

# **Nanocomposite Vibration Dampers formed by Reinforcement in Viscoelastic Materials**

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**ABSTRACT:** Materials have a great impact on human comfort and lifestyle. Design engineers always remain in search of light weight, more strong and stiff materials to be applied as vibration damping pads. Dynamic stability of machines necessitates an effective, durable and versatile kind of mechanism which can absorb the kinetic energy of vibration to prevent the system from resonance. The mechanical properties of various damping materials are improved through nanoscale reinforcement. Many researchers in the recent years successfully applied nanomaterials in developing a light-weight and cost-effective energy absorbing materials. This study presents a brief overview of nanocomposites formed by nanoparticles reinforcement in polymers/elastomers.

**KEYWORDS:** Nanoparticles, Vibration, Elastic Properties, Damping.

## **I. INTRODUCTION**

In machines, structures and dynamic systems the vibration causes not only unpleasant motion and noise but premature failure of the system due to resonance. The amplitude of structural vibration can be attenuated by providing suitable level of damping. In technique, the damping is usually defined as the decrease of oscillations, in which the mechanical energy contained in the vibrating system is converted into heat [1]. Also damping may be defined as the mechanism by which the kinetic energy of vibration is converted into noise and heat [2]. In recent years nanotechnology has a promising scope in enhancing the strength / damping behavior and reducing the noise of engineering structures through the utilization of nanomaterials that dissipate a substantial fraction of the vibrational energy that they receive [3]. Nanoparticles and nanofilms are finding increasing applications from household appliances to aerospace applications. Nanomaterials continue to be applied to increasingly complex and intelligent controls systems for both machinery and structures [4]. Fig. 1 shows a comparative application of nanomaterials in various fields [5]. Many developing countries have specified share in their budget reserve for research on nanotechnology. Even though extensive research in nanotechnology has been conducted, its results need to be refined, especially with regards to manufacturing and production techniques [6].

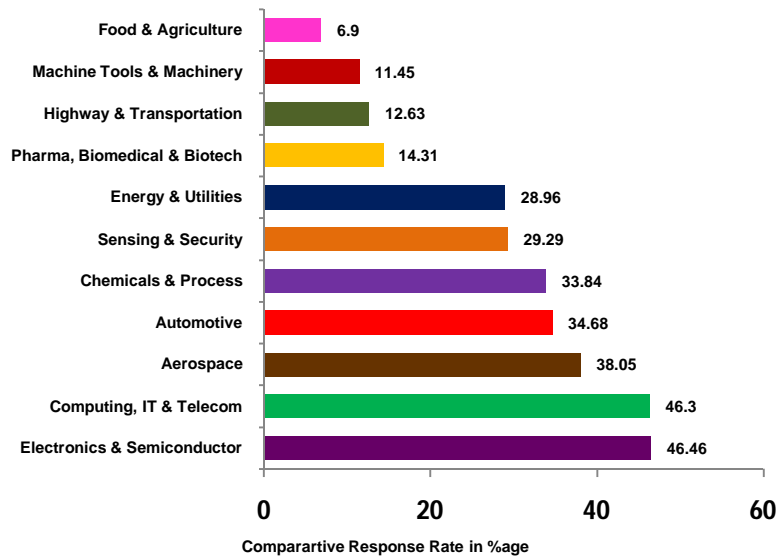


Fig.1.Comparative application of nanomaterials invarious fields. The highest is in electronics and semiconductor industry and the least is in food and agriculture field. [5]

