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# Study the Properties of High-Density Polyethylene with Nano Particles Silica Composite

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## Abstract

In this research work high density polyethylene (HDPE) and silica nanoparticles ($SiO_2$ NPs) were studied. Samples having 0-10 % composition variation were prepared by injection molding. HDPE and $Sio_2$ NPs constituents were combined at microscopic level and they are insoluble into each other. This phase is called as “Reinforcing” Phase. Soft and ductile phase is called Matrix phase. Matrix phase provides base support to the reinforcing phase and it is protecting the reinforcing phase from the hot environment against the degradation of Polymer Matrix Composites (PMC). Silica dioxide Particle in the form of powder was examined by Electron microscopic method (46.69% silica &53.31% oxygen) with size 2-20 nm. It has large specific surface area/surface energy. Sample of HDPE/SiO2 NPs composites were characterized by mechanical and thermal analysis. It was concluded that the including the SiO2 NPs into HDPE resulted in higher tensile and flexural properties. It has increased the impact strength of composite by 23.58% (5% by wt. addition of silica nanoparticles) and 46.42% (10% by wt. addition of silica nanoparticles).

**Keywords:** HDPE, Nanoparticles, Specific Heat, Silica, Thermal Analysis.

## 1. Introduction

This research article evaluates reinforcement of polyethylene high density using silica nanoparticles. Polymers are substances whose molecules are comprised of many units. The units contain several atoms which are generally referred to as the segments of the polymer. In the process of polymerization of a mixture of two monomers, the structure of individual macromolecule consists of units of both monomers. Such kind of polymer is known as copolymer and the process of its synthesis is known as copolymerization. Polyesters are referred to as one of the most versatile synthetic copolymers.

Stiffness of the material increases with increase in density because more density means more crystalline in which there is a close packing of molecules causing the stiffness. Tensile strength increases with increase in density (there is close packing of molecules) therefore strong intermolecular forces causing the increase in tensile strength. Impact strength decreases with increase in density therefore higher the crystalline lower the impact strength. LDPE is less crystalline (having more impact strength) HDPE is more crystalline (having less impact strength). Torsional strength increases with increase in density. Figure 1 shows different types of materials.

The chemical resistance of polyethylene is just like that of alkenes. Alkalis, non-oxidizing acids, and many aqueous solutions do not chemically attack on the polymer. Polyethylene is a crystalline hydrocarbon polymer that is incapable of interaction with any liquid and there are no solvents at room temperature. Environmental stress cracking resistance decreases with increase of density. HDPE has higher stress cracking resistance compared to LDPE. Development of composite material with the combination of HDPE (high density polyethylene) and nano silica ($SiO_2$) were studied. Considering the field of mechanical they are promising candidates for scaffold fabrication useful in tissue regeneration. HDPE is known for its large strength-to-density ratio. The density of HDPE can range from 0.93 to 0.97 g/cm$^3$ or 970 kg/m$^3$.

## 2. State of the art Literature Survey

In the previous research papers the mechanical properties and degradation of HDPE were studied. It has shown good stability UV HDPE. In previous research work researchers have studied only the thermal and mechanical properties. Researchers worked on Different light sources on HDPE and found out, degradation of material property for HDPE. The degradation of Polyethylene was seven times much faster in July than in December. A chain of filters was utilized to find out the wavelengths majorly responsible for degradation of polypropylene that did and did not possess ultraviolet absorbers [1-3].

