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The Effect of Additives on the Mechanical and Physical Properties of Polyvinyl Chloride (PVC) Compounds

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***Abstract**: Polyvinyl Chloride (PVC) is one of the most widely used plastic materials globally, owing to its versatility and cost-effectiveness. However, its inherent thermal instability and rigidity necessitate the incorporation of various additives to enhance its processability and final product properties. This paper investigates the influence of common additives—specifically calcium carbonate (as a filler), tin carboxylate (as a stabilizer), and impact modifiers—on the mechanical and physical characteristics of rigid PVC compounds, particularly those used in pipe manufacturing. The study is based on the formulation and testing of three distinct PVC blends (A, B, and C) with varying proportions of calcium carbonate and stabilizers. The methodology focuses on compounding and impact testing, aiming to determine the optimal formulation for improved performance and reduced raw material cost. The findings are expected to contribute to the development of more durable and cost-efficient PVC pipe formulations.*
Keywords: Rigid PVC compounds; calcium carbonate filler; tin carboxylate stabilizer; impact modifiers; mechanical properties; pipe formulation optimization.

1. Introduction

Polyvinyl Chloride (PVC) has maintained its position as a critical material in the construction and industrial sectors for over five decades [1]. Its broad application range, from window frames and wire insulation to piping, is a testament to its adaptable nature. The base PVC polymer is a white, odorless powder that is inherently rigid and thermally sensitive, requiring compounding with various additives to achieve the desired end-product characteristics [2]. These additives facilitate processing and determine the final properties, including mechanical strength, thermal stability, and color [3]. The primary challenge in PVC processing is its susceptibility to thermal degradation at temperatures above 150°C, which leads to the release of hydrogen chloride gas and a rapid deterioration of mechanical properties [4]. Therefore, stabilizers are essential components in all PVC formulations. Furthermore, the use of fillers, such as calcium carbonate ($CaCO_3$), is a common practice to reduce raw material costs, increase stiffness (E-modulus), and improve hardness [5**].** Impact modifiers are also crucial for enhancing the material's resistance to breakage during handling and service [6]. This study focuses on evaluating the performance of PVC compounds formulated with varying levels of these key additives, mirroring the industry's continuous effort to balance performance and cost. Recent research has extensively explored methods to enhance the performance and sustainability of PVC compounds, particularly through the use of various additives and fillers. Wang et al. (2020**)** investigated the effect of organic tin, calcium–zinc, and titanium composites as reinforcing agents on the thermal stability of PVC, finding that the addition of organic tin (OT) at 0.5 phr resulted in excellent thermal stability [7]. Similarly, the role of fillers in improving mechanical properties has been a major focus. Samuilova et al. (2024) studied plant-filled polymer composites based on highly plasticized PVC, concluding that the plant filler significantly improved mechanical characteristics, suggesting its potential as a substitute for unfilled PVC compounds [8]. In the context of sustainability, Ali (2024) explored the use of viable metal oxides additives in the thermo-chemical processes of plastic waste, including PVC, finding that these additives enhanced the formation of alkanes during co-pyrolysis [9]. Jiang et al. (2020**),** focusing on selective modification for plastic flotation, noted that various additives are applied to improve PVC properties and that enhanced surface hydrophilicity leads to the sinking of PVC, a key factor in recycling processes [10]. Jiang et al. (2021) further established a novel and clean flotation method to separate PVC and polycarbonate micro plastics using selective aluminum coating, leveraging the strong affinity of aluminum for the PVC surface [11]. The mechanical response of PVC composites has also been analyzed in detail; Liu et al. (2023**)** described a new method for preparing composite materials using PVC films and polyurethane foam elastomers, which could lead to materials with tailored mechanical properties [12]. Minale et al. (2025) investigated the mechanical properties of PVC/TPU blends enhanced with a sustainable bio-plasticizer, revealing that the bio-plasticizer significantly increased flexibility and elongation at break, although it reduced thermal stability [13]. Dziendzioł (2025**)** also studied new biobased plasticizers for PVC derived from saturated compounds, analyzing their physicochemical, mechanical, and thermal properties to determine their plasticizing effect in PVC blends [14]. Zhou (2025) reviewed the physical and chemical modifications of nano-SiO_2 and the preparation methods of SiO_2 PVC composites, highlighting the potential of nanocomposites for enhanced performance [15]. Dastnaei (2025) provided a review of recent findings on the role of fillers and their influence on the mechanical and physical properties of composites, emphasizing that the interaction between the filler and the matrix is crucial for material properties [16]. Mnyango and Hlangothi (2024) reviewed PVC applications and end-of-life management, noting that additives like {NaOH}and/or $CaCO_3$ can be used in recycling processes and that the COVID-19 pandemic impacted the PVC market in 2020 [17]. Bhide (2020) discussed the role of stabilizers, mentioning that sulfur-free organotin carboxylates (like tin maleates) are used and that calcium carbonate is the predominant filler in PVC [18]. Kuspanov