## II. NANOCOMPOSITES

The history of nanocomposite materials is as ancient as human being itself. Human bone is the best example. A composite is termed as nanocomposite when its any ingredient has at least one dimension in nanometers. Nanoparticles, Nanofilms and Carbon Nano Tubes (CNT) are most commonly used nanomaterials individually or reinforced in a matrix to form a nanocomposite. Metal, ceramic and their composite nanoparticles are obtained by various physical, chemical and mechanical processing methods. Nanoparticle reinforced composite materials are formed by using three types of matrix i.e. metals, polymers and ceramics. Selected matrix will mostly determine the mechanism of energy dissipation [7, 8]. Carbon nanotubes are particularly promising cost-decreasing reinforcement material [9]. The Young's modulus (elastic modulus) of Single Walled Carbon Nano Tubes (SWCNTs) lies close to 1 TPa, also reported by some researchers as 1.8 TPa. The maximum tensile strength is close to 30 GPa [10, 11]. Hence small CNT volume (1-5%) may greatly affect materials behavior due to these extreme nanotube properties over traditional materials [12-14]. Boron nitride or silicon carbide nanotubes are another possible candidate for aerospace material reinforcement [15]. Nanotube metal matrix composite materials are still rarely studied [16]. Carbon Nano Tube reinforced ceramic-matrix composite materials are a bit more frequently studied [17]. Nanotube-polymer composite materials are now intensively studied, specifically epoxy and polymethylmethacrylate (PMMA)-matrix composites [18-21]. In nanoparticles and nanotube composites, the most advanced composites are polymer matrix composites. They are characterized by relatively low cost, simple manufacturing and high strength. Their main drawbacks are low working temperature, sometimes high coefficient of thermal and moisture expansion and, in certain directions, low stiffness [22]. Polymer matrix is reinforced to improve the mechanical properties, specifically stiffness without considerable mass increment. Glass fibers are widely used because their advantages include high strength, low cost and high chemical resistance [23]. Some examples of the nanocomposites are shown below;

- i) Nelcy *et al.* [24] have shown cobalt ferrite composite thin films,  $\text{CoFe}_2\text{O}_4/\text{SiO}_2$ , were prepared by sol-gel process, using tetraethylorthosilicate (TEOS) as a precursor for silica, and metallic nitrates as precursors for ferrite.
- ii) Abothu *et al.* [25] have shown barium magnesium tantalate,  $\text{Ba}(\text{Mg}_{1/3}\text{Ta}_{2/3})\text{O}_3$  (BMT) was prepared by a nanocomposite processing route.

- iii) Joe *et al.* [26] have discussed poly (urethane urea) nanocomposites prepared with diamine-modified laponite.
- iv) Singha and Thomas [27] have studied the dielectric properties of epoxy nanocomposites with insulating nano-fillers, viz., TiO<sub>2</sub>, ZnO and Al<sub>2</sub>O<sub>3</sub> were investigated.

### III. NANOCOMPOSITE VIBRATION DAMPERS

Traditional damping polymers perform poorly at elevated temperatures [28]. But the polymers composed with carbon nanoparticles, carbon nanotubes, and nanoclays show remarkable promise for enhancements of mechanical, electrical, thermal, and barrier properties of polymeric materials [29]. It is clearly established in the literature that the filler amount in nanocomposites has a significant effect on the material behavior [30]. Nanocomposites can provide excellent damping at high temperatures, suggesting a great potential for a variety of applications in aircraft, spacecraft, satellites, automobiles, wind turbines, sensors for missile systems, as well as any structure that is exposed to unwanted vibrations [31]. The methodology consists of the reinforcement of nanoparticles into elastomers which improves significantly their damping characteristics and dynamic mechanical properties. [32]. The most important parameters that affect the vibration damping in aerospace-related structures are;

- Temperature (ranged from -140<sup>o</sup>C in cryogenic applications and upto 600<sup>o</sup>C or higher)
- Rotational speed (upto 10000 r.p.m. in turbine engines)
- Frequency and amplitude of vibrations[33]

Nanocomposite materials formed by metallic or ceramic particles reinforced in polymer, ceramic or vitreous matrices have significance in the field of catalysis and electronics. Some researchers have discussed a very interesting type of nanocomposite material which is formed by dispersing nanometer sized magnetic particles in insulating matrix [24]. Fig. 2 by Zhang *et al.* [34] shows a relationship between hardness and toughness of nanocomposites. Reinforcement of nanoparticles enhances considerably the stiffness of the matrix polymer resulting in improved energy absorbing capacity. Selection of nanoparticles reinforced dampers depends on their price and production volume. Industries such as domestic appliances have a need for damping that is cheaper than current-bitumen based coatings.