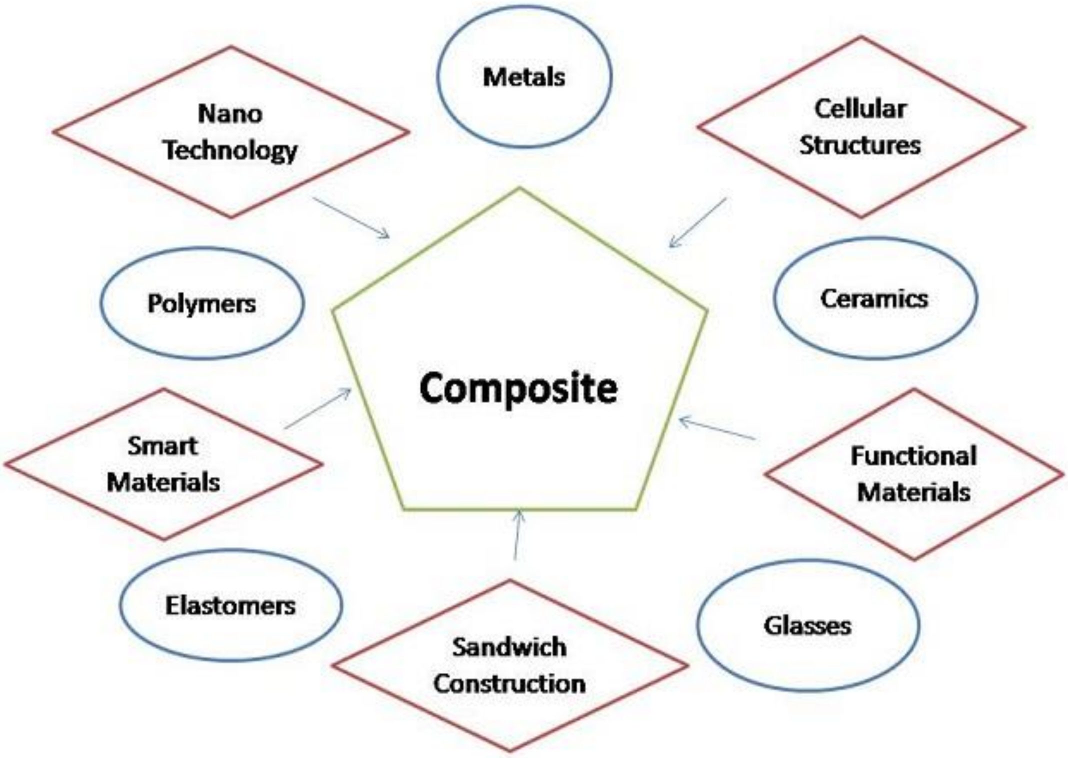

Figure 1: Classification of materials and structures.

Researchers have studied the durability of HDPE geomembranes and they have found three steps of the process of oxidative degradation under the conditions that provide a nearby approximation to field conditions. This work includes the mechanisms and basic concepts concerned to the durability of PEHD geo-membranes and explains the factors that regulate the service life of geo-membrane liners. The durability of Geo-membrane is conveyed with reference to laboratory test results and field performance under distinct conditions. Their projected service life that might vary from several centuries to less than ten years depending on the exposure conditions and type of material is discussed. An inspection on the field long-term and degradation of HDPE geo-membranes has been discussed. The process of oxidative degradation of HDPE geo-membranes consists of three steps. Firstly, antioxidants, also known as the protective agents, are depleted either by loss by percolate or by simple reaction with oxygen. At the end of this stage the material becomes tender to any oxygen present. The second step comprises of the induction time that is in agreement with the required time before the relevant properties start to be altered. The last step corresponds to the elapsed time before the geo-membrane gets failed. Therefore, the overall service life should be an addition of the duration of the three steps. The model of oxidative degradation is discussed for more inclusive laboratory investigations for understanding the degradation in a better way that occurs in geo-membranes as a best result of their exposure. Therefore, the future investigations must have the capabilities to incorporate the conditions that will allow the quantification and identification of the three steps of the oxidative degradation process under distinct conditions that provide a near about approximation to field conditions [4-8].

The degradation of giant polymers in the course of weathering was analysed, and they have studied the characteristics and behaviour of polymer. As the polymer industry developed, appreciable efforts were made to understand the procedure of degradation of giant polymers throughout weathering and different ways were obtained to prevent or retard their chemical modification and depletion of their physical and mechanical properties. Weathering is remarkably critical for polymers because it joins the photochemical and photo physical effects of ultraviolet radiation with hydrolytic and oxidative consequences of the outdoor environment. This article explains photo-oxidation degradation (the behaviour of polymers as a result of outdoor factors) and emphasizes mainly on the photo-oxidative degradation of poly (vinyl) chloride and polyolefins. Polymer photo stabilization with ultraviolet screeners, quenchers, hydro peroxide decomposers, and radical scavengers is also described [9-12].

