Some Mechanical and Thermal Properties of Unsaturated Polyester Composite Reinforced with Kaolin Powder

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Abstract

In this study, an unsaturated polyester composite reinforced with kaolin powder was prepared at weight reinforcement ratios of 0%, 5%, 10%, 15%, and 20%. The mechanical impact resistance of the prepared samples was tested, and it was found that the reinforcement ratio (20%) was the optimal reinforcement ratio in terms of mechanical properties. The glass transition temperature was determined by DSC examination of the selected optimal sample, which reached 113.7°C compared to the pure sample, which recorded at 71°C. This reflects the positive role of kaolin powder particles in raising this temperature.

Keywords: Unsaturated polyester; Mechanical properties; Thermal properties; Kaolin powder
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1. Introduction

Unsaturated polyester (UPE) composites reinforced with kaolin powder exhibit altered mechanical and thermal properties. The addition of kaolin, a naturally occurring clay mineral, typically enhances the stiffness and hardness of the composite, leading to improved tensile and flexural modulus [1]. Impact strength and compressive strength can also see improvements, depending on the kaolin content and particle dispersion. However, increased filler loading can sometimes lead to a reduction in elongation at break, indicating a more brittle material, particularly if interfacial adhesion between the kaolin and UPE matrix is poor [2,3].

Regarding thermal properties, kaolin can improve the thermal stability of UPE composites, acting as a barrier to heat transfer due to its low thermal conductivity and high specific heat capacity. This can lead to increased degradation temperatures and better performance at elevated temperatures. The degree of improvement is highly dependent on the kaolin's particle size, distribution, and overall loading within the polyester matrix [4-6].

With technological development and advanced industries, it has become necessary to have products with distinct and unique properties that are unmatched by traditional materials such as metal, plumbing, and ceramics. The industry is unique in producing materials with properties sufficient for engineers to apply them in the industrial field, such as durability, hardness, resistance to environmental conditions, such as corrosion resistance, etc. [7]. Here, the importance of composite materials emerges exclusively, as they possess new and diverse properties. Up until this study, unsaturated polyester ester was used as the basic material for the polymer composite, reinforced with kaolin particles, as polyester resins are distinguished by their effectiveness, where only a small percentage is missing. It is widely used in electrical construction. It is resistant to moisture and acids. Kaolin, a clay made of natural aluminum and silicates, has a wide range of applications in various industries due to its unique properties. Kaolin is known for its whiteness, purity, and fine particle size, and is a basic component in the manufacture of ceramics, paper, paints, pharmaceuticals, and others [8].

2. Experimental Work

The unsaturated polyester composite was prepared by mixing unsaturated polyester produced by the Saudi Industrial Resins Company, as a matrix material with kaolin powder at particle size 212 µm at weight ratios of 0, 5, 10, 15, and 20% with 1% of hardener. The mixing process was carry out manually for 2 min to obtain a homogeneous mixture and a uniform distribution of reinforcement particles. The impact test samples were poured into the molds and after 24 hours the samples were ready for testing. The Charpy impact test was performed using hammer 5J with a zeroing rate of 0.15 J.

3. Results and Discussion

Figure (1) shows a prepared samples for this test, while figure (2) shows an improvement in the impact resistance values of the reinforced samples which recorded at 8.6 kJ/m^2 compared with the pure sample which recorded 5.6 kJ/m^2. This improvement indicates the extent of the effect of adding kaolin particles on increasing the impact resistance values. This aligns with the explanation in reference [9].

The most striking feature of the graph is the clear increase in impact strength with increasing kaolin weight percentage. The impact strength for the neat polyester (0% kaolin) starts at approximately 5.5 KJ/m². As kaolin content increases, the impact strength rises, reaching approximately 8.6 KJ/m² at 20% kaolin. However, the rate of increase is not linear. There appears to be an initial significant enhancement up to around 10-15% kaolin, after which the curve starts to flatten out or shows a marginal increase towards 20%. This suggests that there might be an optimal kaolin loading for achieving the maximum practical impact strength benefit within this range.

Fig. (1) The prepared kaolin-reinforced polyester composite samples

During 0% to 5% Kaolin, there is a significant initial improvement. The impact strength increases from ~5.5 KJ/m² to ~7.0 KJ/m². This is a substantial jump, indicating that even a small addition of kaolin has a noticeable positive effect on the composite's ability to resist sudden loads. The possible mechanisms are energy dissipation, bridging effect, and increased stiffness, which is an indirect effect. In case of energy dissipation, kaolin particles can act as stress concentrators, but more importantly, they can promote crack deflection and energy dissipation mechanisms. When a crack propagates through the composite, it encounters the rigid kaolin particles. The crack might have to detour around the particles, creating a longer path and consuming more energy. In case of bridging effect, the particles can also "bridge" microcracks, preventing their further propagation and contributing to the overall toughness. While not directly measured as impact strength, increased stiffness due to filler addition can sometimes distribute stress more broadly, potentially delaying catastrophic failure under impact.

