in rigid polyurethane foam (RPUF) composites significantly influences combustion characteristics. Specifically, the addition of perlite reduces the average burning time, with the most pronounced burning resistance observed at 0% filler (approximately 57 seconds), which decreases to around 20 seconds at a 35% filler concentration. This inverse relationship indicates that higher perlite content enhances fire resistance by reducing combustion duration. **Implication:** These findings highlight the potential of perlite stone powder as an effective additive for improving the fire-retardant properties of polyurethane composites, suggesting its applicability in developing safer, flame-resistant materials for construction and insulation purposes. **Limitation:** The study's limitations include a focus on a specific particle size (≤ 125 µm) and a limited range of filler concentrations, which may not fully capture the material's behavior under varying environmental conditions or with different filler characteristics. **Future Research:** Future studies should explore the effects of different particle sizes, filler types, and composite formulations on combustion properties, as well as investigate the long-term thermal stability and mechanical performance of these composites under real-world conditions.

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