

## **Study of Physical and Mechanical Properties of Nanocomposites Incorporating Polysiloxane**

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### **Abstract**

This study delves into the examination of the physical and mechanical attributes of nanocomposites integrating polysiloxane. Polysiloxane, a versatile and widely-used polymer, is chosen as a key component due to its exceptional flexibility, heat resistance, and dielectric properties. By incorporating polysiloxane into nanocomposites, we aim to explore how these desirable characteristics can be enhanced or modified to suit specific applications. The nanocomposites under scrutiny are synthesized by dispersing nanoscale fillers within the polysiloxane matrix. These fillers may include nanoparticles like graphene, carbon nanotubes, or silica nanoparticles, each possessing unique properties that can potentially augment the composite's overall performance. Throughout this investigation, we rigorously assess the physical properties, such as thermal conductivity, electrical conductivity, and thermal stability, alongside mechanical properties such as tensile strength, elasticity, and hardness. By comprehensively understanding the interplay between polysiloxane and nanoscale fillers, we aim to unlock new possibilities for tailoring advanced materials with enhanced physical and mechanical characteristics, thereby opening avenues for innovative applications across various industries.

### **Introduction**

Polysiloxane nanocomposites have garnered significant attention in recent years due to their remarkable physical and mechanical properties. These materials combine the benefits of both polysiloxanes, which are known for their flexibility, thermal stability, and biocompatibility, and nanoparticles, which can enhance mechanical strength, thermal conductivity, and other properties. The introduction of nanoparticles into polysiloxane matrices allows for tailoring the material's characteristics to meet specific application requirements. In this study, we delve into the exploration of the physical and mechanical attributes of polysiloxane nanocomposites. The unique combination of organic and inorganic components in these materials gives rise to

intriguing possibilities for various industries, including aerospace, electronics, and biomedicine. By systematically investigating the effects of nanoparticle type, concentration, and dispersion on the final properties of the nanocomposites, we aim to provide a comprehensive understanding of how these factors interplay. One of the key aspects of our investigation involves the dispersion of nanoparticles within the polysiloxane matrix. The uniform distribution and interfacial interactions between the organic and inorganic phases significantly influence the overall mechanical performance and other functional attributes of the resulting nanocomposite material. We will employ advanced characterization techniques, such as scanning electron microscopy (SEM) and X-ray diffraction (XRD), to analyze the morphology and crystalline structure of the materials at different stages of their synthesis.

The thermal and mechanical properties of these nanocomposites will be thoroughly examined. Differential scanning calorimetry (DSC) and dynamic mechanical analysis (DMA) will be employed to evaluate the thermal transitions and viscoelastic behaviour, respectively. Additionally, tensile testing and hardness measurements will provide insights into the mechanical enhancements achieved through nanoparticle incorporation. This study aims to shed light on the intricate relationship between nanoparticle characteristics, their dispersion within the polysiloxane matrix, and the resulting physical and mechanical properties of the nanocomposites. By advancing our understanding of these relationships, we aspire to contribute to the design and development of tailored polysiloxane nanocomposites with exceptional performance for a wide array of industrial applications.

### **Types of Polysiloxane**

Polysiloxanes, also known as silicones, are a class of polymers that are composed of alternating silicon and oxygen atoms. These polymers can exhibit a wide range of properties depending on the specific chemical groups attached to the silicon atoms and the length of the polymer chains. Here are some common types of polysiloxanes:

Methyl Polysiloxanes (PDMS):

Methyl polysiloxanes, often referred to as polydimethylsiloxanes (PDMS), are one of the most well-known types of polysiloxanes. They are characterized by having methyl (-CH<sub>3</sub>) groups

attached to the silicon atoms. PDMS is widely used due to its excellent thermal stability, low surface energy, and biocompatibility. It finds applications in cosmetics, medical devices, lubricants, and as a base material for elastomers.

#### Phenyl Polysiloxanes:

Phenyl polysiloxanes have phenyl ( $-C_6H_5$ ) groups attached to the silicon atoms. These groups can influence the polymer's properties, making phenyl polysiloxanes more resistant to high temperatures and more suitable for applications requiring thermal stability. They are often used in high-temperature coatings, adhesives, and electronic materials.

#### Vinyl Polysiloxanes:

Vinyl polysiloxanes have vinyl ( $-CH=CH_2$ ) groups attached to the silicon atoms. These groups allow for cross-linking of the polymer chains through radical polymerization reactions. Vinyl polysiloxanes are used in dental impression materials due to their ability to accurately capture fine details and their ease of removal from the mouth.

#### Hydroxyl-Terminated Polysiloxanes:

Hydroxyl-terminated polysiloxanes have hydroxyl ( $-OH$ ) groups at the ends of their polymer chains. These groups enable further functionalization and cross-linking of the polymer. They are used in the production of silicone elastomers and sealants.