Using FTIR spectroscopy thermal degradation of HDPE was studied. The degradation of polymeric materials takes place by exposure to several factors such as UV light, microbes, heat, irradiation ozone and mechanical stress. Degradation is enhanced by humidity, strain and oxygen, and it causes flaws like cracking, fading and brittleness [13].

Researchers have worked on study of outdoor weathering of HDPE and found out, the degradation of mechanical properties measurement. The weathering of high-density polyethylene (HDPE) specimens, with and without additives, subjected to natural atmosphere, was analysed and thermal, structural and mechanical changes were determined. The results showed a magnificent environmental oxidative degradation of non-stabilized HDPE. Thin film degradation by chlorinated water or UV light was studied and found out decrease the stress concentration due to cause slow degradation. Deformation of HDPE pipe was studied and found that more pressure in pipe causes leakage in pipe so all test properties are considered under pressure head. In this research work, the leakage characteristics of the visco-elastic material HDPE is determined and compared to other materials like Poly vinyl chloride which is elastic and galvanized steel which is rigid in nature.

## 3. Research Gap

From previous studies it was found that reinforcement of HDPE by the Nano particles was missing, whereas silica acts as binder. This has been identified as research objective to use Nanoparticle of silica with HDPE.

### 3.1 Research objective

From previous studies following research gap was identified.

1. To study the mechanical characterization of High-density polyethylene sample
2. Lifetime prediction of composite sample.
3. Lifetime prediction exposure to accelerated condition studies as per ASTM D 3045

## 4. Experimental Setup

In this research work HDPE and nanoparticle of silica were selected as materials. Silica is selected as reinforcement component of HDPE. It has special properties for binding. In this study mechanical property of sample were studied for tensile, flexural and impact test. To determine thermal properties thermal conductivity test using LASER flash and Differential Scanning Calorimetry (DSC) & Thermo-Gravimetric Analysis (TGA) Test were performed.

To study thermal Conductivity test using LASER Flash, samples were cleaned with acetone and in order to dry samples were heated for 60 minutes in the oven. The samples were coated with the thin layer of graphite to attain unit emissivity. In argon atmosphere front side of samples were subjected to Xenon flash lamp (Lamp voltage 304 V and pulse width 0.31ms). The energy of the pulse was recorded at the rear side of the samples.

