Multi-Walled Carbon Nanotube - Nano Silicon Carbide Particles on Functional Behaviour of High Density Polyethylene Composites

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**Abstract.** The effects of using nano-sized silicon carbide particles and multiwalled CNT to reinforce HDPE are investigated in the current study. Standardized compression molding was used to create the composites. Because of the natural rigidity of ceramics the incremental addition of n-SiC (2.5 to 7.5 weight percent) further increased flexural and impact strength and the addition of 1.5 weight percent MWCNT improved load transfer and tensile stiffness. According to mechanical tests, the ideal formulation (i.e) HDPE + 1.5 weight percent MWCNT + 5 weight percent n-SiC improved impact resistance by 50% and tensile strength by up to 80% when compared to clean HDPE and these results demonstrate the promise of these nanocomposites for high-performance, lightweight automobile applications.

# Introduction

The semicrystalline polymer known as high density polyethylene is prized for its superior chemical resistance, simplicity of production and affordability. However its use in loadbearing or structural applications is restricted by its generally poor mechanical qualities, particularly its tensile strength and impact resistance. By improving stiffness, energy dissipation and stress transmission, the incorporation of nanofillers has become a viable way to improve these characteristics. Multi-walled carbon nanotubes, are well known for their notable Youngs modulus (1 TPaapprox) and tensile strength (60 GPaapprox). They are perfect for increasing tensile and flexural strength because of their high aspect ratio and robust interfacial contact with polymer matrices. However, when appropriately distributed in polymers, nano silicon carbide, a ceramic material with high hardness (25 GPaapprox), thermal conductivity and wear resistance, effectively improves stiffness and impact performance.

The mechanicalcharacteristics, thermalcharacteristics and tribological characteristics of these high density polyethylene composites supplemented with hybrid nanofillers such as nano silicon carbide and multiwalled carbon nanotubes (MWCNTs), have significantly improved. The special qualities of the fillers and their cooperative interactions within the polymer matrix are primarily responsible for these improvements. Because of the strong interfacial bonding of fillers and efficient stress transfer Padhy and Kandasubramanian (1) showed that adding both MWCNTs and SiC nanoparticles to ultra high molecular weight polyethylene greatly increased tensile strength. Functionalized silicon carbide nanotubes in polymer matrices enhanced mechanical performance and fracture resistance through efficient nanoscale load transfer processes according to molecular dynamics investigations [1-5] crosslinked polyethylene nanocomposites that were enhanced with hybrid nanofillers. They found that the dielectric, mechanical and thermal characteristics were significantly enhanced by the hybridization process. According [6-9], who studied a range of hybrid composites, the combination of graphene and carbon nanotubes in polymer matrices may result in superior reinforcing effects in the mechanical and thermal domains. The combination of MWCNTs and n-silicon carbide in HDPE is consistent with this concept. Research [10] used a unique micromechanical model to assess interfacial characteristics in polymer nanocomposites. They concluded that composite strength depending on filler distribution may be predicted using particle identification techniques which is important for materials that contain many nanofillers.

Research [11]analyzed friction stir (spot) welding in lightweight structures and the significance of nanocomposite reinforcement in enhancing weld strength and thermal stability that suggests a growing tendency towards integrating hybrid fillers with sophisticated processing. Research [12-14] concentrated on polyaniline nanocomposites reinforced with carbon nanofillers providing supplementary information on filler dispersion methods that may also be useful for HDPE systems. Using compression and heat pressing [15-18]investigated hybrid nanocomposites that combine carbon fibres and nano silicon carbide. They validated improved tensile and impact strength performance supporting earlier findings that dual filler systems provide superior reinforcing over single filler composites. silicon carbide nanoparticles were used in hybrid ultra high molecular weight polyethylene composites for biological applications by Mishra and Gangwar (9) in a similar manner.