During 5% to 15% kaolin, continued enhancement, but softening of the curve, is observed. The impact strength continues to rise from ~7.0 KJ/m² to ~8.1 KJ/m². The rate of increase is still positive but visibly less steep than in the initial segment. In this range, it's plausible that the kaolin particles are still relatively well-dispersed within the polyester matrix, allowing the aforementioned toughening mechanisms to continue operating effectively. More particles mean more opportunities for crack interaction and energy absorption. As filler content increases, there's always a risk of particle agglomeration. If some agglomeration starts to occur in this range, it could explain the slightly reduced rate of improvement, as large agglomerates can act as flaws rather than toughening agents.

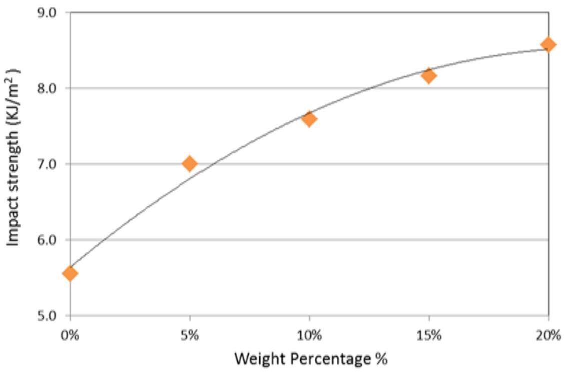

Fig. (2) Relation between impact strength and weight ratios

During 15% to 20% kaolin, a plateau or diminishing returns. The impact strength increases only slightly from ~8.1 kJ/m² to ~8.6 kJ/m². The curve appears to be approaching a plateau. At higher filler loadings, the probability of kaolin particle agglomeration significantly increases. Agglomerates are poorly bonded to the matrix and can act as macroscopic defects, initiating cracks rather than deflecting them. This offsets the toughening mechanisms. With a higher surface area of kaolin, it becomes more challenging for the polyester matrix to completely wet and encapsulate all the particles. Poor interfacial adhesion creates weak points where cracks can easily initiate and propagate, reducing the overall toughness. A very high filler content effectively reduces the volume of the ductile polyester matrix that can absorb energy. The composite becomes more rigid and less able to deform plastically under impact. High filler loadings can also increase the viscosity of the composite melt, leading to difficulties in processing and potentially introducing voids or other defects that compromise mechanical properties. There might be a "saturation point" where the maximum number of effective crack-toughening sites has been introduced. Adding more filler beyond this point provides little additional benefit and starts to introduce the negative effects mentioned above.

The reinforcing particles work to impede crack growth within the composite material and change the direction and shape of the crack, which leads to an increase in the surface area of the crack and consequently increases the energy expended, then improved impact resistance of the polymer composite.

From the differential scanning calorimetry (DSC) examination, the glass transition temperature (T_g) was determined for the kaolin-reinforced polyester composite at a reinforcement ratio of 20% as shown in Fig. (3). The sample was heated at a rate of 10 °C/min until a maximum temperature of 200°C, and the glass transition temperature (T_g) was recorded at 113.7 °C compared with pure unsaturated polyester sample which was recorded at 71°C. This explains an agreement with Ruban et al. [10]. This indicates an improvement in adhesion between the polymer and kaolin particles then raising the glass transition temperature.

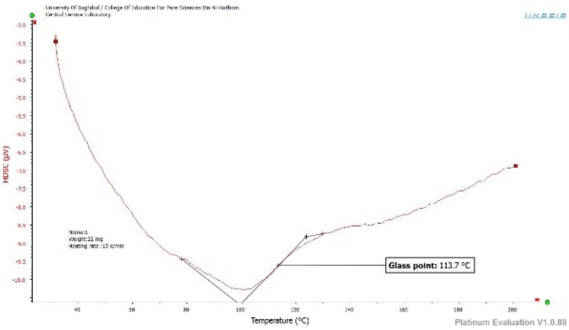

Fig. (3) Glass transition temperature of unsaturated polyester material reinforced with 20% of kaolin

4. Conclusion

The results of mechanical tests (impact test) showed the role of reinforcing additives, specifically at a ratio of 20% of kaolin powder in improving impact resistant. The glass transition temperature (T_g=113.3°C) obtained from the differential scanning calorimetry (DSC) test also gave an indication of the possibility of using this composite and its suitability for industrial applications in the Iraqi environment. This type of composite material can be used as coating and covering layers for metal surfaces, as it provides good mechanical and thermal properties, in addition to the fact that unsaturated polyester, as a polymer material, has resistance to salts and acidic materials.

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