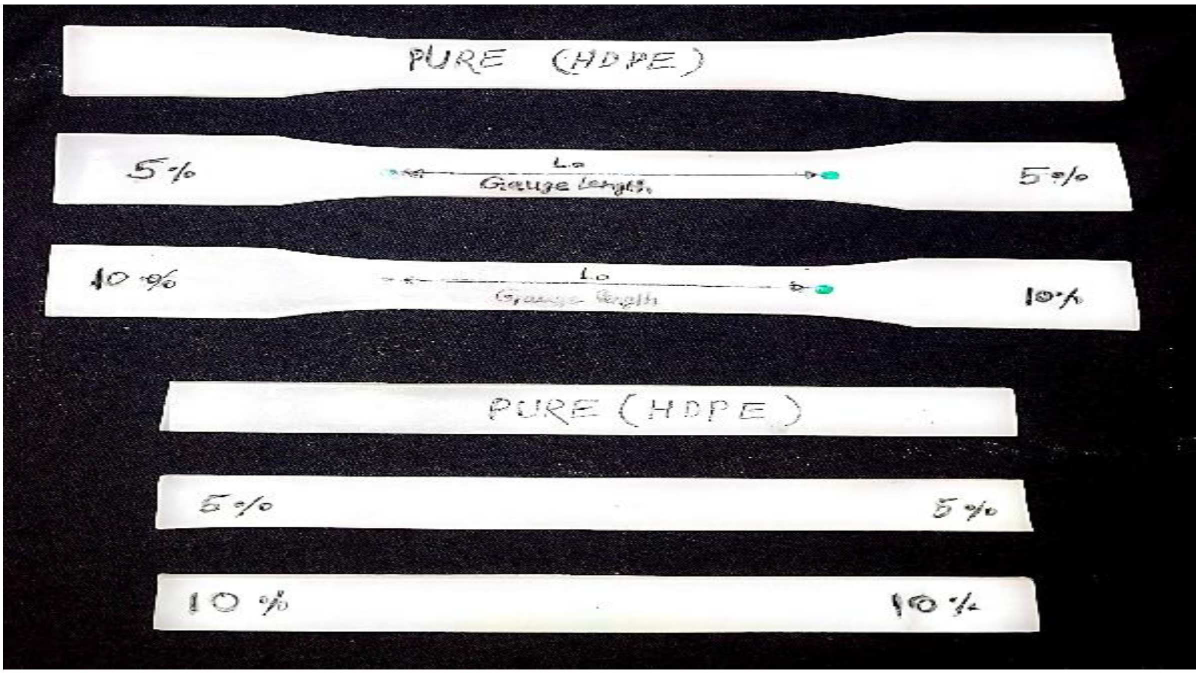

**Figure 2: Experimental sample of HDPE and nanoparticle of Silica**

For STA test, STA 6000 machine was used comprising of two pans in which one of the pan was kept empty and on the other pan the sample weighing 20 mg was kept in an alumina crucible by pouring a small amount of white colour aluminum oxide powder and then the machine was allowed to operate. Heat flow was allowed to vary between the temperature ranges of $30^0$C to $100^0$C with the heating rate of $1^0$C / min. Liquid nitrogen was used in the amount 20ml/ min. for maintaining the temperature above the ambient condition. It shows that the empty pan absorbed negligible amount of heat whereas loaded pan containing the sample absorbed more amount of heat and there occurred the thermal instability between the two pans and order to maintain the thermal stability machine automatically supplies some more amount of heat and excess heat which is used to maintain the thermal stability as a function of temperature is calibrated.

## 5. Results and Discussion

For tension test dogbone shape polymer sample was prepares as shown in Figure 2. Uniaxial tension test was performed to study the elongation behaviour of the polymer. Figure 3 show the loads application and corresponding changes in elongation (mm). Two different samples 5% and 10% by wt. addition of silica nanoparticles in HDPE and results are shown in table 1. Sample 1 at 1050.80 N maximum loads, 12.5 MPa tensile strength was observed. Sample 2 shows 11.2 MPa maximum tensile strength at 941.95 N loads.

