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# Structure Property Relationship in ZnO–Silicone Rubber Nanocomposites: Mechanical and Morphological Insights

Abhishek Sharma[1]*, Shyama Prasad Mahapatra [2], Richa Shrivastava [3]

[1]Department of Chemistry, Dr. C.V. Raman University, Bilaspur 495001 India *

[2]Department of Chemistry, National Institute of Technology Raipur 492010 India

[3]Department of Chemistry , Govt. Naveen Girls College Baikunthpur 497335 India

abhisheksharma@cvru.ac.in

***Abstract:*** Silicon elastomer nanocomposite samples have been prepared using different concentrations (1-7 wt%) of ZnO nanoparticle via mechanical mixing and hot press molding. The surface morphology of prepare Silicon elastomer nanocomposite has been studied by scanning electron microscope (SEM) which reveals the smooth dispersion of Zinc Oxide nanoparticles inside matrix and at higher concentration (7 wt%) agglomerates are formed. The mechanical property of Silicon elastomer nanocomposite show the increase in tensile strength, modulus and decrease in elongation at break with ZnO concentrations, this can be recognized towards excellent distribution and reinforcing action of the nanoparticle in the polymer matrix. At high concentration (7 wt%) the rate of increase of mechanical properties is small due to agglomeration of nanoparticles. The incorporation of ZnO nanoparticles resulted in a significant improvement in the mechanical properties of SR. Tensile strength, Young's modulus exhibited continuous enhancement with increasing filler concentration, primarily due to strong interfacial interactions, restricted polymer chain mobility, and improved stress-transfer mechanisms. An optimal improvement was observed in the 5–7 wt% range, where the formation of an effective reinforcement network contributed to maximum mechanical strength without inducing agglomeration-related defects. The study demonstrates that ZnO nanoparticles act as efficient reinforcing agents for silicone rubber, offering a promising route for developing high-performance nanocomposites suitable for, electrical insulation, and flexible device applications.

***Keywords:*** Zinc Oxide, Silicon Elastomer, Nanocomposites, Mechanical Properties, Morphology.

## I. INTRODUCTION

Polymer nanocomposite emerges as new, multifunctional and high performance materials in place of traditionally filled polymer composites. Polymer nanocomposites are the collection of two or more components of altered physical and chemical nature but distinct at microscopic level in which any single physical component have a phase dimension of lesser than 100 nanometer [1]. Hence, these nanocomposites are incorporated with nanofillers that are differentiated due to their surface activity, size and shapes, structure, physical and chemical nature [2]. Many potential advantages of these silicone rubber composites include their reduced weight, significantly saves construction also shipping costs; low conductivity; along with excellent mechanical strength, particularly at lower temperatures [3]. Metal oxide filler are considered as a significant part of investigation due to their unique structure and properties. Nature of filler decides the physical and mechanical behaviour of composite materials however; polymer plays a role in controlling the environmental characteristics of composites [4]. The main purpose to prepare polymer nanocomposite is to achieve the modified matrix with appropriate interactions of nanofillers with elastomer matrix in order to attain new and advanced functional materials with specially improved mechanical properties. Polymer composites reinforced with nanosized fillers have come to be the integral part of mechanical design as a result of value added alternatives to metallic, ceramic and pure polymeric engineering materials. Reinforcement in polymer nanocomposites have much influence on the morphology, mechanical properties, rheological properties, visco-elastic behaviour of rubber matrix due to the formation of matrix-filler interactive forces that resist the mobility of polymeric chains. The polymeric material having both viscous and elastic features during deformation are characterised as visco-elastic materials. Visco-elastic nature of reinforced rubber supports the hypothesis that the mechanism of filled rubber of networking filler particles is established on the development of restrained immobilised polymer chains [5-8]. Hence it is very exciting to study the morphology, physico-mechanical, rheological properties of elastomer composites reinforced through nanoparticles in which the nanosized filler avail the interactions at molecular level in polymeric system. Overall performances of the polymer nanocomposites properties like mechanical, visco-elastic and other feature are significantly affected by the reinforcing effects of nanofillers. An elastomer visco-elastic property will be governed by several features of reinforcing agent like size of filler, type and form of filler, concentration, processing circumstances and strain history. Broad analysis of physico-mechanical and rheological properties over the wide range of temperature and strain amplitude of filled elastomer is necessary to understand the visco-elastic nature of polymer nanocomposites. The elastomer filled with graphene oxide considerably enhances the strength, stiffness, conductivity, thermal stability, etc. of the prepared materials. Extent of augmentation of these properties into nanocomposites is based on the belongings of nanofiller like size, structure, degree of dispersion moreover interaction with polymer matrix [9-10]. Introducing nanofillers into the polymeric system is the best way to transform insulated rubber matrix into the conductive material by forming an inter-connected carrier pathway to transport electrons [11].