Research [19], who examined recent developments in polymers including metal oxide nanocomposites demonstrated that hybrid fillers also improved tribological performances. Hybrid fillers they pointed out, offer better wear resistance, which is essential for applications subjected to dynamic loading. In addition [20-25] investigated composites containing copper oxide nanoparticles in a poly(vinylpyrrolidone) matrix and emphasized the significance of matrix filler compatibility and nanoparticle dispersion in reaching the intended structural and optical qualities. In a detailed assessment of the impacts of melt blending in polymer nanocomposites, Albdiry (12) discovered that filler alignment and distribution two important factors when combining MWCNTs with n-SiC are significantly impacted by processing conditions. A thorough review of micro- and nano fillers in value-added polymer composites was given [26-28] who also highlighted the strategic importance of hybrid fillers in modifying composite behavior for certain engineering applications. SiC reinforced polyethylene composites made by injection molding shown improved tensile and hardness properties in experimental studies conducted by [29-31], confirming the idea that hybrid nanofillers increase the stiffness and strength of HDPE-based systems. Lastly, [32-35] evaluated recycled HDPE composites reinforced with carbon nanotubes using representative volume element (RVE) modelling and simulation. This study demonstrated the possibility of obtaining dependable mechanical properties through predictive modelling, which can be extended to HDPE - MWCNT- SiC hybrids for design stage optimisation.

Due to synergistic interaction within the HDPE matrix the study's premise is that a dual-filler system—MWCNT for load transfer and n-SiC for rigidity will perform better than single-filler systems. Finding the ideal filler composition to maximise mechanical performance while preserving low density and processability is the aim of this effort.

# Materials and Methods

## Materials

Due to its excellent mechanical stability processing qualities and chemical resistance these polyethylene was selected as the polymer matrix for analysis and the HDPE grade was used in this study has melt flow index of 4 g/10 min that made it perfect for compression molding applications requiring reliable filler dispersion and effective melt flow during fabrication. With a fixed loading of 1.5 weight % multiwalled carbon nanotubes were employed as reinforcing agents. A high aspect ratio produced by the MWCNT average diameter of 10–20 nm and length of 10–30 µm enhances the mechanical strength, electrical conductivity and thermal performance. To enhance the structural and functional qualities, nano sized silicon carbide particles which have an average size of around 50 nm were added at concentrations of 2.5 weight %, 5 weight % and 7.5 weight %.

## Composite Preparation and Formulations

Moisture was removed from all materials by drying them for 12 hours at 80°C. A high speed mixer was used for dry blending and for ensuring uniform dispersion and minimize void formation the powder mixture was processed in compression moldingunder 10 MPa pressure at for 10 minutes 180 °C.

5 different compositions were created to observe the influence of hybrid nano reinforcements on the functional performance of high density polyethylene composites with the first composition functioned as the control sample and it was made entirely of pure HDPE with no filler. The second composition consisted of HDPE reinforced with 1.5 wt% multiwalled CNTsfor determining the individual effect of nanotube reinforcement. The third, fourth and fifth compositions had a fixed 1.5 wt% MWCNT as well as varied percentages of nano sized silicon carbide (n-SiC) particles at 2.5, 5, and 7.5 wt%, respectively. These hybrid formulations were developed to investigate the synergistic relationship between MWCNTs and n-SiC in refining the mechanical, thermal and Surface performances of the HDPE matrix. The study sought to identify the best reinforcement combination for achieving improved composite properties by systematically altering the n-SiC concentration while maintaining a constant MWCNT level.

## Characterization Techniques

The impact of MWCNT and n-SiC reinforcement, tensile, flexural and impact testing were used to mechanically characterize the produced HDPE based composites in compliance with established protocols. In order to determine the strength and ductility of the composites and tensile tests were conducted in accordance with ASTM D638 criteria in a universal testing machine of 50 mm/min as crosshead speed. A 3 point bending setup and the ASTM D790 procedure flexural characteristics were evaluated to find stiffness and resistance to bending deformation and in order to find fracture propagation under dynamic loading circumstances impact strength was assessed from the Izod impact method in accordance with ASTM D256 utilising notched specimens. Three specimens from each composition group were made and evaluated for each test in order to assure statistical validity. The mean values of the results were then computed and presented in order to appropriately represent the mechanical performance.