#### Amino-Terminated Polysiloxanes:

Amino-terminated polysiloxanes have amino ( $-NH_2$ ) groups at the ends of their polymer chains. These polymers can be used for various applications, including surface modification, adhesion promotion, and as precursors for functional materials.

#### Elastomeric Polysiloxanes:

Elastomeric polysiloxanes are cross-linked silicone polymers that exhibit rubber-like elasticity. They are used to create silicone rubber products, such as gaskets, seals, and medical devices.

#### Fluorinated Polysiloxanes:

Fluorinated polysiloxanes have fluorine atoms incorporated into the polymer structure. These polymers combine the properties of silicones with the chemical resistance and low surface energy of fluoropolymers. They find applications in coatings, release agents, and materials requiring resistance to harsh chemicals.

These are just a few examples of the many types of polysiloxanes that can be synthesized by varying the chemical groups attached to the silicon atoms and controlling the polymerization process. Each type offers distinct properties and advantages, making polysiloxanes versatile materials with a wide range of applications.

### **Need of the study**

In addition to the aforementioned reasons, this study addresses a critical knowledge gap in the field of nanocomposites. While the benefits of nanoparticle incorporation into polymers are well acknowledged, a comprehensive understanding of how these nanoparticles influence the physical and mechanical properties of polysiloxane nanocomposites is still evolving. The lack of in-depth insights hinders informed material design and optimization. By meticulously investigating the interactions, dispersion, and resulting effects on properties, this study aims to contribute valuable insights that can aid researchers and engineers in making informed decisions when developing tailored nanocomposite materials. This knowledge can lead to advancements that not only improve the performance of existing technologies but also inspire the creation of entirely new solutions with far-reaching implications across various industries.

### **Literature Review**

**Schmidt, D. F., & Giannelis, E. P. (2010).** Nanocomposites based on polysiloxane matrices and layered silicate materials have garnered significant attention due to their potential for enhancing material properties in various applications. This study focuses on the dispersion of layered silicates within a polysiloxane matrix and its influence on mechanical reinforcement. We investigate the nanocomposite's microstructure using advanced characterization techniques, including electron microscopy and X-ray diffraction. Our results reveal a well-dispersed layered silicate structure within the polymer matrix, leading to improved mechanical properties. Specifically, tensile strength, modulus, and fracture toughness are found to significantly increase

with the incorporation of layered silicates. To elucidate the reinforcement mechanisms, we delve into the interactions between the polymer chains and the silicate layers at the nanoscale. The intercalation and exfoliation of the layered silicates contribute to enhanced load transfer and improved stress distribution, resulting in the observed mechanical reinforcement. This research highlights the potential of polysiloxane/layered silicate nanocomposites for engineering applications requiring enhanced mechanical properties. The findings presented here offer valuable insights into the design and development of advanced nanocomposite materials with improved performance characteristics.

**Zhang, M. M. et al (2015)** In the quest for advanced composite materials with exceptional mechanical properties, the incorporation of graphene oxide (GO) has shown great promise. This study explores a novel approach in which hyperbranched polysiloxane is used to functionalize GO and enhance its compatibility with cyanate ester matrices, aiming to improve the overall mechanical performance of nanocomposites. Through a systematic synthesis and characterization process, we successfully graft hyperbranched polysiloxane onto GO sheets, ensuring a homogeneous dispersion within the cyanate ester matrix. This functionalization strategy not only enhances the interfacial interactions between GO and the polymer but also mitigates issues related to agglomeration. Mechanical testing of the resulting nanocomposites reveals remarkable improvements in tensile strength, modulus, and impact resistance compared to pristine cyanate ester. The hyperbranched polysiloxane-functionalized GO acts as an effective reinforcing filler, facilitating load transfer and stress distribution within the nanocomposite structure.

### **Literature Review**

**Ramezanzadeh, B., et al (2011)** Automotive and industrial coatings require clearcoats that not only provide aesthetic appeal but also offer robust mechanical properties to withstand harsh environmental conditions. This study delves into the enhancement of a typical acrylic/melamine clearcoat through the incorporation of polysiloxane additives and nano-SiO<sub>2</sub> particles, aiming to improve its mechanical performance. We systematically investigate the impact of polysiloxane additives and nano-SiO<sub>2</sub> on the clearcoat's mechanical properties, including hardness, scratch resistance, and adhesion strength. Through a series of formulations and characterization techniques, we demonstrate that the addition of polysiloxane additives enhances the clearcoat's

flexibility and toughness, reducing brittleness and improving its ability to withstand mechanical stress. Furthermore, the incorporation of nano-SiO<sub>2</sub> particles into the clearcoat results in improved hardness and scratch resistance, making it more resilient to abrasion and wear. This effect is attributed to the reinforcement provided by the nanoscale SiO<sub>2</sub> particles, which act as a barrier and reduce the propensity for surface defects.

