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# UHMWPE / AL2O3 SYNTHESIS AND MECHANICAL PROPERTIES EVALUATION

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**Abstract:** UHMWPE being similar to HDPE has got more interesting properties like chemical stability and most importantly the abrasion resistance property. The applications of UHMWPE among important sectors have drawn researcher's attention towards improving the properties of UHMWPE by filling it with micro and nano particles (ceramic oxides). In this work, the major concentration is on developing UHMWPE composites reinforced with Al2O3 and ZnO nano particles and analysing the mechanical, tribological and microstructural characteristics. The nano reinforcements were synthesized using sol-gel process and used in the study. Mechanical characterization was done through standard procedures with specimen standards corresponding to ASTM. Compositions selected for the study were 2.5, 5, 7.5, 10 and 12.5 % of Al2O3/ZnO NPs along with UHMWPE as base matrix. Density test was conducted using the standard procedure and porosity in percentage was calculated. It was clearly observed that with an addition of 12.5% NPs, the porosity increases rapidly because of the pore nucleation due to increased surface area and shrinkage due to volume contraction because of agglomeration. Hardness test was conducted on Vicker's hardness tester and for both the reinforcements an increase in hardness with an increase in NP fillings was seen. Although, at 12.5% NP, there was no such improvement in hardness. This directly is related to the porosity of the composite at 12.5% NP. Impact and compression strength results also show the same trend.

## INTRODUCTION

Since its development in the early 1950s, ultra-high molecular weight polyethylene (UHMWPE) has gained popularity owing to its bio-compatibility [1–4], self-lubricating properties [5], chemical stability [6], and wear and impact resistance, thereby making it an excellent choice for a range of engineering and biomedical applications. In the biomedical field, UHMWPE has proven to be an excellent material for spine, hip, and implant therapies [7,8]. UHMWPE fibers have been used in personal and vehicle armor development, owing to its excellent impact resistance [9]. Its excellent wear and abrasion resistance have rendered it an excellent choice for industrial bearing applications [6,10]. However, the use of pristine UHMWPE systems in demanding tribological applications has often been limited by its poor load-bearing capabilities, coupled with low thermal stability under high p-v conditions [11–13]. To overcome these hurdles, researchers over the years have resorted to modifying pristine UHMWPE using a variety of techniques, including, but not limited to, radiation crosslinking [14,15], ion implantation [16], application of diamond-like carbon (DLC) top coats [17], and ceramic, metallic, carbon-based, and mineral fillers' infusion into the UHMWPE matrix to produce composite systems with improved mechanical and tribological properties [1,18–26].

Owing to its excellent tribological properties in terms of low friction and high wear resistance, recently researchers have started developing UHMWPE coatings to protect metallic mating parts in the absence of liquid lubrication. Just like in the case of bulk UHMWPE, it is essential to improve the load bearing capacity of the UHMWPE coating for better performance. One of the strategies used by researchers is to develop UHMWPE nanocomposite and hybrid nanocomposite coatings reinforced with various nanofillers, such as carbon nanotubes (CNTs) [27,28], graphene [29], nanoclay [30], and nanoclay/CNTs [31]. Azam et al. [30] reinforced UHMWPE with different wt % of nanoclay and found that 1.5 wt % nanoclay-reinforced UHMWPE coating did not fail until 100,000 cycles at a normal load of 9 N and a linear speed of 0.1 m/s. However, the 1.5 wt % nanoclay/UHMWPE coating could not sustain a load of 12 N, whereby it failed immediately. To further improve the performance of the coating, they developed a hybrid nanocomposite coating reinforced with 1.5 wt % nanoclay and 1.5 wt % CNTs [31]. They reported an increase in the load-bearing capacity of UHMWPE coating to 12 N, in this case. Of the various options available to researchers involved in the development of UHMWPE nanocomposites in bulk and in the form of coatings, ceramic nanoparticles [21–23] offer a variety of properties which tend to enhance the performance of UHMWPE. Alumina (Al2O3) is one such ceramic particle which presents itself as an excellent choice of a nanofiller, owing to its extremely high hardness retention at elevated temperatures, bio-inertness, ability to enhance the pristine polymer's load-bearing ability, and exceptional corrosion resistance [23,25,26,32,33].

