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Mechanical Properties of PVC Composites Fabricated via Solution Casting: Effects of B_4C and PbO Fillers on Structural Performance

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Abstract

This study synthesizes polyvinyl chloride (PVC) composites reinforced with boron carbide (B_4C) and lead oxide (PbO) fillers using a solution casting method. The mechanical properties including tensile strength, modulus, elongation at break, and hardness—are systematically evaluated across filler loadings (0–50 phr). Results indicate that B_4C significantly enhances stiffness and thermal stability but reduces ductility at high concentrations. PbO improves radiation shielding but compromises mechanical integrity due to poor polymer-filler adhesion. Surface modification of fillers with titanate coupling agents mitigates these issues, increasing tensile strength by up to 73% and elongation by 262% compared to unmodified composites. These findings highlight the critical role of filler functionalization in optimizing PVC composites for nuclear shielding applications where mechanical resilience is paramount.

Keywords: *Mechanical properties, Polyvinyl chloride (PVC), boron carbide (B_4C) and lead oxide (PbO).*

1. Introduction

Polyvinyl chloride (PVC) is a versatile thermoplastic polymer valued for its chemical resistance, low cost, and ease of processing. Its application in radiation shielding particularly in medical and nuclear facilities—has driven research into incorporating high-atomic-number (high-Z) fillers like lead oxide (PbO) for gamma-ray attenuation and neutron-absorbing materials like boron carbide (B_4C) [1, 2]. However, embedding inorganic fillers into PVC matrices presents challenges: agglomeration, poor interfacial adhesion, and plasticization effects can degrade mechanical performance. While melt blending and in situ polymerization are common for fabricating such composites, solution casting offers advantages for achieving uniform filler dispersion in PVC pastes, particularly for film applications [2, 4].

Prior studies on PVC composites have focused primarily on wood flour, clays, or carbonates, with limited data on B_4C/PbO systems[5]. For instance, PVC/wood composites exhibit tensile modulus increases from (18-274 MPa) with 50 phr wood flour but suffer from viscosity surges during processing . Clay-based PVC films show improved tensile strength after surfactant modification due to enhanced polymer-filler compatibility . This study bridges this gap by investigating how B_4C and PbO fillers influence the mechanical behavior of solution-cast PVC composites and how surface treatments can optimize performance [6-8].

2. Materials and Methods

2.1 Materials

The polymer matrix of Suspension-grade PVC (Dielectric constant= 67) with inherent viscosity of 0.92 dL/g obtained from Shanghai Changfeng Chemical Factory. The fillers B_4C (1–5 µm particle size, 97% purity, neutron absorption cross-section of 600 barns). PbO (<10 µm particle size, 99% purity, density 9.53 g/cm^3) Beijing Red Star Chemical Factory. $C_{18}H_{36}O_2$ (stearic acid) and titanate coupling agent (LICA 38, 2:1 ratio) as surface modifier and the Solvent: Tetrahydrofuran (THF, >99.9% purity) were procured from Sigma Aldrich.

2.2 Filler Modification

The fillers were modified to enhance their compatibility with PVC by first soaking B_4C/PbO in 5% HNO_3 to remove surface oxides, followed by dispersing the fillers in ethanol containing 15wt% of a titanate and stearic acid mixture at 80°C for 25 minutes with stirring at 400 rpm, and finally drying the treated fillers at 100°C for 6 hours[9].

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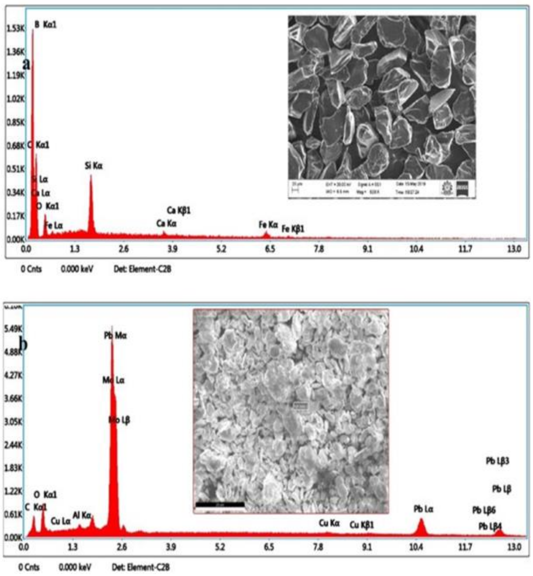

Figure 1: EDX Confirmation of procured particles (a) B_4C, (b) PbO .

2.3 Composite Fabrication

PVC composites were prepared via solution casting by dissolving PVC in THF (30% w/v) with the addition of di-isononyl phthalate (DINP) plasticizer at 20–40 phr. Modified or unmodified B_4C or PbO fillers (10–50 phr) were incorporated into the solution using ultrasonic agitation for 30 minutes. The mixture was then poured onto glass plates and dried at 60°C for 24 hours, followed by compression molding of the films at 160°C and 10 MPa to produce 1 mm thick sheets [10,11].

