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Optimization of Impact and Thermal Performance of Phenolic Composites through Bentonite Reinforcement

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Abstract-- *The increasing demand for composite materials with both good mechanical properties and fire resistance has driven research into flame-retardant additives. One such candidate is montmorillonite bentonite, a mineral with high thermal stability. This study investigates the effect of montmorillonite bentonite powder addition on the mechanical properties and flame resistance of phenolic resin-based composites. Composite samples were prepared with bentonite weight fractions of 0%, 5%, 10%, and 15%. Mechanical performance was evaluated through impact testing using the Izod method to determine impact energy and impact strength. Flame resistance was tested according to ASTM D635, measuring Time of Burning (TOB) and Rate of Burning (ROB). Results indicate that bentonite addition reduces the impact strength, with the highest of 8.2 kJ/m² in the 0% fraction and the lowest of 0.8 kJ/m² in the 5% fraction. The highest impact energy was 0.145 J at 10% bentonite. This reduction is attributed to the catalyst inhomogeneity and voids within the composite. Conversely, flame resistance improved significantly; the 15% fraction showed the highest TOB (20 s) and the lowest ROB (9.4 mm/min), indicating better flame retardancy. The presence of silica and alumina in bentonite likely contributes to burning retardation by increasing material density and thermal stability. These findings suggest that montmorillonite bentonite has potential as a flame-retardant additive in composites, although further optimization is needed to balance fire resistance and mechanical strength.*

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1. INTRODUCTION

In the field of composite materials, the addition of inorganic fillers such as bentonite has been a significant focus of research, especially in an effort to improve the thermal properties and fire resistance of polymer materials [1] . Bentonite, as a clay-based filler, offers the potential to modify the composite characteristics of phenolic polymers, which are often used in applications that require thermal stability and fire resistance [2]. The test results showed a strong correlation between the fraction of bentonite filler and the time of burning propagation, where an increase in the bentonite fraction significantly slowed down the rate of fire propagation [3]. Samples with a bentonite fraction of 15% showed a burn propagation time of more than 10 minutes, signaling a substantial increase in resistance to heat and fire, indicating the effectiveness of bentonite in inhibiting flame propagation through insulation mechanisms and physical barriers to heat transfer [4] . However, this increase in thermal resistance has consequences for impact strength, which tends to decrease as the bentonite fraction increases. The inhomogeneous distribution of bentonite particles in the polymer matrix can lead to the formation of weak points that reduce the material's ability to withstand impact loads [5]. Inorganic fillers such as bentonite tend to be less effective at absorbing impact energy compared to fiber reinforcers such as E-glass or natural fibers [6]. In recent years, phenolic polymer composites have gained attention for heat shielding applications due to their excellent thermal resistance. However, enhancing thermal protection often leads to reduced mechanical strength, making optimization a key challenge. Therefore, this study aims to explore in depth the effect of bentonite filler addition on the mechanical and thermal characteristics of phenolic composites, with special attention to the trade-offs between fire resistance and structural performance. The research also highlights the potential use of locally sourced bentonite as an alternative additive in composite materials for thermal protection, focusing on composition optimization to achieve the desired balance of properties [7].

The increase in bentonite fractions in phenolic polymer composites significantly affects their thermal characteristics, especially in terms of fire resistance. The test results showed a positive correlation between the fraction of bentonite filler and the propagation time of the burn, where the higher the bentonite fraction, the longer it took for the flame to propagate through the composite material [3]. The mechanism of slowing the spread of fire by bentonite involves the formation of an insulating layer on the composite surface when exposed to heat [8]. This layer serves as a thermal barrier, inhibiting heat transfer to the layer of material underneath and slowing down the rate of burning. Furthermore, bentonite can also release moisture when heated, which helps to cool the surface of the material and reduce the concentration of oxygen around the flame, further inhibiting the burning process. Thus, local bentonite has great potential to be used as an effective and economical alternative material in composite materials for heat shielding applications [9].

2. METHODOLOGY

This study adopts an experimental methodology to investigate the effect of bentonite filler addition on the mechanical and thermal characteristics of phenolic polymer composites. Composite samples were fabricated with bentonite weight fractions of 0%, 5%, 10%, and 15% [10].

In the mixing stage, bentonite powder was combined with a liquid phenolic resin matrix and mechanically stirred using a laboratory overhead stirrer at a constant speed of 500 rpm for 15 minutes to achieve a homogeneous dispersion. After mixing, the composite mixture was molded using a hot compression molding process at a temperature of 150 °C and a pressure of 20 MPa for 10 minutes, followed by cooling under pressure to maintain dimensional stability [11].

For each composition, five specimens were produced, totaling 20 samples to ensure statistical reliability of the test results. The impact test was performed using the Izod method based on ASTM D256 to evaluate the material’s energy absorption and resistance to shock loads. Flame resistance testing followed the ASTM D635 standard, which involves horizontal burning tests to measure the Time of Burning (TOB) and Rate of Burning (ROB). TOB is defined as the time taken for the flame to travel a fixed distance across the specimen, while ROB is calculated based on the flame propagation rate in mm/min [12].