(2024) investigated the effect of calcination temperature on the morphology and photocatalytic activity of materials, a process relevant to the preparation of certain fillers used in PVC [19]. Hadi (2025) conducted a thermo-mechanical investigation on functional polymeric membrane materials, revealing increased flexibility and heat resistance in certain PVC blends [20]. Campisi (2025) reviewed PVC, its additives, and microplastic formation, noting that additives can be used to obtain both rigid (PVC-U) and softened PVC [21]. Ademola (2025) found that reinforcement with particulate fillers is effective in enhancing PVC mechanical properties, particularly in PVC reinforced composites [22]. Ganapathy et al. (2024) reviewed eco-friendly fillers for polymer composites, pointing out that many raw polymers have insufficient mechanical properties and require additives like UV stabilizers [23]. Finally, the effect of $CaCO_3$ on PVC pipe properties was highlighted by Rollepaal (2025)**,** who stated that a higher $CaCO_3$ level increases the E-modulus, making the material stiffer [24]. This body of work underscores the complexity and ongoing innovation in PVC compounding to meet diverse application requirements.

2. MATERIALS AND METHODS

The materials and methods employed in this study are based on the compounding and testing procedures for rigid PVC pipe formulations. The core objective is to evaluate the performance of three distinct PVC blends (Specimens A, B, and C) with varying compositions of key additives.

2.1. Materials

The PVC compounds were prepared using the following components:

Material	**Role**
PVC Resin	Base Polymer
Calcium Carbonate ($CaCO_3$)	Filler / Cost Reducer
Stabilizer (Tin Carboxylate)	Thermal Stabilizer
Titanium Dioxide {Tio_2)	Pigment / UV Stabilizer
Mercowax	Lubricant
Impact Modifier	Enhances Impact Resistance
Ultramarine Blue / Carbon Black	Color Pigments

2.2. Compounding Formulations

Three different formulations were prepared, with quantities expressed in parts per hundred parts of resin (PPH), as detailed in Table 3.1. The primary variables are the $CaCO_3$ content and the stabilizer concentration.

Table 3.1: Compounding Formulations (PPH)

Materials	**Specimen A**	**Specimen B**	**Specimen C**
PVC Resin	100	100	50
Calcium Carbonate	25	75	50
Stabilizer (Tin Carboxylate)	0.31	0.58	0.21
Titanium Dioxide	0.30	0.30	0.10
Mercowax	0.30	0.60	0.30
Impact Modifier	0.15	0.30	0.10
White pipe - Ultramarine Blue	0.20	0.20	0.20
Gray pipe - Carbon black	0.20	0.20	0.20

2.3. Compounding Process

The PVC resin and additives were mixed using a high-speed mixer to ensure a homogeneous blend. The mixing process is critical for proper dispersion of the additives and achieving the desired compound properties. The resulting dry blend was then processed, likely through extrusion, to form the final pipe specimens.

2.4. Impact Test

The impact resistance of the thermoplastic pipe specimens was evaluated using a drop-weight impact test, which provides a measure of the material's resistance to breakage during handling and installation [25].