Morphology, Physico-mechanical of ZnO reinforced silicone elastomer (SR) nanocomposite have been studied and reported in this chapter. The effect of ZnO nanofiller concentration on specific mechanical characteristics like dispersion, strength, elongation at break, modulus, and toughness of silicone elastomer nanocomposite have been discussed in detail. Silicone elastomer nanocomposite have also been discussed in this paper as a function of concentration to observe the ultimate strength of prepared materials in applied field.

## II. MATERIALS AND EXPERIMENTAL

Bayer AG provided silicon elastomer (Mooney viscosity ML1+4 at 100C 14 60). (Germany). Platonic Nanotech Private Limited Mohanpur, Mahagama, Godda, Jharkahand – 814154 supplied ZnO Nanoparticles with a purity of 95%. Other chemicals utilised as curing agents, such as stearic acid and DicumylBefore to usage, reliable sources supplied peroxide (chemically pure grade).

### 2.1 Experimental Technique

### 2.2 Preparation of ZnO-SR Elastomer nanocomposites

The rubber was combined with the chemicals according to the mix's recipe (Table 1). Compounding was done in a Brabenderplastograph (Germany) at 60 r/min, followed by a laboratory-sized (325x150 mm) two-roll mixing mill with a friction ratio of 1:1.25, all while conforming to ASTM D3182 standards for temperature, nip gap, and mixing duration. The temperature range for mixing was 65°C to 70°C. The elastomer compositions were moulded in an electrically heated hydraulic press (Moore Pumps, Inc., Friendship, Tennessee, USA) at a pressure of 10 MPa and a temperature of 160 0C, following ASTM D2084 and ASTM D5289 procedures, with moulding conditions determined by a Monsanto Rheometer (R-100) (Montech, USA).

Table 1 The composition of ZnO nanoparticle-reinforced Silicone elastomer nanocomposites.

| Constituents | SR-1 | SR- 3 | SR- 5 | SR-7 |
|---|---|---|---|---|
| Silicon Rubber (gms) | 100 | 100 | 100 | 100 |
| ZnO Nanoparticles (gms) | 1.0 | 3.0 | 5.0 | 7.0 |
| Stearic Acid (gms) | 0.5 | 1.5 | 2.5 | 3.5 |
| DCP (gms) | 1.5 | 1.5 | 1.5 | 1.5 |

Table 2 Component of Silicone Elastomer nanocomposite with ZnO nanoparticle as reinforcing agent.

| Ingredients | Part per hundred part of Rubber (phr) |
|---|---|
| Silicone Elastomer | 100 |
| Dicumyl peroxide (DCP) | 1.5 |
| ZnO Nanoparticle | 1,3,5,7 |
| Stearic Acid | 1.5 |

## III. MORPHOLOGY OF ZINC OXIDE REINFORCED SILICONE ELASTOMER NANOCOMPOSITES

SEM photomicrographs were use to study Surface morphology of ZnO/SiR nanocomposites. Figure 1 depicts the surface morphology of SiR nanocomposites with various concentrations of zinc oxide nanoparticles. The bright phase detects ZnO nanoparticles, whereas the black phase identifies silicone rubber. Zinc oxide dispersion is a key ingredient in improving the characteristics of a silicone rubber nanocomposite. Although the photomicrographs reveal homogenous dispersion of zinc oxide nanoparticles, agglomeration develops at higher concentrations (7 wt%).

This is due to a high volume proportion of ZnO, resulting in greater nanofiller–nanofiller interactions than polymer–nanofiller contact. Despite the fact that zinc oxide nanoparticles are in very small quantities because of their homogeneous distribution in the silicone matrix, good load transfer between the elastomer composites and the nanofillers suggest itself. This appears to be supported by mechanical properties [12-13].