# Results and Discussion

## Tensile Strength Analysis

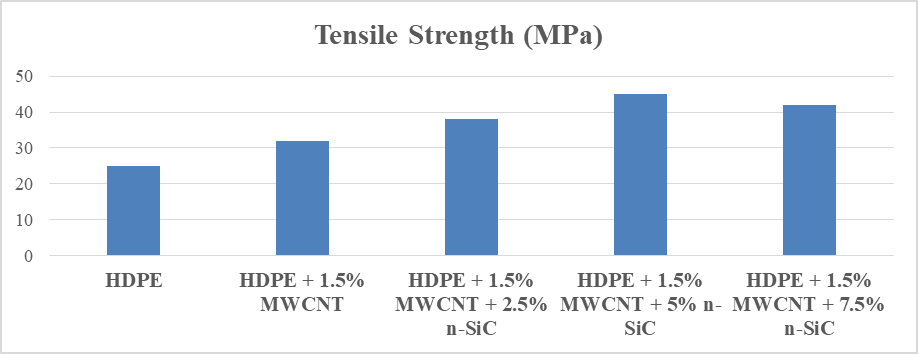
When hybrid nano-reinforcements were added to HDPE composites, their tensile strength increased significantly. The neat HDPE sample had a baseline tensile strength of about 25 MPa. The inclusion of 1.5 wt% multi walled carbon nanotubes boosted tensile strength significantly due to the nanotubes' superior loadbearing capacity and high aspect ratio, allowing for operative stress transmission from the HDPE matrix to the reinforcement. This was primarily as a result of the strong interfacial interface between the MWCNTs and the HDPE matrix which played an important role in limiting polymer chain slippage under tensile stress [36-39].

The addition of nanoscale silicon carbide particles resulted in even greater gains. Tensile strength increased dramatically when 2.5 wt% n-SiC was coupled with 1.5 wt% MWCNTs, and the trend persisted at 5 wt% n-SiC reaching a high tensile strength of 45 MPa. This was an 80% improvement above unreinforced HDPE demonstrating the effect of the dual reinforcing method. The addition of n-SiC increased the composite's overall stiffness and limited the mobility of the polymer chains hence improving resistance to tensile deformation. The nanoscale dispersion of SiC also provided effective stress transfer points and served as crack propagation inhibitors.

However, above the 5 wt% loading of n-SiC, a minor decrease in tensile strength was found. At 7.5 wt% n-SiC, the tensile strength dropped marginally to 42 MPa. This reduction was attributed to the tendency of nano-SiC particles to clump together at higher concentrations due to van der Waals interactions and surface energy effects. Such aggregation causes poor dispersion, stress concentration areas, and probable matrix flaws, preventing efficient load transfer and weakening the composite structure [41-44].

**TABLE 1.** Mechanical Properties Summary Table

|  |  |  |  |
| --- | --- | --- | --- |
| **Composite** | **Tensile Strength (MPa)** | **Flexural Strength (MPa)** | **Impact Resistance** |
| HDPE | 25 | 28 | 60 |
| HDPE + 1.5% MWCNT | 32 | 34 | 72 |
| HDPE + 1.5% MWCNT + 2.5% n-SiC | 38 | 40 | 80 |
| HDPE + 1.5% MWCNT + 5% n-SiC | 45 | 48 | 90 |
| HDPE + 1.5% MWCNT + 7.5% n-SiC | 42 | 45 | 85 |

