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SHORT COMMUNICATION

Curing and Mechanical Properties of Polyvinyl Chloride Waste and Acrylonitrile Butadiene Rubber Blends for Environmentally Friendly Polymer Applications

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ABSTRACT

Acrylonitrile-butadiene rubber (NBR), also known as Buna-N, is widely used in the automotive industry due to its excellent oil resistance. On the other hand, polyvinyl chloride (PVC) is one of the most important thermoplastics in the plastics industry, second only to polyethylene, with a global annual production capacity of more than 30 million tons. Disposal of polyvinyl chloride is commonly done via incineration. This polymer's high chlorine concentration makes complete combustion challenging. In addition, when it breaks down thermally, hazardous dioxins and furans are produced, and incorrect incineration conditions fuel public outrage. In this study, a composite of PVC (waste) and NBR was developed, with calcium carbonate added as a filler to neutralize hydrogen chloride released during degradation. The compatibility of waste PVC powder with NBR was assessed by evaluating the tensile and tear strength of the resulting samples. No significant difference was observed in tensile or tear strength across positions of the composite (one-way ANOVA, $p>0.05$), indicating uniform dispersion. Therefore, these data allowed for the conclusion that the integration of waste polyvinylchloride and acrylonitrile butadiene rubber has been accomplished effectively. The mean tensile strength of the blend was 3.77 MPa when the NBR to PVC ratio was 60:40, and the tensile strength remained below 5 MPa. Along with that the resulting polymer composite exhibited a modulus of 2.35 MPa, and a tear strength of 18.04 N/mm at an NBR to PVC ratio of 60:40. This combination not only demonstrates compatibility but also provides a final homogeneous dispersion with desirable physical properties. Moreover, these findings suggest that the composite material has the potential to be further enhanced and utilized as an effective raw material for product development in a variety of industries.

Keywords: *Acrylonitrile rubber blends, Compatibility, Polyvinyl chloride, Stability, Waste polyvinyl chloride*

INTRODUCTION

Compounding is multidisciplinary science that involves adjusting the properties of rubber, elastomers, or blends of polymers and other materials to fulfill specific service requirements or performance standards (Bandyopadhyay, 2024). The uniform mixture of rubber compounds, prepared using rubber additives such as processing aids, fillers, and curing agents, possesses unique physical and chemical characteristics (Rodgers *et al.*, 2005; Sisanth *et al.*, 2017).

Popular polyvinyl chloride (PVC) has excellent mechanical, electrical, chemical, and heat resistance qualities as well as a long lifespan. In the years 2017-2018, 5.5 million tons of PVC were produced per year and 75% of it was used for industrial applications (Plepiene *et al.*, 2021). In the last few years, the rapid development of plastic has caused many environmental problems. Many countries of the world dump this PVC waste into the landfill (Wojnowska *et al.*, 2022). However, in the near future, the need to adopt waste recycling methods has arisen due to the limited availability of suitable landfill sites.

The industry has been using blends of PVC and acrylonitrile-butadiene rubber (NBR) extensively in recent years (Lai *et al.*, 2023). The miscibility of PVC with NBR depends on its additives and processing conditions and is mainly influenced by the acrylonitrile (AN) content in the NBR (Komori *et al.*, 2023). Recycled PVC powder mitigates environmental harm and offers a more cost-effective alternative to newly manufactured PVC powder. PVC improves the ozone resistance, chemical resistance, thermal ageing and abrasion resistance of NBR (Shokri *et al.*, 2006; Pappa *et al.*, 2011). In addition, most NBR/PVC blends have oils, fuel and solvent resistance characteristics (Maciel *et al.*, 2013).

Calcium carbonate is traditionally used as a bulking agent (filler) to replace expensive polymers in plastics. Calcium carbonate ($CaCO_3$) particles at an aspect ratio close to unity are expected to change the viscosity of the polymer melt. Their favorable thermal conductivity contributes to the homogeneity of the melt and promotes good dispersion within the polymer matrix (Gorna *et al.*, 2008). In addition, it gives stability and UV resistance to the PVC. Stearic acid and zinc oxide (ZnO) are the two most important activators for sulphur vulcanization. Both of these activators have a marked influence on the rate and degree of crosslinked network formation in vulcanizates (Beniska and Dogadkin, 1959; Shokri *et al.*, 2006). Some studies report that phthalate plasticizers have lower mass loss compared to non-phthalate plasticizers (Tüzüm and Ulutan, 2013). Dioctyl phthalate (DOP) is a plasticizer used specifically for PVC (Dalagnol *et al.*, 2022). For usage with PVC resin DOP has a wide range of compatibility, outstanding heat and UV light stability, and excellent hydrolysis resistance. The above properties are helpful to further improve the product. All these materials are mixed and fluxed using typical machinery for this purpose, such as two-roll mills.