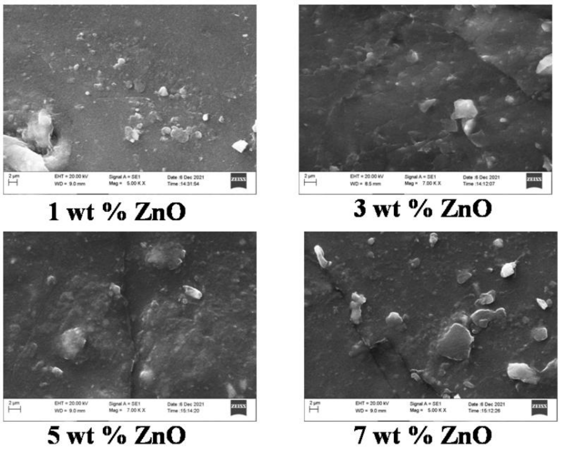


**Figure 1** SEM microscopy images of ZnO/SR nanocomposites with varying nanoparticle concentrations: (a) 1%, (b) 3%, (c) 5%, and (d) 7%.

## IV. PHYSICO-MECHANICAL PROPERTIES OF ZINC OXIDE REINFORCED SILICONE ELASTOMER NANCOMPOSITES

The physico-mechanical properties of ZnO-SR nanocomposite, including hardness, tensile strength, elongation at break, modulus, and toughness have been studied. Table shows that tensile strength, modulus and toughness increase with ZnO concentration, whereas elongation at break decreases. This is attributed to the improved reinforcing nature of ZnO nanoparticles in the silicone elastomer matrix.

The most significant properties of a few rubber nanocomposite material is mechanical strength. Strength of polymer nanocomposite depends upon the physical and chemical composition as well as binding capability of nanoparticles present inside the matrix. The area just around the interface of the polymer matrix and nanofller is an important and A potential feature of the nanocomposite material. The metal oxide and polymeric phases exhibit unique characteristics from the interface. Inter-phases play a crucial impact in mechanical properties. The amazing properties of the reinforcing nanofiller control the load distribution between the reinforcing nanofiller and the polymer links. To be efficient, a mechanical load requires a large interfacial interaction. Composite materials have two significant properties: tensile strength and modulus. The table shows that ZnO concentration increases the tensile strength of SiR nanocomposites due to the reinforcing action of nanoparticles. ZnO-SR nanocomposites' tensile strength, modulus, and toughness increase as the concentration of nanoparticles increases. This leads to increased elastomer nanofiller interactions in the matrix and, consequently, better properties of the vulcanizates that are formed. Additionally, it is noted that there is a notable improvement in mechanical properties up to 5 weight percent of nanoparticles; this suggests that ZnO functions as both an accelerator and a filler at lower concentrations and as nanofiller at higher concentrations. When ZnO nanoparticles are added, the SiR nanocomposite's tensile strength value improves up to 7 weight percent concentrations, indicating increased reinforcement and interactions. Since agglomerates form beyond the concentration and the rate of improvement of mechanical characteristics is continuous up to 5 weight percent of ZnO, this could be referred to as percolation.

limit in rubber silicone. Due to the increased volume percentage of reinforcing material within the SR, elongation at break reduces with ZnO concentration [14-16].

Figure 4.1 shows that hardness of ZnO-SR nanocomposites increases with increasing concentrations of ZnO nanoparticles outstanding to crosslinking of nanocomposite matrix. The hardness value of silicone elastomer nanocomposites is showing higher value as zinc oxide is having high surface area.