Procedure:

1 A piece of the pipe specimen of a certain length was placed in the lower area of the testing device.
2 A block of specific weight, determined according to the thickness and length of the pipe, was attached.
3 The block was allowed to fall from a specified height onto the pipe specimen.
4 The test was conducted at two different drop heights: 20 cm and 30 cm.
5 The result was recorded as "Pass" if the pipe endured the shock without failure, or "Fail" otherwise.

Table 3.2: Impact Test Results

Specimen	Height of the block (20 cm)	Height of the block (30 cm)
A	Pass	Pass
B	Pass	Pass
C	Pass	Pass

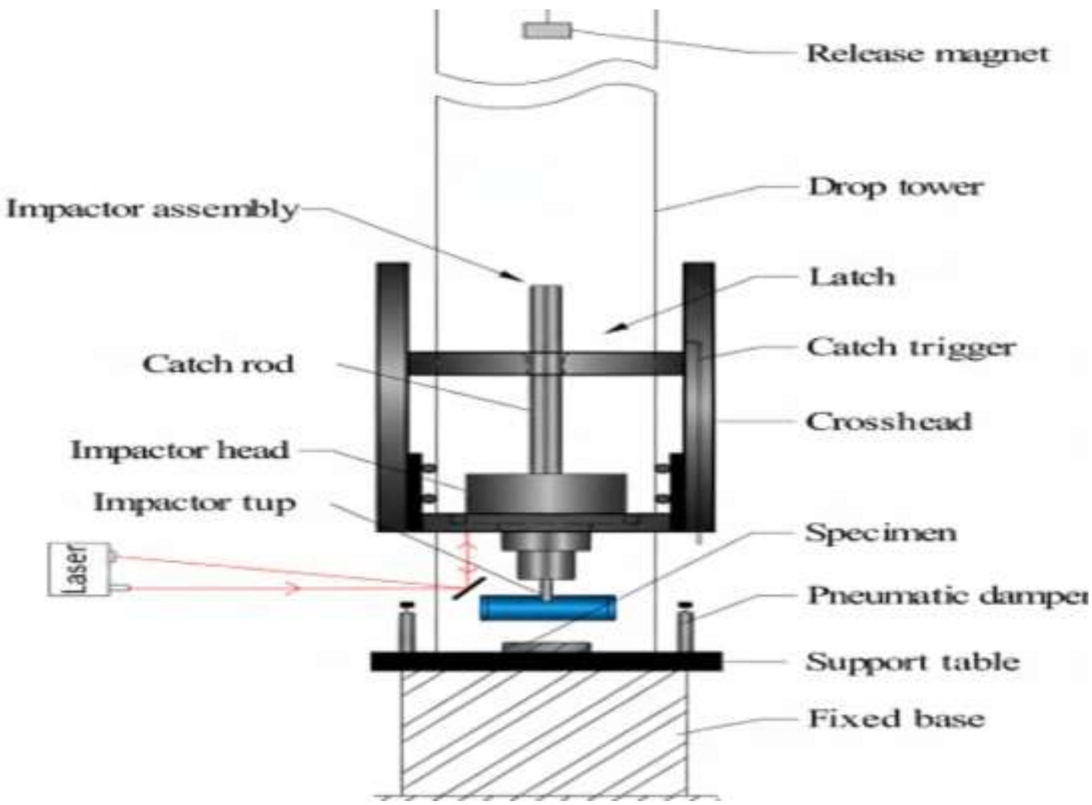

Figure 1: Schematic Diagram of the Drop-Weight Impact Test Setup

3. RESULTS AND DISCUSSION

The impact test results, as summarized in Table 3.2, indicate that all three formulations (A, B, and C) successfully passed the impact test at both 20 cm and 30 cm drop heights. This suggests that even the formulation with the highest filler content (Specimen B, 75 PPH {$CaCO_3$) and the formulation with the lowest overall component quantities (Specimen C) maintained sufficient impact resistance for the tested conditions.