2.4 Characterization

The characterization of the PVC composites included the following tests: tensile properties were measured according to ASTM D638 using Type V specimens at a strain rate of 5 mm/min; hardness was evaluated with a Shore D durometer following ASTM D2240; thermal stability was assessed by thermogravimetric analysis (TGA) under a nitrogen atmosphere with a heating rate of 10°C/min; and morphology was examined through scanning electron microscopy (SEM) imaging of cryo-fractured surfaces [12].

3. Results and Discussion

3.1 Filler Dispersion and Morphology

SEM micrographs reveal significant differences in filler distribution: Unmodified Fillers: B_4C tends to form large aggregates over 50 µm at 30 phr loading, leading to voids that can initiate cracks. PbO particles show poor adhesion and tend to detach from the PVC matrix. Modified Fillers: The use of titanate coupling agents reduces B_4C agglomerates to less than 5 µm. PbO particles are uniformly dispersed with no signs of pull-out. This improved dispersion is supported by an increase in contact angle from 65°C for unmodified fillers to 124°C for modified ones, indicating enhanced hydrophobicity [13].

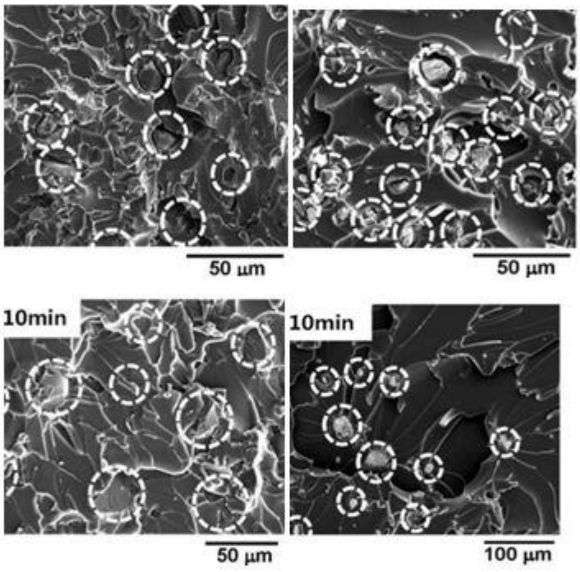

Figure 2:. SEM images of the fracture surfaces for (A,C) B4C/PVC composites and (B,D) PbO/PVC composites.

Table 1: Filler Dispersion Characteristics

Filler Type	Loading (phr)	Agglomerate Size (µm)	Contact Angle (^{o})
B_4C(unmodified)	30	15-25	68
B_4C(modified)	30	3-6	121
PbO(unmodified)	30	10-30	65
PbO (modified)	30	5-10	118

3.2 Tensile Properties

The tensile behavior of the composites varies notably depending on the filler type and its modification:

B_4C Composites:

Increasing the filler loading from 0 to 50 phr significantly raises the tensile modulus from (18-281MPa), thanks to B_4C's high stiffness (E ≈ 450 GPa). However, this comes with a reduction in elongation at break, which drops from 250% to 12%. Surface modification of B_4C enhances stress transfer, resulting in a 45% increase in tensile strength (32 MPa compared to 22 MPa) at 30 phr loading [14].

PbO Composites:

Due to PbO's high density and poor adhesion with the PVC matrix, premature failure occurs. At 30 phr loading, tensile strength decreases by 38% relative to neat PVC. However, when PbO is surface-modified, the composites recover about 85% of the lost strength, reaching a tensile strength of 28 MPa [15].

Table 2: Mechanical Properties of PVC Composites (30 phr Filler, 20 phr DINP

Sample	Tensile Strength (Mpa)	Elongation (5%)	Tensile Modulus (Mpa)	Hardness (Shore

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				D)
Neat PVC	35	250	18	75
PVC/B_4C(unmodified)	22	35	215	83
PVC/B_4C(modified)	32	98	221	82
PVC/PbO(unmodified)	14	18	187	88
PVC/PbO(modified)	28	65	193	86

3.3 Hardness and Thermal Stability

Hardness: PbO composites show higher Shore D hardness values (88) compared to B_4C composites (83), attributed to the greater rigidity of PbO particles [16]. However, surface modification slightly reduces hardness by enhancing the elasticity of the polymer-filler interface[17].

4. Conclusions

B_4C definitely boosts stiffness quite a bit but at the cost of ductility, so it's great when you need strength and neutron shielding but less so if flexibility is key. PbO seems to weaken mechanical strength due to interfacial flaws, but using titanate coupling agents to modify the surface can really improve filler dispersion and adhesion, leading to a big jump in tensile strength.

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