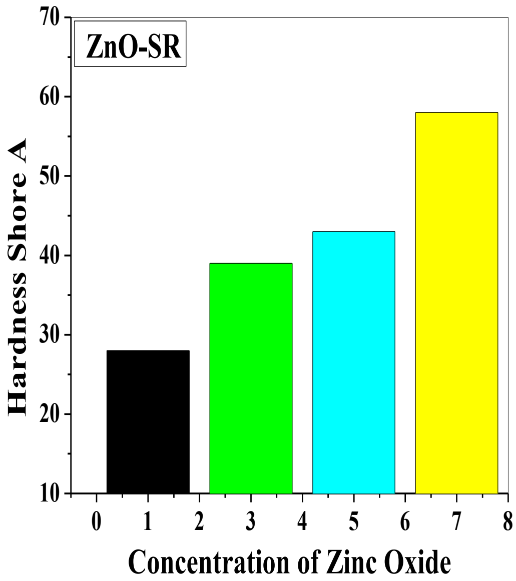


Figure 4.1 Variation of hardness with Zinc oxide

concentration in silicone elastomer nanocomposites.

The tensile strength of zinc oxide silicone elastomer nanocomposites is shown in Figure 4.2 Figure shows that the tensile strength increases with increasing concentration of ZnO nanoparticles. The silicone elastomer nanocomposites gives the maximum tensile strength value at 5 wt% nanofiller concentration which signifies most filler-rubber interaction, however the rate of increase decreases after 5 wt% ZnO concentration, this is due to the formation of percolation threshold. Unlike conservative filler, zinc oxide has extremely large area of surface hence form a strong interaction of surface polymer contact, which results in a greater vulcanization content. The use of ZnO as nanofiller is a significant source of dissipating energy, which increases the tensile strength of the nanocomposite structure [17-20].

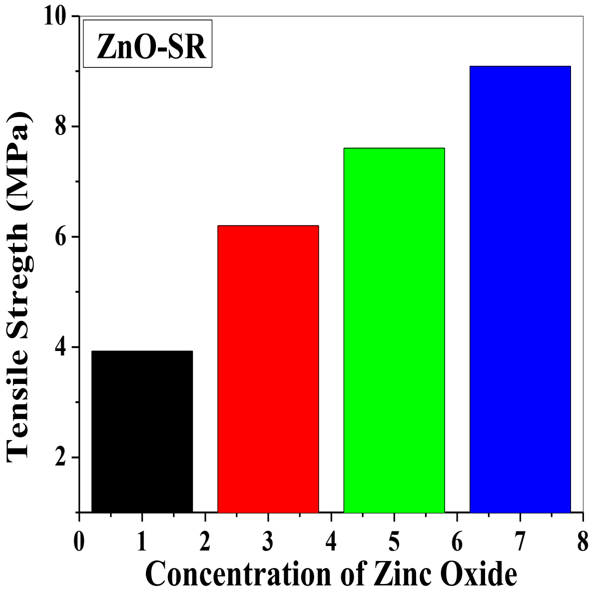


Figure 4.2 Variation of tensile strength with ZnO concentration in silicone elastomer nanocomposites.

The elongation at break of zinc oxide silicone elastomer nanocomposites is shown in Figure 4.3. It is observed from the figure that the elongation at break gradually decreases with rising concentration of ZnO nanofiller due to better reinforcement. The incorporation of nanofiller of high surface area restricts the chain movement with applied force, hence elongation of SiR nanocomposite decreases with ZnO concentration. The modulus of ZnO/SiR nanocomposites increases with increasing concentration of ZnO due to the formation of more crosslinks and reinforcement for the duration of vulcanization, thus deceiving the free ends of polymer chains. The same is shown in Figure 4.4. ZnO nanoparticles of high elastic-modulus are incorporated throughout low down elastic-modulus matrix SR, hence clear that the modulus of the nanocomposite will exceed than the base matrix. This also indicates that ZnO-SR adhesive force is large which confirms better elastomer-nanofiller interactions with concentration. At 7 wt% concentration as nanofiller-nanofiller interactions are more hence marginal increase in modulus has been observed [21-22].