**Tjong, S. C. (2006).** Polymer nanocomposites have garnered significant attention in materials science due to their remarkable structural and mechanical properties. These materials consist of a polymer matrix reinforced with nanoscale fillers, such as nanoparticles or nanofibers. The incorporation of these nanofillers imparts several advantageous characteristics to the composites. Structurally, polymer nanocomposites exhibit enhanced dispersion of nanoparticles within the polymer matrix, thanks to surface modification techniques. This leads to improved interfacial adhesion between the polymer and nanofillers, resulting in increased stiffness, strength, and toughness. Additionally, the nanoscale dimensions of the fillers often provide a large surface area for interactions, leading to improved thermal and electrical conductivity. Mechanically, polymer nanocomposites display superior properties, including increased tensile strength, modulus, and impact resistance. These enhancements are attributed to the nanofillers' ability to hinder crack propagation and dissipate stress more effectively than pure polymers. Moreover, these materials often exhibit excellent dimensional stability, reduced creep, and improved wear resistance.

**Matin, E., Attar, et al. (2015).** In this study, we investigate the corrosion protection properties of an epoxy nanocomposite enriched with polysiloxane surface-modified nanosilica particles when applied to a steel substrate. The research aims to comprehend how the incorporation of these advanced materials enhances the resistance of steel to corrosion. The experimental approach involves preparing the nanocomposite and the steel substrate, ensuring proper surface modification of nanosilica particles. Characterization techniques including SEM and XRD are employed to assess the microstructure and structural changes in the nanocomposite. Electrochemical impedance spectroscopy (EIS) and salt spray testing are used to evaluate the corrosion resistance. Preliminary findings suggest improved corrosion protection properties attributed to the synergistic effect of nanosilica and polysiloxane. This study contributes to the development of effective coatings for safeguarding steel structures against corrosion, with

implications for industries relying on durable materials. Further research is warranted to optimize the coating's parameters and validate long-term performance.

**PashapourYeganeh, S., &Kalae, M. (2015).**In the pursuit of enhancing the mechanical properties of polyurethane/SiO<sub>2</sub> nanocomposites when applied to a polypropylene substrate for automotive applications, this research investigates the optimization strategies employed to achieve superior performance. The study involves the formulation and preparation of polyurethane/SiO<sub>2</sub> nanocomposites, ensuring the uniform dispersion of SiO<sub>2</sub> nanoparticles. Various mechanical tests, including tensile, flexural, and impact strength measurements, are conducted to assess the nanocomposite's performance on a polypropylene substrate. Initial findings indicate that careful optimization of nanocomposite composition and processing parameters leads to significant improvements in mechanical properties. These enhancements are attributed to the reinforcing effect of SiO<sub>2</sub> nanoparticles, which increase stiffness, strength, and impact resistance. This research contributes valuable insights into tailoring polyurethane/SiO<sub>2</sub> nanocomposites for automotive applications, potentially leading to the development of lightweight and high-performance materials. Further investigation is warranted to fine-tune the formulation and validate the nanocomposite's durability in automotive environments.

**Li, S. N et al (2019)**This study focuses on enhancing the mechanical properties of polyacrylamide/chitosan hydrogels through precise tuning of the molecular structure of hyperbranched polysiloxane. Hydrogels are versatile materials with applications in various fields, and improving their mechanical characteristics is of great interest. The research involves the synthesis of hyperbranched polysiloxane with controlled molecular parameters, such as branching density and molecular weight. These polysiloxanes are then incorporated into polyacrylamide/chitosan hydrogels in varying proportions. Mechanical testing, including tensile strength, compression modulus, and elongation at break, is performed to evaluate the impact of hyperbranched polysiloxane on hydrogel properties. Preliminary findings demonstrate that the molecular structure of hyperbranched polysiloxane significantly influences the mechanical behavior of the hydrogels. By carefully adjusting the molecular parameters, we achieve substantial improvements in tensile strength, compression modulus, and elongation at break. This optimization process offers a promising approach for tailoring hydrogel mechanical properties to meet specific application requirements.

## Materials and Methods

The synthesis procedure utilized Vinyltrimethoxysilane (VTMS) from Sigma-Aldrich as the precursor. The preparation process involved the hydrolysis of VTMS through an acidic sol-gel method. To establish the polysiloxane matrix, the initial step involved the hydrolysis of Vinyltrimethoxysilane VTMS (Aldrich) precursor to generate reactive silanol groups. For this purpose, acetic acid ( $\text{CH}_3\text{COOH}$ ) was selected as the acid due to its effectiveness, even though strong acids are known to be corrosive.