In this study, the process-level dispersion uniformity of PVC powder with NBR was assessed by evaluating the tensile and tear strength of the resulting samples, and the novelty lies in utilizing recycled PVC waste as a functional component in NBR blending (ratio 60:40), together with the strategic use of calcium carbonate to stabilize the system during processing. This approach not only addresses PVC waste-management challenges but also evaluates, the compatibility and mechanical integrity of NBR/waste-PVC composites prepared using conventional rubber-processing techniques.

MATERIALS AND METHODS

Acrylonitrile-butadiene rubber was used the polymer in the present study. PVC in powder form was blended with NBR. A combination of zinc oxide (ZnO) and stearic acid was used as the activator system for vulcanization of NBR. Dioctyl Phthalate (DOP) was utilized as the plasticizer. White oil was used to soften the rubber products that are made. Sulphur and Tetramethylthiuram disulfide (TMTD) were used as vulcanizing agents. Other additives, calcium carbonate ($CaCO_3$) and N-tert-butyl-benzothiazole sulfonamide (TBBS), were used as filler and an accelerator, respectively. The rubber compound was prepared using two-roll mill. In addition, a Mooney Viscometer and Compression Moulding Machine were used.

PVC powder was prepared using waste PVC pipes. The PVC pipes were washed thoroughly with distilled water and air dried, ground, and the powder was sieved using a 1 mm sieve. The compound was prepared by incorporating ingredients as shown in Table 1. Five replicates were prepared.

Table 1: Formulation of rubber compound

Ingredient	Parts per hundred Rubber	In grams
NBR	55	134
PVC	45	60
ZnO	4	6
Stearic Acid	1	1.5
DOP	20	30
White oil	0.5	0.75
$CaCO_3$	10	15
Sulphur	2	3
TBBS	0.7	1.05
TMTD	0.5	0.75

Acrylonitrile-butadiene rubber was masticated using a Two Roll Mill (CT Thailand) in 125°C with a 70°C down temperature, (roller diameter was 152.4 mm) and ZnO and stearic acid were added while adding PVC powder in small portions. Dioctyl phthalate and white oil were added along with $CaCO_3$ in two stages. White oil was added to increase the processability. The second stage of mixing was done by adding TBBS (primary accelerator) and TMTD (secondary accelerator) along with sulphur. After the preparation of the compound, curing characteristics were measured using a Mooney Viscometer (Figure 1). The compound was cured using the Compression Moulding Machine at 125°C for 22.58 min. Tensile (ASTM D638) and tear tests (ASTM D624) were also conducted.

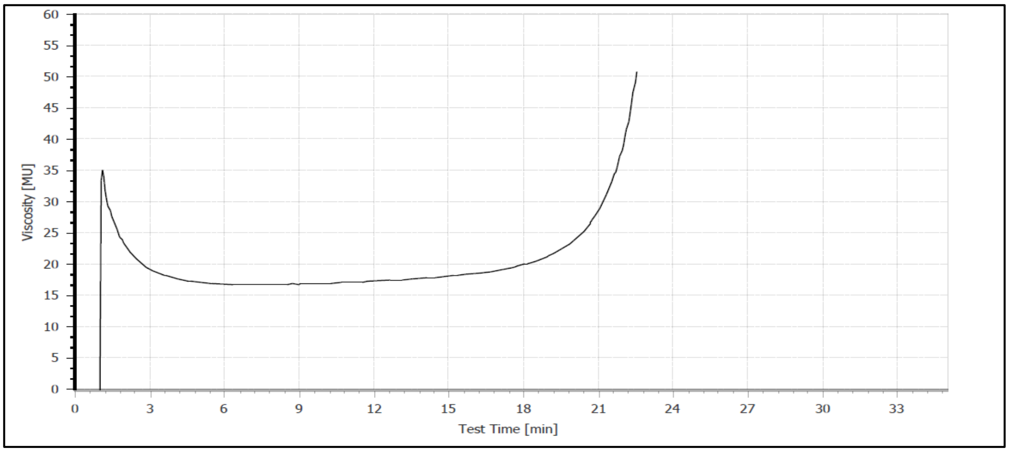

Figure 1: Curing time for compression moulding

RESULTS AND DISCUSSION

The compound that was prepared using waste PVC and NBR was greyish both prior to and after vulcanization. Figure 2 and figure 3 show the compound of NBR-PVC prior and after vulcanization, respectively. The vulcanized sample had a smooth surface.