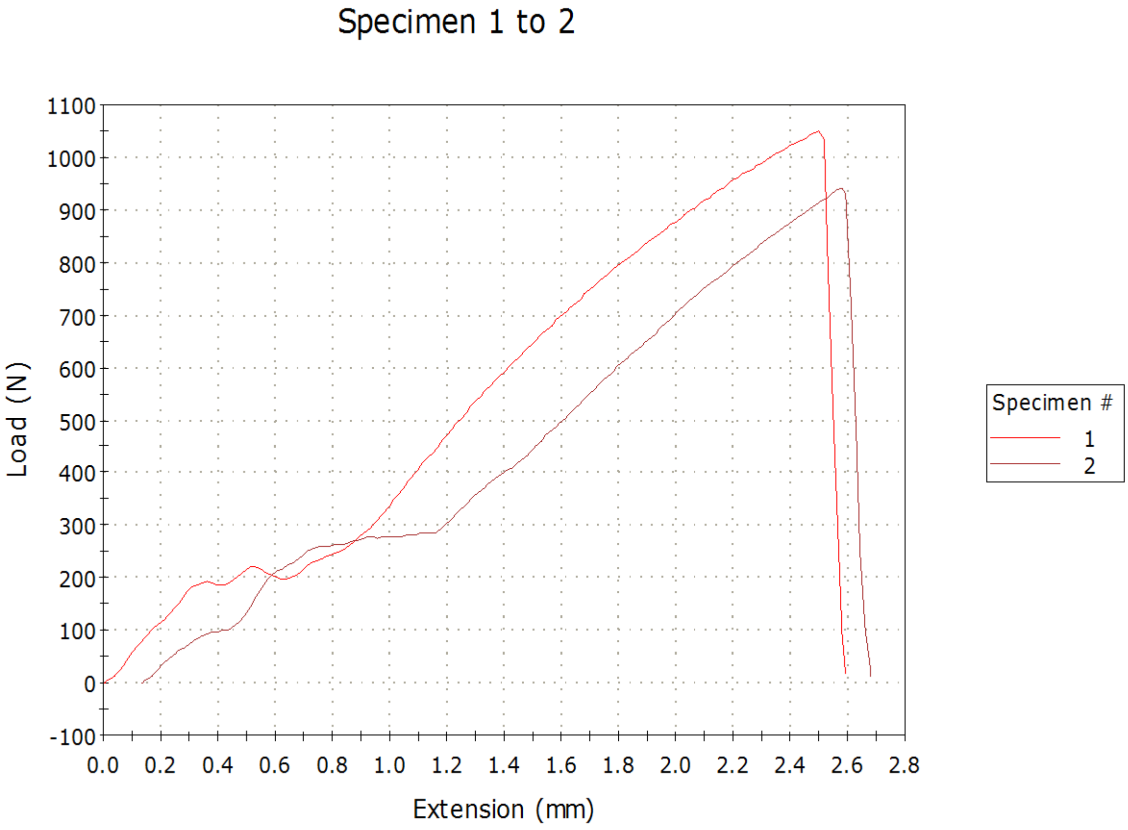

Figure 3: Plots for Loads vs. Extension under Tensile Test

**Table 1: Observation table of tensile test**

| Stages | Length (mm) | Thickness (mm) | Width (mm) | Maximum Load N | Tensile stress at Maximum Load (MPa) |
|---|---|---|---|---|---|
| Sample(1) with 5% NPs | 115.00000 | 6.50000 | 12.90000 | 1050.80 | 12.5 |
| Sample(2) with 10% NPs | 115.00000 | 6.50000 | 12.90000 | 941.95 | 11.2 |

**Table 2: Observation of flexural test**

| Stages | Maximum Load (N) | Flex Modulus (MPa) | Width (mm) | Thickness (mm) | Support span (mm) |
|---|---|---|---|---|---|
| Sample (1) with 10% NPs | 73.20 | 666.50 | 13.00 | 6.50 | 104.00 |
| Sample (2) with 5% NPs | 62.07 | 644.07 | 13.00 | 6.50 | 104.00 |

Table 2 shows the results of flexural test. This test was performed to find the flexural strength of the samples. At 73.20 N load sample 1 shows 666.50 MPa flexural modulus. Sample 2 shows 644.07 MPa flexural modulus at 62.07 N loading conditions. Figure 4 shows flexural stress and strain variation for both samples and table 3 shows stress values 20.78 MPa and 17.62 MPa corresponding 10% and 5% by wt. silica NPs variations.

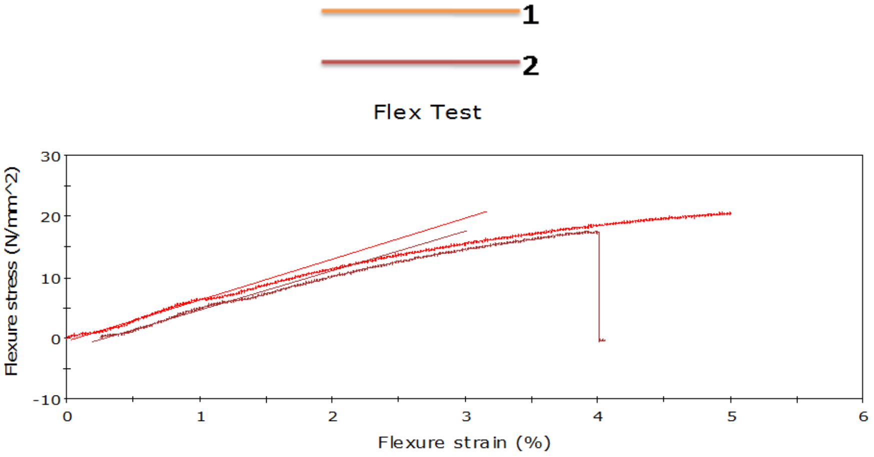

**Figure 4: Flexure Stress vs. Flexure Strain plot.**

**Table 3: Observation Table of flexural test at different stages**

| Stages | Flexure stress at Maximum Flexure load (MPa) |
|---|---|
| Sample (1) with 10% NPs | 20.78931 |
| Sample (2) with 5 % NPs | 17.62826 |