3. RESULTS AND DISCUSSION

3.1 Impact Test Results

The impact strengths of bentonite-reinforced phenolic composites vary, with the highest value being 8.2 kJ/m² at the 0% fraction and the lowest being 0.8 kJ/m² at the 5% fraction. The highest impact energy was 0.145 J in the 10% fraction and the lowest was 0.0637 J in the 0% fraction as shown in Table 1. This difference is due to uneven material strength, poor fiber stress distribution, inhomogeneous catalyst dissolution, excess catalyst composition, and the presence of air cavities that weaken the composite. The addition of bentonite has a significant impact on the material's ability to absorb impact energy. The results of this study also show that the higher the percentage of bentonite added, the smaller the impact energy produced. This is because bentonite is an inorganic filler that cannot absorb impact energy optimally when compared to other reinforcing materials such as natural fibers.

Table 1. Average value of E absorbent and impact strength of bentonite composite

No	Heavy Fraction (%)	Impact Energy (J)	Impact Strength (kJ/m²)
1	0	0.0637	8.2
2	5	0.0777	0.8
3	10	0.145	3.4
4	15	0.111	1.2

The relationship between the weight fraction and the impact strength and absorbed energy can be seen in the Figure 1.

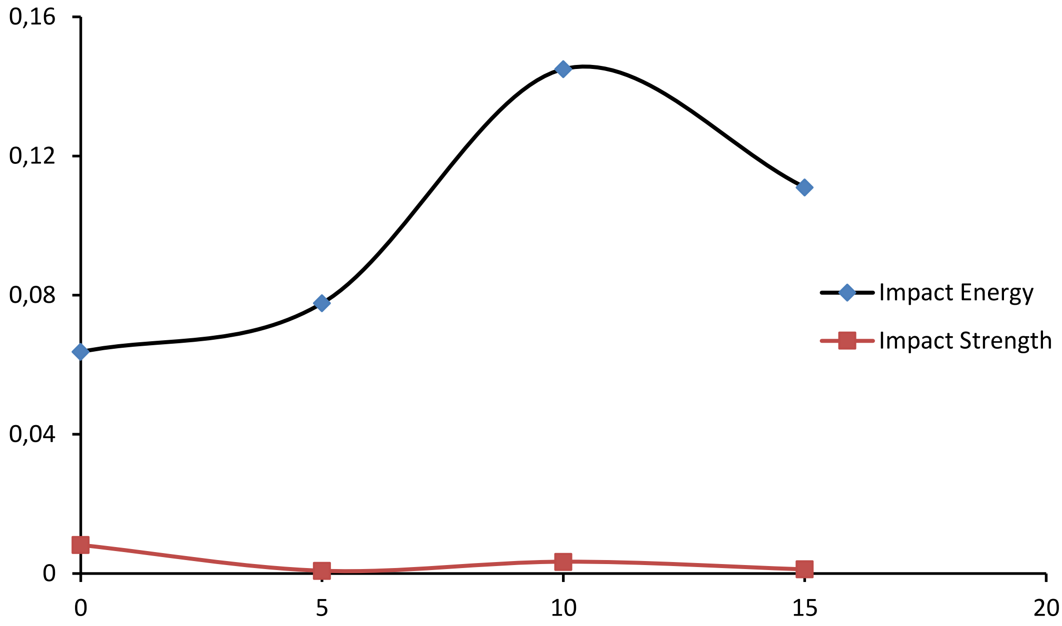

Figure 1. Graph of the relationship between the weight fraction and the value of the impact and the absorbed energy

These findings confirm that the addition of bentonite has a significant influence on the mechanical properties of composites, especially in terms of impact strength and impact energy.
In the results of the impact test, the difference in the average impact strength of the composite is due to several factors that can be explained in detail:

a) The test piece has uneven strength in each place and the stress distribution of the fibers is less uniform, so the absorbed energy becomes smaller. There are certain parts that are strong, while in other parts they are weak, and these weak parts are the beginning of composite damage. This is due to the inhomogeneity of the catalyst dissolution into the matrix, so that the part that gets a larger portion of the catalyst becomes harder than the other part.
b) The composition of the excess catalyst results in the matrix bonding with the fibers not being perfect because the matrix dries faster.
c) The presence of air cavities weakens the composite, since from this void the beginning of composite damage occurs [13], [14], [15].

Figure 2. Impact test results of the Izod *method*

3.2 Horizontal Burning Test Results

The burning resistance of bentonite composites with variables of 0%,5%,10%,15% includes Time Of Burning (TOB) testing and Rate Of Burning (ROB) testing.

Table 2. Composite flame resistance test results.