Hence research in the damping properties of the low cost materials is required. Commercial utilization of a damping technology depends from both technical performance and business environment. Though extensive research in nanotechnology is continuously carried out, some factors, such as mass production of nanoparticles, nanoscale metrology etc., still restricts its commercialization. For the next generation of transportation we need light-weight, cost-effective and reliable vibration absorbing materials [35, 36]. Lin and Lu [37] have discussed that the existing damping techniques have offered improved damping performance for structural components and systems, but they are still limited by the deficiencies of the basic polymer matrix/substrates and/or increasing weight and power penalties. Designers and material science researchers are continuously working to develop advanced materials for damping applications that can overcome these limitations. Natural structures of polymer molecular chains have voids to provide favorable conditions for hysteresis damping. Hence polymeric materials provide enhanced damping over traditional metals and ceramics in normal environmental conditions, but their stiffness, performance and durability is decreased at high temperatures (above 200<sup>o</sup>C) [38]. High damping (due to polymer) and increased stiffness (due to reinforcement) of a material is the best option. Higher stiffness gives a flatter response at low frequencies and gives smaller displacements for a given force input. This is shown by the similar shapes in the three response curves at high frequencies in Fig.3. This suggests that raising the stiffness of a system is always a desirable course of action [39] for its dynamic stability.

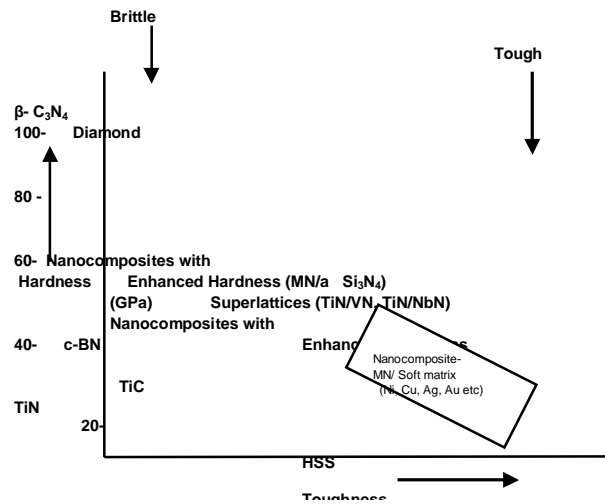


Fig.2. The range of mechanical properties obtained by nanocomposites. Hardness higher than TiC and TiN can be obtained whereas toughness comparable with most ductile materials such as Cu, Ag, Au etc can be developed. [34]

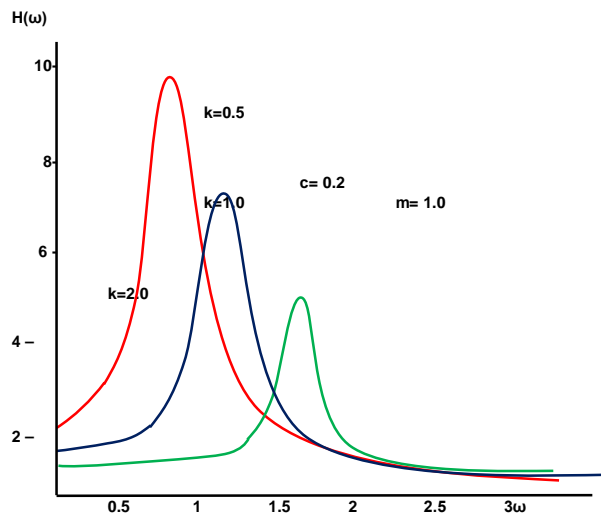


Fig.3. Change in amplitude with stiffness. For the same level of external damping provided the inherent stiffness of the material has a great effect on amplitude of the vibration. Reinforcement in elastomers improves the stiffness and energy absorbing capacity of the materials. [39]

#### IV. RUBBER- NATURAL DAMPER

Many researchers [40-44] have discussed that viscoelastic materials such as high loss factor polymers have been the most frequently used in modern damping applications. Brackbill *et al.* [45] have investigated both experimentally and analytically that the elastomeric materials operated in simple shear were used for helicopter damper applications. High damping is capable to improve the tracking and positioning characteristics in certain ultra-precision instruments such as read/write head of a computer hard disk drive, the accuracy of the weapon systems mounted on aircrafts and land and actuators and transducers in robotic arms.