**Table 4: The calculated impact strength of different composite samples**

| Specimen | Impact Strength (J/m) | | |
|---|---|---|---|
| | Sample A (0% $SiO_2$) | Sample B (5% $SiO_2$) | Sample C (10% $SiO_2$) |
| **1** | 171 | 211.7132 | 251.9235 |
| **2** | 171 | 214.7136 | 237.4328 |
| **3** | 169.5689 | 205.8392 | 259.6667 |

Table 4 shows the impact strength of different composite samples. At 0% $SiO_2$ Nanoparticles the impact strength of sample 1 is minimum i.e. 171 J/m. The above result shows increment in impact strength of 23.58% and 46.42% with the addition of 5% and 10% $SiO_2$ Nanoparticles. DSC and TGA test was carried out in thermal analyser in the temperature range of $30^0$C-$100^0$C with the heating rate of $1^0$C/min. For maintaining the above variation of temperature the liquid nitrogen is used with the rate of 20ml/ min.

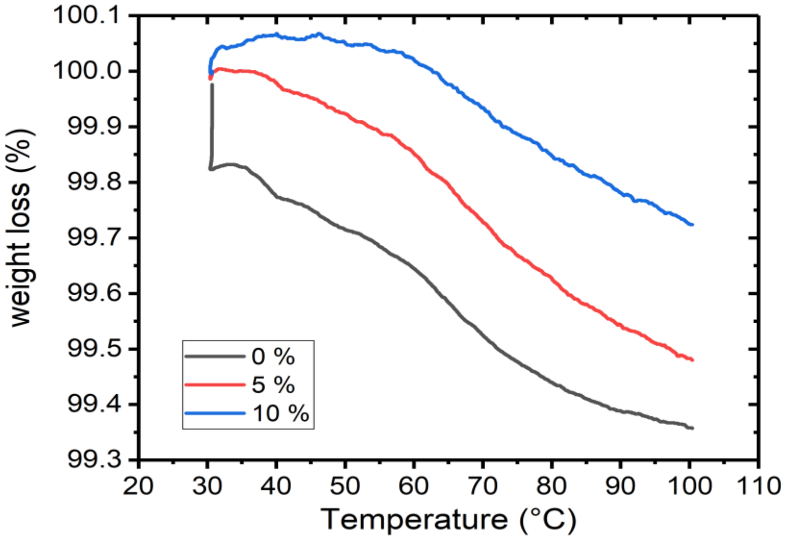

Figure 5: Comparison of percentage weight loss with the variation of the Silica nanoparticles

Figure 5 shows the percentage weight loss by varying the silica nanoparticles. The results shows the percentage weight loss is reduced by 58.87% and 98.30% with the addition of 5% and 10% silica nano particles at $60^0$C respectively. Similarly, it is reduced by 25.49% and 64.37% at $90^0$C.

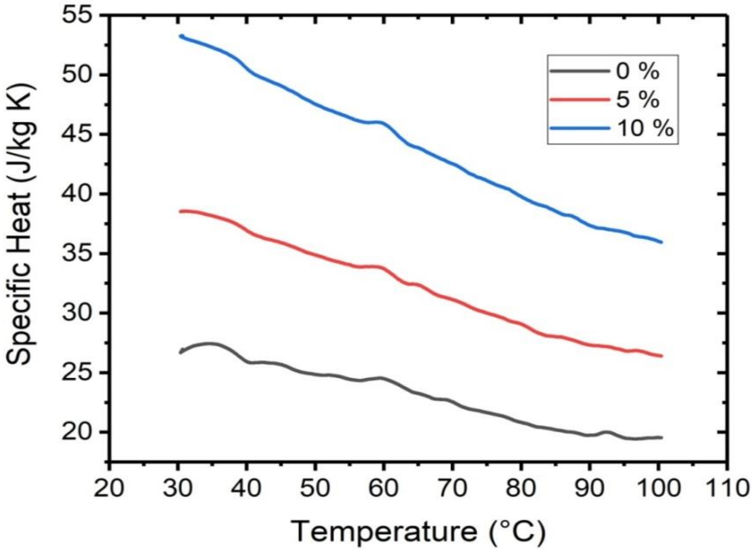

**Figure 6 Comparison of Specific heat with the variation of the silica nanoparticles**

Figure 6 shows the specific heat with varying temperature. The test results shows that the specific heat is increased by 37.90% and 87.32% with the addition of 5% and 10% silica nanoparticles at 600C respectively. Similarly, it is increased by 38.35% and 89.36% at 900C.