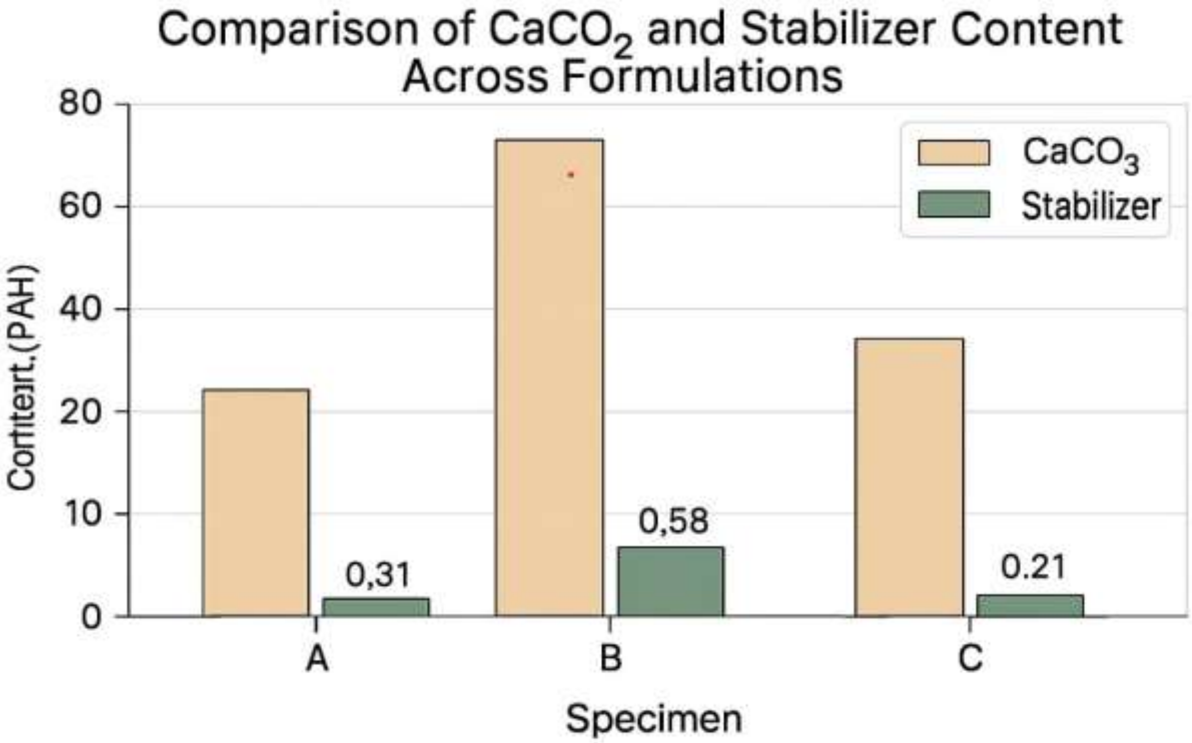

Figure 2: Comparison of $CaCO_3$ and Stabilizer Content Across Formulations

The successful performance of Specimen B, which contains three times the $CaCO_3$ of Specimen A, is particularly noteworthy. This demonstrates that a significant increase in filler content can be achieved without compromising the critical impact strength, provided the stabilizer and impact modifier levels are appropriately adjusted (Specimen B has higher stabilizer and impact modifier content than A). This finding supports the economic objective of reducing raw material costs through increased filler loading while maintaining product quality. Specimen C, despite having the lowest PPH of PVC resin (50 PPH) and the lowest stabilizer and impact modifier levels, also passed the test. This suggests that the ratio of additives to the base resin in Specimen C is still adequate to provide the necessary thermal stability and impact resistance for the tested pipe dimensions. Further analysis, including density, tensile strength, and thermal stability tests, would be required to fully characterize the differences between the three formulations and determine the optimal balance of cost and performance.

4. CONCLUSION

This study successfully demonstrated that rigid PVC pipe compounds formulated with varying levels of calcium carbonate, tin carboxylate stabilizer, and impact modifier can achieve the required impact resistance as measured by the drop-weight test. All three tested formulations passed the impact test at both 20 cm and 30 cm drop heights. The results suggest that increasing the filler content (Calcium Carbonate) to 75 PPH (Specimen B) is feasible without compromising impact strength, which is a key finding for cost optimization in PVC pipe manufacturing. Future work should focus on a comprehensive characterization of the mechanical and thermal properties of these compounds to fully validate the optimal, cost-effective formulation.

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