## MATERIALS AND METHODS

UHMWPE was obtained directly from the market and the reinforcements were synthesized as show below:

### Sol-gel synthesis of Al2O3:

Aluminum wire (Al) (having a diameter of approximately 4 mm - 5 mm) has been cut into small pieces approximately 3-4mm length. A stock solution of sodium hydroxide (NaOH) 25 weight% has been prepared. A few grams of aluminum wire pieces have been taken into 2000ml capacity round bottom flask. About 200ml NaOH solution is carefully added into round bottom flask, which was kept on a heating mantle, and a water condenser set up has been fixed. A content of the round bottom flask has been heated gradually for speeding up of complete dissolution of aluminum wire. This process is known as refluxing, as shown in flow sheet. Upon cooling, the contents of round bottom flask have been filtered through filter paper (Whatman 41) with the help of vacuum filtration process, to obtain clear solution of sodium aluminate (NaOAl). Equal volumes of sodium aluminate and isopropyl alcohol (IPA) have been taken in a clear beaker. The content of this beaker namely organic-inorganic mixture have been carefully transferred into round bottle flask(2000ml), the content of the round bottom flask have been refluxed as described above. After 48 hours of refluxing, the contents of round bottom flask have been cooled to room temperature. This process is known as alkoxylation, and the excess isopropyl alcohol has been collected by distillation process. The remaining solution, which is left over, consists of aluminium isopropoxide has been found to have a pH value in the range of 12-14. Aluminumisopropoxide has been collected in a clean dry beaker of 500ml capacity. Neutralization of this solution has been carried out by the addition of dilute hydrochloric acid (HCl) drop by drop with vigorous stirring, using magnetic stirrer. Naturalization process has been continued until the pH of this solution is in near neutral range (~pH=7).This solution consist of nano aluminium hydroxide solution [$Al(OH)_3$]. In the initial stages of neutralization, sol formation and towards completion of neutralization process, formation of gel has been observed.

Figure: (a) Refluxing Setup & (b) Vacuum filtration setup (c) Aluminum balls (60g), (d) Sodium hydroxide solution, and (e) Dissolution of Aluminum foil in NaOH.

### Synthesis of Nano ZnO

As discussed in the methodology, among the different methods solution process synthesis have been considered in the initial studies. In the solution process synthesis, a 0.3M of zinc acetate di-hydrate was dissolved in 100 ml of distilled water with 3M concentration of sodium hydroxide.

White-colored residue was appeared for few seconds but disappeared after 2–3 minutes. The obtained solution was stirred for 10 minutes for complete dissolution. The pH of the solution was adjusted to 13, the solution containing the precipitate was refluxed at 90$^0$C. After refluxing, the white powder was washed with methanol several times and dried at room temperature.

In figure photographs of different stages of preparation of nano ZnO are presented.

Figure 6.5: Photographs of (a) White-colored residue of [NaOH +ZnOAc], (b) Clear solution of NaOH with ZnOH precipitate at the bottom, (c) Refluxing set up, and (d) Dried Nano ZnO.

## Evaluation of Mechanical properties

### Density test

The characteristic of the composite is reflected by its physical property known as density. While considering a composite, the proportion of matrix and reinforcement can be expressed as weight fraction, which has relevance to fabrication or volume fraction, used in the property calculations. Density test for the prepared composites is conducted using displacement method and the values obtained for different compositions are tabulated. Initially unreinforced composite is calculated for its density theoretically by the use of rule of mixture and as shown below.