## 6. Conclusions and Future Scope

In this research work three samples (A, B, & C) having the silica nanoparticles variation by 0%, 5% and 10% by wt. in HDPE. Three samples were tested for obtaining the mechanical and thermal properties according to ASTM standard. From the experiments following results were concluded:

- From the experiments it is concluded that tensile strength of samples decreases and flexural strength increases as per increment of nanoparticles of silica (0%, 5% and 10% by wt.) in HDPE.
- From Izod Impact testing it was concluded that adding 5% and 10% by wt. silica nano particles the strength is increased by 23.58% and 46.42%.
- From thermal test it was concluded that 5% and 10% addition of silica nanoparticles in HDPE has improved the thermal conductivity by 27.63% and 46.69%.
- From STA test it was found that samples thermal stability increases with increasing silica nanoparticles and specific heat decreases with increasing temperature but increases with increasing silica nanoparticles.
- In future reinforcement of HDPE can be evaluated using different materials and can be tested for making different equipments and components.

## References

[1] Kanagaraj, S., Varanda, F. R., Zhil'tsova, T. V., Oliveira, M. S. A., & Simões, J. A. O. (2007). Mechanical properties of high density polyethylene/carbon nanotube composites. Composites Science and Technology, 67(15-16), 3071–3077. doi:10.1016/j.compscitech.2007.04.024.

[2] Sandler J, Shaffer MSP, Prasse T, Bauhofer W, Schulte K, Windle AH. Development of a dispersion process for carbon nanotubes in an epoxy matrix and the resulting electrical properties. Polymer 1999;40:5967–71.

[3]Gong X, Liu J, Baskaran S, Voise RD, Young JS. Surfactant-assisted processing of carbon nanotube/polymer composites. Chem Mater 2000;12(4):1049–52.

[4] Ji XL, Jing JK, Jiang W, Jiang BZ. Tensile modulus of polymer nanocomposites. Polym Eng Sci 2002;42(5):983–93.

[5] Zou Y, Feng Y, Wang L, Liu X. Processing and properties of MWNT/HDPE composites. Carbon 2004;42:271–7.

[6] Edidin AA, Kurtz SM. Development of validation of the small punch test for UHMWPE used in total joint replacements. Funct Biomater 2001;198:1–40.

[7] Tang W, Santare MH, Advani SG. Melt processing and mechanical property characterization of multi-walled carbon nanotube/high density polyethylene (MWNT/HDPE) composite films. Carbon 2003;41:2779–85.

[8] Wang A, Sun DC, Stark C, Dumbleton JH. Wear mechanisms of UHMWPE in total joint replacements. Wear 1995;181– 183:241–9.

[9] Coleman JN, Cadek M, Blake R, Nicolosi V, Ryan KP, Belton C, et al. High performance nanotube-reinforced plastics: Understanding the mechanism of strength increase. Adv Funct Mater 2004;14:791–8.

[10] Frankland SJV, Caglar A, Brenner DW, Griebel M. Molecular simulation of the influence of chemical cross-links on the shear strength of carbon nanotube–polymer interface. J Phys Chem B 2002;106:3046–8.

[11] Verma A, Singh VK, Verma SK, Sharma A. Human Hair: A Biodegradable Composite Fiber – A Review. International Journal of Waste Resources 6:206. doi:10.4172/2252-5211.1000206.

[12] Jun Ma , Mao Song Mo, Xu Shend Du, Klaus Friedrich , Hsu Chiang Kuan. Effect of inorganic nanoparticles on mechanical property, fracture toughness and toughening mechanism of two epoxy systems, Polymer, Vol. 49, Issue 16, p.n. 3510-3523.

[13] Ruan SL, Gao P, Yang XG, Yu TX. Toughening high performance ultrahigh molecular weight polyethylene using multiwalled carbon nanotubes. Polymer 2003;44:5643–54.