No	Variable specificity (%)	TOB (s)	ROB (mm/min)
1	0	6	4.16
2	5	13	6.32
3	10	17	6.15
4	15	20	9.4

Table 2 shows the ignition time and burning speed of the composite relative to the variation in the volume fraction of the sokka tiles. The results of this study are visualized in diagrams and graphs to show the effect of the addition of montmorillonite bentonite on the ignition time and burning speed of composites (Figure 3) [16], [17].

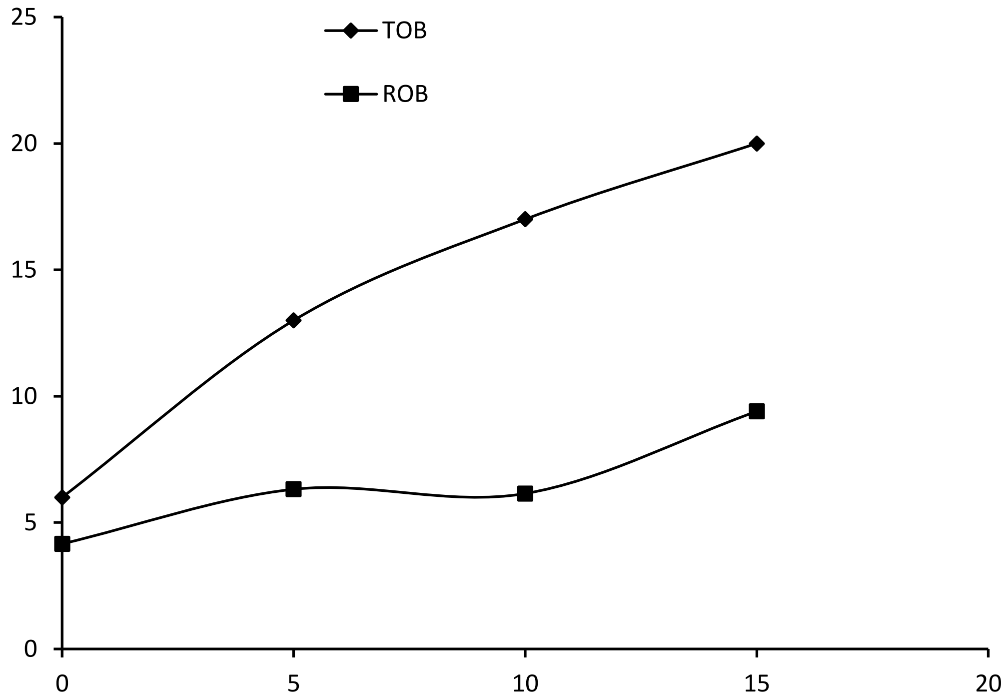

Figure 3. Comparison chart of *montmorillonite bentonite* powder Against Time Of Burning dan Rade Of Burning

The diagram above shows the flame resistance of montmorillonite bentonite composites tested using ASTM D635. The highest Time Of Burning (TOB) time is 20 seconds at the 15% variable, indicating the composite takes a long time to ignite. The lowest flame propagation speed was 9.4 mm/min at the same variable. An increase in the volume fraction of montmorillonite bentonite correlates with an increase in flame resistance because bentonite powder increases the density of the material [18], [19].

Montmorillonite bentonite powder contains the mineral montmorillonite with characteristic properties such as the ability to expand in water and exchange ions, as well as elements such as silica, alumina, and oxides with a melting point of 845°C. This increased powder content increases TOB and decreases the burn speed, as the contact between particles in the composite increases. The test results showed that the more the content of montmorillonite bentonite powder, the higher the TOB value and the slower the flame propagation.

Figure 4. Sample results of the Burning Vine test results

4. CONCLUSION

Based on the test results, it can be concluded that the addition of montmorillonite bentonite powder affects the mechanical characteristics and flame resistance of phenolic resin-based composites. In the impact test, the highest impact strength was recorded in the composite without bentonite (0%) of 0.0082 J/mm², while the highest impact energy occurred in the 10% fraction of 0.145 J. A significant decrease in the impact strength of certain bentonite fractions was caused by the inhomogeneity of the catalyst distribution, the excess content of the catalyst that accelerated the drying of the matrix, and the presence of air cavities that became the starting point of damage. This suggests that the addition of bentonite needs to be carefully controlled so as not to degrade the mechanical integrity of the composite.

On the other hand, the increase in bentonite fraction actually makes a positive contribution to the flame resistance of composites. The results of the ASTM D635 test show that the 15% bentonite fraction has the longest ignition time (20 seconds) and the lowest flame propagation speed (9.4 mm/min). The thermal properties of bentonite, such as silica and alumina content, as well as their ability to increase material density, help slow down ignition and burn rate. Thus, montmorillonite bentonite can be considered as a flame retardant additive in composite materials, although optimization is required so as not to compromise mechanical performance significantly.

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