The only elastomer used for industrial application was the natural rubber (NR). Natural rubber is extracted from latex produced by the Hevea brasiliensis tree. Hevea commercial plantations are mainly located in India. During World War-II, United States were cut off from rubber-growing areas and developed synthetic alternates for natural rubber applications. Rubber has a complex microstructure which consists of long flexible molecular chains randomly arranged in space and linked together to form large molecular networks. Such a microstructure gives to rubber-like materials some extraordinary elastic properties. In order to increase their stiffness, fillers are usually added to the rubber compounds [46]. Chlorinated, hydrochlorinated and cyclized natural rubber are manufactured for industrial applications but these category is much dominated by oil-based synthetic products [47-49]. Despite the fact that rubber is used in a wide range of industrial and consumer products, we still do not have a complete understanding of its mechanical behavior and we lack constitutive models to accurately simulate some of its response. This is particularly true for products made of filled rubber compounds that operate under dynamic loads, such as the tyre and air-spring [50]. Generally the vibration absorbing properties of rubber can be evaluated under two conditions; free vibration and forced vibration [51]. For very small deformation, rubber is assumed as a linear viscoelastic material and its dynamic material properties have been found to be independent of the magnitude of the deformation [52]. The dynamic mechanical properties are usually determined by complex modulus and phase angle or, equivalently, in terms of the storage and the loss modulus [53]. Experimental results have further shown that rubbers subjected to dynamic loading conditions exhibit more complicated results and temperature effects. Hysteresis loss decreases with increasing temperature and decreasing strain rate in addition to a significant loss in stiffness with increasing dynamic amplitudes [54].

#### V. NANOSYSTEM INTERACTIONS

Nanoparticles can accommodate in the vacant locations at different geometric orientations of the molecular structure of rubber. The ability of the rubber molecular chains to form nano or microscale-diameter spheres around individual nanoparticles or small cluster of nanoparticles favors the formation of a strong bond with the rubber matrix [55]. Size of reinforced nanoparticles may vary from 1 to 100nm in diameter and length. The number and size of nanoparticles affect the stress concentration in the composite [56]. Short and round particles are the strongest one and acts as crack trapping by blocking the holes in the composites, but longer fibers are flexible and may be worth for damping [57, 58]. The geometric orientation of an individual nanoparticle and its surrounding matrix is modeled as shown in Fig.4 [59, 60]. In layer A, the rubber molecular chain is static and its motion is restricted by the surface. Layer B is loosely bound in which the frictional slip and vibrational energy dissipation takes place. The outer layer C is the rubber matrix which provides the inherent damping properties of the rubber itself. The thickness of each layer is controlled by the size [61-63], the rigidity and the surface area of the nanoparticles, the volume of the filler [64] and the nature of the rubber matrix [65].

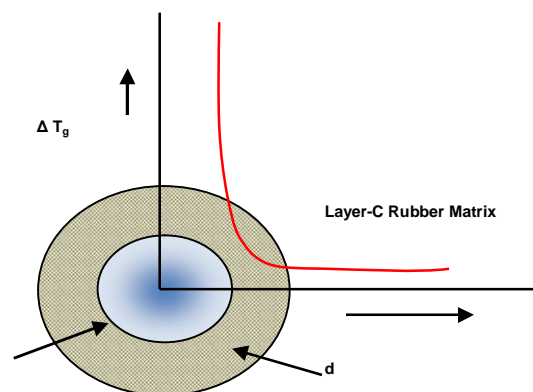


Fig.4. Schematic of individual nanoparticle. Individual particle with physical or chemical bonding with rubber matrix is shown in different layers. T<sub>g</sub> is glass transition temperature and d is the distance from nanoparticle center shown as blue gradient circle. [59, 60]

The reinforced nanoparticles may or may not actively interact with rubber matrix during variable loading conditions of a vibrating system. Active nanoparticles can form physical or chemical bonding with rubber matrix and enhance exceptionally the mechanical properties of the nanocomposites. A physical bond between the filler and matrix can improve the friction at their surface interaction which can increase the vibrational energy dissipation. The chemical bonding may develop a solid solution like strengthening mechanism by creating a solute-solvent relationship between the reinforced nanoparticles and rubber base [66, 67]. The extent of improvement in the mechanical properties depends on the bonding strength between the nanoparticles and the rubber matrix. Fig.5 indicates a schematic representation of storage modulus distribution for the different layers of nanocomposite over a range of strain values [68]. At higher strain conditions the nanoparticles have a tendency to agglomerate in the form of cluster, as shown in Fig.6, known as filler network. The formation of the filler network and its effect on rubber properties has been studied in depth by many scholars [69-71].