1. Composition A = UHMWPE -2.5% Al2O3/ZnO
2. Composition B = UHMWPE -5% Al2O3/ZnO
3. Composition C = UHMWPE -7.5% Al2O3/ZnO
4. Composition D = UHMWPE -10% Al2O3/ZnO
5. Composition E = UHMWPE -12.5% Al2O3/ZnO

Density calculations for theoretical density are done using the below given formula:

$$\rho_c = \rho_m V_m + \rho_{Al2O3} V_{Al2O3}$$

Where,

$\rho_c$ = Total density of the composite

$\rho_m$ = Total density of the matrix

$\rho_{Al2O3}$ = Total density of Aluminium oxide

$V_m$ = Total volume of matrix

$V_{Al2O3}$= Total volume of Aluminium oxide

Volume of Aluminium oxide, $v_{Al2O3} = v_m \times / 1-x$ Where,

$v_m$ = Volume of Aluminium matrix

x = Volume fraction of $Al_2O_3$

Total Volume of UHMWPE Matrix $V_m = v_m / v_c$

Total Volume of Aluminium oxide $V_{Al2O3} = v_{Al2O3} / v_c$

Volume of Composite, $v_c = v_m + v_{Al2O3}$

Porosity in percentage can be calculated using the formula:

P = theoretical density-measured density/Theoretical density X 100

Table: Density of different compositions of composites with micro reinforcements (Al2O3)

| Composition | Mass of sample in air (grams) | Mass of sample in water (grams) | Density for each trial (grams/cc) | Density (0.93) Measured | Density (grams/cc) Theoretical | Porosity (%) |
|---|---|---|---|---|---|---|
| Composition A | 5.232 | 4.968 | 0.948 | **0.947** | **0.952** | **0.525** |
| | 5.682 | 5.327 | 0.946 | | | |
| | 5.368 | 5.296 | 0.947 | | | |
| Composition B | 5.392 | 5.266 | 0.983 | **0.986** | **0.993** | **0.705** |
| | 5.547 | 5.496 | 0.986 | | | |
| | 5.418 | 5.396 | 0.988 | | | |
| Composition C | 5.652 | 5.563 | 1.087 | **1.086** | **1.101** | **1.362** |
| | 5.258 | 5.139 | 1.082 | | | |
| | 5.365 | 5.236 | 1.088 | | | |
| Composition D | 5.358 | 5.299 | 1.110 | **1.114** | **1.136** | **1.936** |
| | 5.368 | 5.263 | 1.117 | | | |
| | 5.411 | 5.321 | 1.113 | | | |
| Composition E | 5.386 | 5.206 | 1.286 | **1.273** | **1.321** | **3.633** |
| | 5.639 | 5.521 | 1.258 | | | |
| | 5.424 | 5.361 | 1.274 | | | |

Table: Density of different compositions of composites with nano reinforcements (Al2O3)

| Composition | Density (grams/cc) Measured | Density (grams/cc) Theoretical | Porosity (%) |
|---|---|---|---|
| Composition A | **0.947** | **0.952** | **0.525** |
| Composition B | **0.986** | **0.993** | **0.705** |
| Composition C | **1.086** | **1.101** | **1.362** |
| Composition D | **1.114** | **1.136** | **1.936** |
| Composition E | **1.273** | **1.321** | **3.633** |