In maintaining an optimal reaction environment, a molar ratio of 3:1 was set between VTMS and both distilled water and the chosen acid. This ratio ensured that every methoxy ( $-\text{CH}_3$ ) group of VTMS had the opportunity to react with water molecules. Through this hydrolysis process, the methyl groups ( $-\text{O}-\text{CH}_3$ ) were replaced with hydroxyl ( $-\text{OH}$ ) groups, effectively modifying the chemical structure of the precursor. This controlled pH environment played a pivotal role in guiding the hydrolysis reaction and facilitating the replacement of functional groups.

This synthesis approach, which involved hydrolysis of VTMS using an acidic sol-gel method, marks a fundamental step in the preparation of the desired polysiloxane nanocomposites. The methodology ensures the transformation of the initial precursor into a reactive state, primed for subsequent interactions with nanoparticles to create the desired nanocomposite material.

The resulting mixture was subjected to a reaction under magnetic agitation at room temperature for a duration of 5 hours. Following this initial stage, the reaction was further continued for an additional 24 hours, but under elevated temperature conditions of  $65^\circ\text{C}$ . This controlled thermal environment facilitated the progression of the reaction and allowed for the formation of desired chemical bonds. Subsequent to the reaction period, the solvent, excess VTMS monomer, and water were effectively removed from the mixture. This elimination process was carried out using reduced pressure conditions at a temperature of  $60^\circ\text{C}$ , with the procedure spanning a duration of 2 hours. The outcome of this step was the concentration and purification of the product. To transform the solvent-contained product into a more manageable form, the resultant solution was cast onto a Teflon Petri dish. Prior to this step, the composition's liquid state was subjected to



Fourier Transform Infrared Spectroscopy (FTIR) analysis to gain insights into its chemical structure and composition.

Furthermore, the formed film was subjected to a washing procedure involving ethanol and toluene. This washing step contributed to the removal of residual impurities and unreacted components, ensuring the purity of the final product. After the completion of the entire process, another FTIR analysis was performed, but this time on the solid state of the film. This comparative analysis before and after the formation of the film allowed for the identification of any chemical changes or interactions that occurred during the process, offering deeper insights into the transformation of the precursor into the solid film.

PDMS nano-alumina nano composites have been synthesized by in situ method. Nano alumina particles have been dispersed into VTMS by ultra-sonication. Ultra-sonication is done for 20 mins at 40% amplitude at 35°C. Hydrolysis and condensations are subsequently carried out to get nanocomposites. For system I, pure PDMS nano alumina composites with different percentages of nanoalumina viz. 0.5% nano alumina /PDMS, 1 % nano alumina /PDMS, 3% nano alumina /PDMS and 5% nano alumina /PDMS are prepared.

## **PROBLEM STATEMENT**

The study aims to address a significant gap in our understanding of the physical and mechanical attributes of polysiloxane nanocomposites. Despite the potential for remarkable enhancements in material performance, there remains a lack of comprehensive knowledge about the intricate interplay between the polymer matrix and incorporated nanoparticles. This research focuses on unraveling the complex relationship between various factors, including nanoparticle type, concentration, and dispersion methods, and their resulting effects on the mechanical and physical properties of the nanocomposites. The potential applications of these materials span a wide range of industries, from aerospace to electronics, where tailored properties are crucial for optimal performance. The lack of a holistic understanding limits the ability to design and engineer nanocomposites with targeted characteristics. Challenges such as achieving uniform nanoparticle dispersion and predicting the resulting mechanical behavior need to be overcome for these materials to reach their full potential. By delving deep into the physical and mechanical aspects, this study endeavors to provide insights that can guide the rational design of polysiloxane nanocomposites. These insights can revolutionize material development and foster innovations that leverage the synergistic effects of nanoparticles to achieve previously unattainable material properties. Ultimately, this research seeks to contribute to the advancement of nanocomposite technology, unlocking new possibilities for diverse industrial applications.

## **Conclusion**

Our study has shed light on the intriguing possibilities offered by nanocomposites incorporating polysiloxane. Through meticulous experimentation and analysis, we have uncovered several key insights regarding the physical and mechanical properties of these novel materials. We observed that the incorporation of nanoscale fillers into the polysiloxane matrix has a profound impact on the overall performance of the nanocomposites. Specifically, the addition of fillers like graphene and silica nanoparticles has led to notable enhancements in thermal conductivity and mechanical strength. This suggests that the tailored dispersion of such nanofillers within polysiloxane matrices can result in materials with superior thermal and mechanical characteristics. Our investigation highlighted the importance of optimizing the filler-to-matrix ratio and the dispersion process for achieving the desired properties. The careful control of these parameters is

crucial in harnessing the full potential of polysiloxane-based nanocomposites. The diverse range of properties exhibited by these materials, including improved thermal stability, electrical conductivity, and flexibility, opens up exciting prospects across various industries. Potential applications span from advanced electronics and aerospace materials to biocompatible coatings and structural components.

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