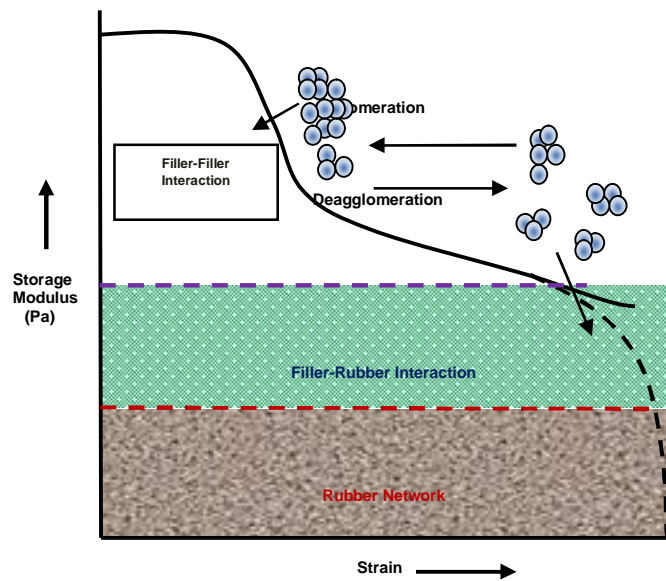


Fig.5. Variation in storage modulus over a range of strain values. The major source of energy consumption is the slip between filler-matrix and filler-filler interaction. [68]

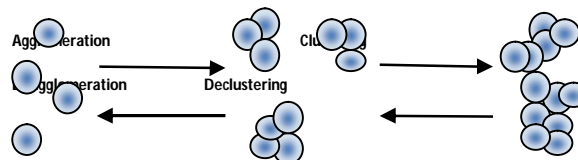


Fig.6. Agglomeration and deagglomeration. Reversible loading causes clustering and agglomeration and declustering deagglomeration of nanoparticles. [69]

Damping is physically an average measure of the rate of energy dissipation of a system. When a nanocomposite system is externally excited then the kinetic energy of vibration is dissipated by three major mechanisms as shown in Fig.7; viz; (i) the structural material damping of the rubber matrix, (ii) the frictional loss resulting from the slips between nanoparticles and rubber matrix and (iii), the frictional loss from the slips between

nanoparticles themselves. In nanoparticles reinforced composites the large surface-to-volume aspect, large damping energy sources for friction and slip-stick motion at interfaces of rubber matrix and nanoparticle can results in enhanced energy dissipation which improves the vibration damping and dynamics of machine components [72].

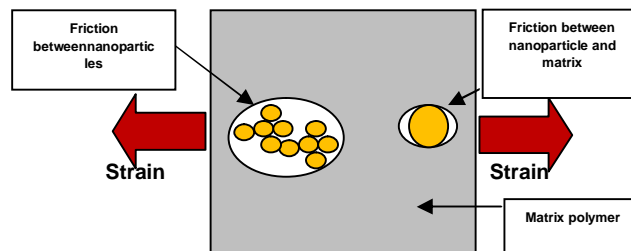


Fig.6. Vibrational energy can be absorbed by three mechanisms. [72]

## VI. CONCLUSION

The major limitation of nanoparticle reinforcement is that it associates a large uncertainty to the desired damping effect. Damping characteristics of such nanocomposite materials are still at the experimental stage and nanoparticle reinforcement in vibration damping should be characterized for a broad frequency spectrum and thermo-dynamic variations. Considering these design parameters, optimized nanoparticles reinforced composites for advanced damping applications can be developed. However one has to consider the cost involved and process capability.

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