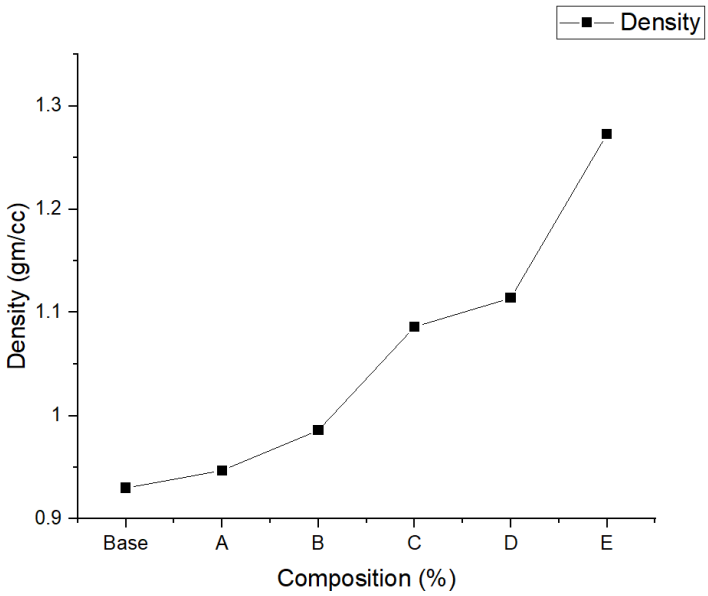


Fig: Variation of density with respect to the composition

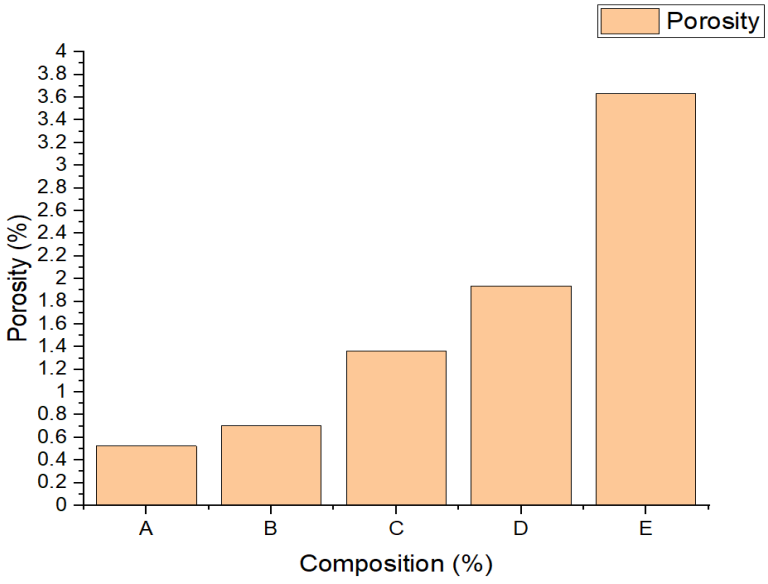


Fig: Variation of porosity with respect to composition

The results of densities (both theoretical and experimental) are recorded and the graph to understand the variation of both density and porosity is plotted. The results show that the density increases with the increase in Al2O3 percentage. Due to the higher values of density of Al2O3 there is an increase in composite density seen after the addition of reinforcements. The major increase in density of about 36.6% can be seen when the reinforcement percentage is 12.5%. During the time of solidification after compression two important observations are made:

1. At the sites of ceramic reinforcement particles pores get nucleated which leads to the increase in surface area and which is due to the presence of AL2O3.
2. Solidifications are accompanied by the shrinkage due to volume contraction and which may be attributed to the agglomeration of reinforcement particles. This increases porosity which then affects the mechanical property due to the pore nucleation.

It can be seen that the porosity does not increase drastically with the addition of reinforcement up to 10%. This may be because the reinforcements are distributed homogeneously and uniformly resulting in less reaction and agglomeration. This in turn reduces the porosity of the composite. When furthermore Al2O3 is added the porosity increases as the pore nucleation starts at the ceramic particulates which lead to shrinkage due to volume reduction which may be due to agglomeration.

Table: Density of different compositions of composites with micro reinforcements (ZnO)

| Composition | Mass of sample in air (grams) | Mass of sample in water (grams) | Density for each trial (grams/cc) | Density (0.93) Measured | Density (grams/cc) Theoritical | Porosity (%) |
|---|---|---|---|---|---|---|
| Composition A | 5.168 | 5.069 | 0.982 | **0.984** | **0.990** | **0.6** |
| | 5.195 | 5.082 | 0.987 | | | |
| | 5.166 | 5.066 | 0.983 | | | |
| Composition B | 5.399 | 5.026 | 1.065 | **1.067** | **1.079** | **1.11** |
| | 5.368 | 5.022 | 1.068 | | | |
| | 5.401 | 5.031 | 1.067 | | | |
| Composition C | 5.569 | 5.046 | 1.102 | **1.106** | **1.136** | **2.6** |
| | 5.559 | 5.042 | 1.109 | | | |
| | 5.567 | 5.044 | 1.106 | | | |
| Composition D | 5.546 | 5.038 | 1.186 | **1.186** | **1.234** | **3.8** |
| | 5.458 | 5.034 | 1.183 | | | |
| | 5.499 | 5.038 | 1.187 | | | |
| Composition E | 5.369 | 5.023 | 1.268 | **1.272** | **1.343** | **5.28** |
| | 5.513 | 5.039 | 1.279 | | | |
| | 5.524 | 5.046 | 1.267 | | | |