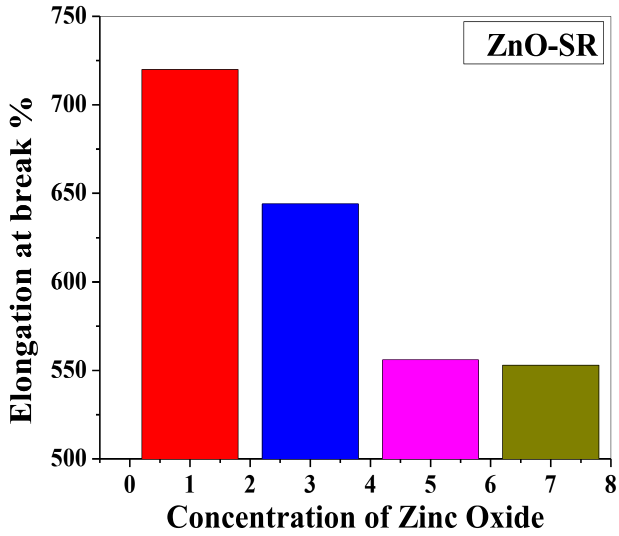


Figure 4.3 Variation of elongation at break with ZnO concentration in silicone elastomer nanocomposites.

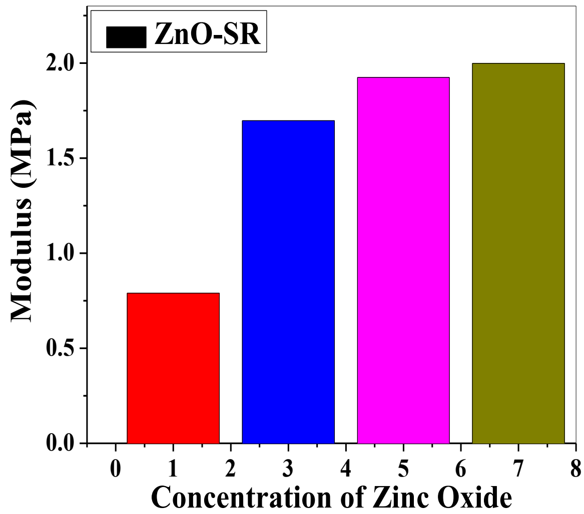


Figure 4.4 Variation of modulus with ZnO concentration in silicone elastomer nanocomposites.

The toughness of zinc oxide silicone elastomer nanocomposites is revealed in Figure 4.5. It is notice from the figure that the toughness gradually increases with increasing concentration of ZnO nanofiller. Mechanical properties of zinc oxide silicone elastomer nanocomposites executed better than the unfilled samples as incorporation of zinc oxide provides the mechanical adhesion and interlocking of free chain [23-25].

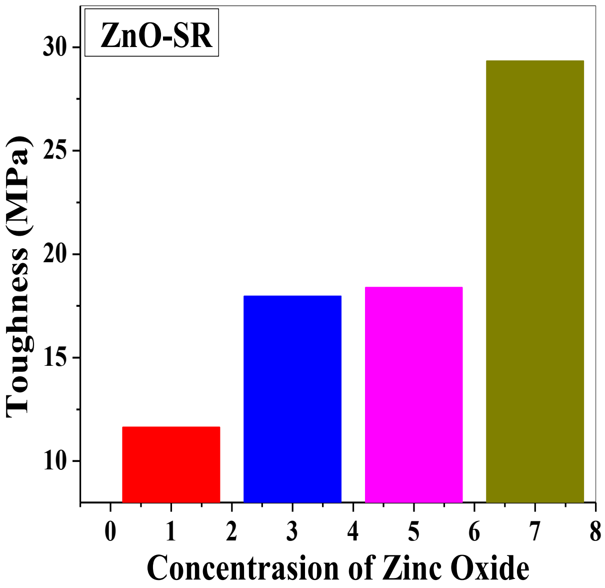


Figure 4.5 Variation of toughness with ZnO concentration in silicone elastomer nanocomposites

## V. CONCLUSION

SEM photomicrographs also demonstrate the good ZnO distribution in the silicone elastomer matrix. It demonstrates the uniform dispersion of ZnO nanoparticles within the silicone elastomer matrix., However, this aggregation happens when the concentration rises above 5 weight percent. Because of an increase in adhesion, cross-linking density, and reinforcing, tensile strength and modulus progressively rise with ZnO concentration. However, due to the higher weight fractions of reinforcing ZnO nanomaterial within the silicone elastomer, elongation at break gradually diminishes. This may be regarded as the percolation limit in silicone rubber because the rate of improvement of mechanical properties of SiR nanocomposites is continuous up to 5 weight percent of ZnO concentration and agglomerates are discovered beyond this. The results show that ZnO-SR nanocomposites could find usage in sophisticated engineering and mechanical applications.

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