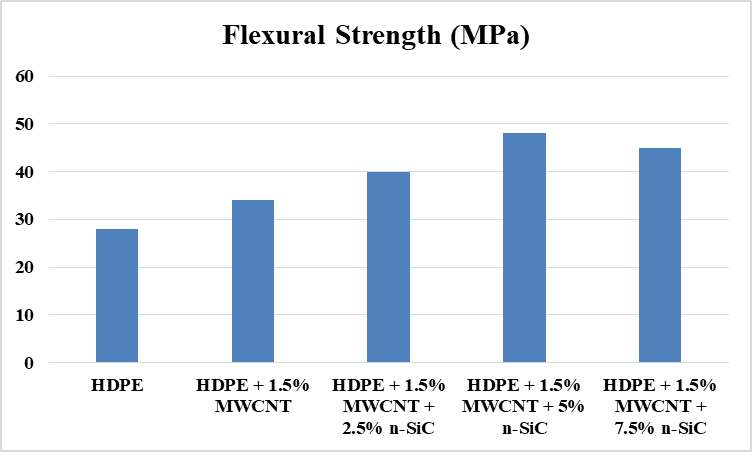


**Figure 1.**Tensile strength

## Flexural Strength Enhancement

The accumulation of hybrid nano reinforcements increased the flexural strength of the HDPE composites indicating better stiffness and resistance to bending deformation. The unfilled HDPE has a baseline flexural strength of about 28 MPa indicating its poor stiffness but inclusion of 1.5 wt% multi walled CNTs boosted flexural strength due to their capacity to bridge microcracks and withstand localized deformation which improved the composite's integrity under bending stresses. MWCNTs, with their high tensile strength and large aspect ratio served as excellent stress transfer agents strengthening the matrix and spreading the applied load more uniformly throughout the material [45-46].

The gradual integration of nano-sized silicon carbide (n-SiC) particles resulted in an even greater increase. At 5 wt% n-SiC loading and 1.5 wt% MWCNTs, the flexural strength peaked at 48 MPa, representing a 71% improvement over pristine HDPE. This large improvement is mostly due to the intrinsic rigidity and brittleness of ceramic n-SiC particles which contributed to increased structural stiffness and resistance to flexural stress. The homogeneous dispersion of n-SiC at this concentration successfully restricted polymer chain mobility and served as reinforcing nodes under bending pressures [47-48].



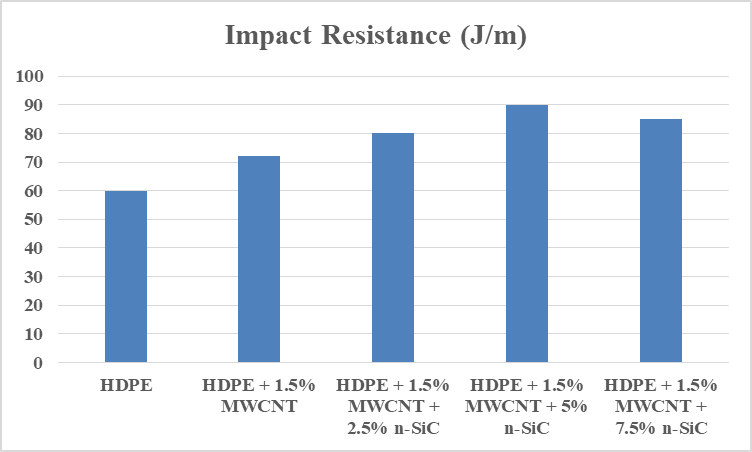
**Figure 2.** Flexural strength

The flexural strength decreased marginally to 45 MPa at 7.5 wt% n-SiC. This drop was most likely caused by the commencement of particle agglomeration at increasing filler concentrations. Clustering of n-SiC disrupted matrix homogeneity resulting in local stress concentrations and reduced reinforcing efficiency. Despite this all reinforced composites outperformed pure HDPE in terms of flexural performance [49-50].