Figure 2: The compound before vulcanization

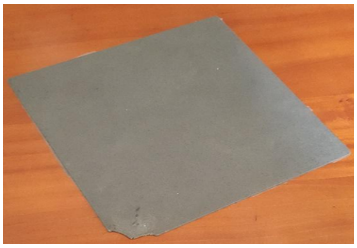

Figure 3: The compound after vulcanization

The prepared compound exhibited an equally distributed greyish colour without unevenly distributed patches. Therefore, according to the visual observations, NBR and waste PVC particles may be well distributed throughout the sample. This can happen due to the increased interaction between NBR and PVC blends

To provide additional clarity, tensile and tear tests were carried out. According to Table 2 and Table 3, the tear and tensile strengths had only slight deviations. Therefore, it can be concluded that the ingredients were effectively distributed, indicating favourable compatibility between NBR and waste PVC.

Table 2: The tensile strength of the sample pieces

Sample Piece (N=5)	Tensile Strength (MPa)	Modulus at 100% (MPa)
1	3.77	2.64
2	3.75	2.32
3	3.62	2.48
4	3.81	2.35
5	3.95	2.2

Table 3: The tear strength of the sample pieces

Sample Piece (N=3)	Tear Strength (N mm^{-1})
1	18.34
2	18.62
3	17.15

The mean tensile strength of the blend was 3.77 MPa when the NBR to PVC ratio was 60:40, and the tensile strength remained below 5 MPa. This indicates that the novel compound has a good tensile strength. The NBR:PVC ratio of 60:40 was selected because higher PVC levels can reduce elasticity, cause phase separation, and increase thermal degradation during processing, especially when using waste PVC (Lai *et al.*, 2025). This ratio provides sufficient PVC to assess its potential as a recycled raw material while preserving the flexibility and processability of NBR. It also ensures stable mixing and vulcanization, as supported by the acceptable tensile (3.77 MPa) and tear (18.04 N/mm) strengths obtained. Therefore, the chosen ratio provides a practical balance between mechanical performance, process-level homogeneity, and the effective utilization of waste PVC. When the PVC percentage of the NBR/PVC blend is increased up to 11.1 weight percent, it declines in tensile strength (Seo *et al.*,1995). In comparison to PVC/NBR blends with calcium carbonate as a partitioning agent, the PVC/NBR blends using PVC as a partitioning agent displayed a higher tensile stress (Gheno *et al.*, 2009).

At the same time, the mean tear strength was 18.04 N mm^{-1} and the traditional NBR/PVC blend has a tear strength of around 30 kN mm^{-1} (Dharmaraj *et al.,* 2022). However, PVC resin lowers the elasticity of NBR molecular chains, allowing stresses to concentrate on certain chains, resulting in chain breakage and drastically reduced tensile strength and elongation (Al-Mosawi *et al.*, 2019). Given this consideration, the utilisation of waste PVC could yield similar mechanical properties.

CONCLUSION

The present study demonstrated that recycled PVC waste can be incorporated into NBR using conventional rubber-processing techniques, resulting in compounds with usable tear and tensile properties. Visual observations, along with the tensile and tear strength measured at different positions of the sheets, indicate acceptable dispersion and a reasonable level of compatibility between NBR and waste PVC at the selected blend ratio. While the mechanical properties are lower than those reported for NBR/PVC blends with virgin materials, the results confirm that waste PVC can contribute to a functional composite with basic performance suitable for further exploration. In addition to its technical feasibility, the utilization of recycled PVC waste in NBR offers environmental benefits by facilitating waste valorization, minimizing landfill disposal, and reducing reliance on virgin polymer resources. Additional studies, such as advanced morphology analysis, thermal stability tests, and evaluation of different blend ratios, are necessary to rigorously evaluate interfacial compatibility and enhance the mechanical performance of NBR/waste-PVC composites. Given that this study is preliminary in nature, more extensive and detailed analysis is essential to validate the observed trends and to develop a deeper understanding of the underlying structure-property relationships within the material system.

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