## Impact Resistance Improvement

The use of hybrid nano reinforcements considerably increased the impact strength of HDPE based composites indicating improved energy absorption and toughness. The pristine HDPE sample had a baseline impact strength of 60 J/m, indicating its inherent ductility but limited capacity to withstand abrupt crack initiation and propagation. The addition of 1.5 wt% multi walled CNTs increased impact strength significantly affects the nanotube ability to efficiently distribute impact energy throughout the matrix. MWCNTs' high aspect ratio and outstanding mechanical strength allowed them to operate as crack arresting agents slowing the formation of microcracks under dynamic loading circumstances.

The addition of nano-sized silicon carbide (n-SiC) enhanced the impact resistance. At an ideal n-SiC loading of 5 wt%, combined with 1.5 wt% MWCNTs, the impact strength peaked at 90 J/m, representing a 50% increase over unreinforced HDPE. This improvement is due to their capacity to absorb energy by forming localized microplastic deformation zones surrounding them during impact. These deformations helped to delay crack development and distribute stress more uniformly across the matrix increasing its overall toughness.



**Figure 2.** Impact resistance

However at 7.5 wt% n-SiC the impact strength decreased slightly, dropping to 85 J/m. This decline indicates the onset of brittleness due to particle agglomeration which reduces energy dissipation efficiency and forms weak zones within the matrix. Despite this all reinforced composites outperformed neat HDPE in impact resistance.

## Application in Lightweight Automotive Panels

Materials with a high strength-to-weight ratio, superior impact resistance and consistent thermal stability are necessary in the automotive sector to enhance vehicle performance, safety and fuel economy and these requirements are successfully satisfied by the HDPE based nanocomposites created in this work which provide a well balanced blend of mechanical toughness and lightweight properties. The composite comprising 1.5 weight % multi walled carbon nanotubes and 5 weight % nano sized silicon carbide are most promising performance among the formulations examined that maintained good process ability and low density while displaying superior stiffness, toughness and impact strength.

Without sacrificing HDPE's natural flexibility and formability this optimized hybrid composite achieves notable improvements in mechanical qualities, making it a solid contender for a range of automotive applications. In particular, it works well for producing parts like inner panels for doors, which need to absorb energy from side impacts and provide structural support. Additionally, it has the potential to be used for lightweight brackets or enclosures and under-hood structural supports, where heat resistance, stiffness and vibration dampening are crucial.

A practical benefit is also added by using compression moulding as the processing method, which is popular in the automobile industry due to its inexpensive tooling costs, quick cycle times, and ability to work with complex geometries. As a result the composite is not only highly effective but also profitable for mass manufacturing. Consequently a strategic material solution that is in line with the changing demands of the automobile sector is provided by the suggested HDPE-MWCNT-n-SiC nanocomposites.

# Conclusion

Multi walled carbon nanotubes and nano sized silicon carbide are hybrid nanofillers are effective in refining the mechanical enactment of high density polyethylene composites. Impact resistance, flexural stiffness and tensile strength were significantly increased as a result of the interaction. With the best mechanical performance across all investigated parameters the composite of 1.5 weight % MWCNT and 5 weight % n-SiC was the best formulation out of the five compositions examined. The even distribution of the hybrid nanofillers inside the HDPE matrix facilitates energy dissipation, limited polymer chain mobility and effective stress transfer all of which are responsible for this improved behavior. Whereas a decrease in mechanical characteristics was noted when the n-SiC level was raised over 5 weight % because of this decrease is particle agglomeration which lowers the effectiveness of reinforcing by creating stress concentration sites and weak interfacial bonding. These results highlight how crucial it is to maintain ideal filler loading and achieve homogeneous dispersion in order to optimise composite performance.

Future studies should investigate methods to enhance filler dispersion such as compatibilizers, surfactants or surface functionalisation of n-SiC particles and MWCNTs. Additionally more research on thermal stability, weathering resistance and ageing behaviour is advised in order to confirm the long-term suitability of these composites in actual automotive settings and for demanding engineering applications such studies offer vital insights into the robustness and dependability of HDPE based nanocomposites.

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