Table: Density of different compositions of composites with nano reinforcements (ZnO)

| Composition | Density (grams/cc) Measured | Density (grams/cc) Theoritical | Porosity (%) |
|---|---|---|---|
| Composition A | **0.984** | **0.990** | **0.6** |
| Composition B | **1.067** | **1.079** | **1.11** |
| Composition C | **1.106** | **1.136** | **2.6** |
| Composition D | **1.186** | **1.234** | **3.8** |
| Composition E | **1.272** | **1.343** | **5.28** |

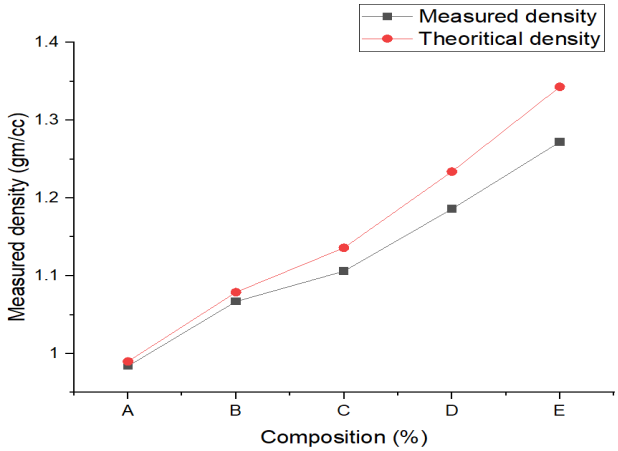


Fig: Variation of density with the varying composition

With the values obtained by experiments and calculations the measured as well as the theoretical densities are tabulated for further analysis. It can be seen that the measured values slightly vary from the theoretical values but almost are same. With the addition of ZnO nano particles the density also increases because the density of virgin UHMWPE is 0.93gm/cc whereas the density of ZnO is 5.61gm/cc. Hence due to the addition of the ZnO nano particles there is an increase of almost 52% when 12.5% addition of ZnO is considered. This may be due to the crystallinity of matrix increases due to the nucleating effect of nano ZnO particles. Apart from 12.5% the other composition shows almost density increase up to 38% which can be seen from the table. Because of the lower content of the matrix and due to less vacant space because of the more filler material, theoretically the porosity has to get reduced with more and more addition of reinforcements. But normally due to the inability of matrix to fill the gap between the filler particles the porosity increases. The increase in porosity can also be attributed to the pore nucleation at the ceramic particulates sites.

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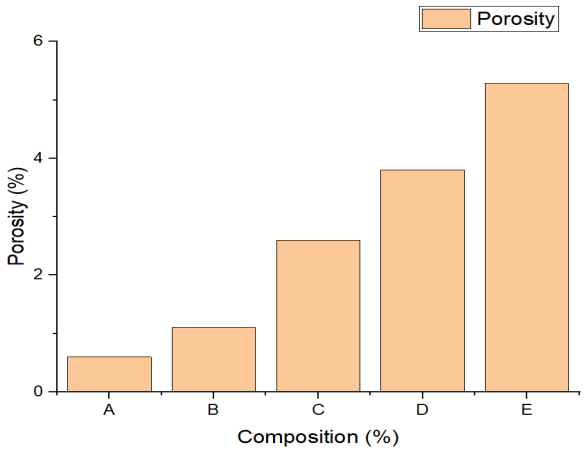



Fig: Variation of porosity with the varying composition

## Hardness Test

The method of testing hardness used in the study is the Vickers hardness test. The applied load in this experiment was 5kgf for 10 seconds. The measured values for different composition are tabulated in the table below. Hardness values which are tabulated are the average values of the measured values of three samples from each composition group. Each sample is measured 15 times for obtaining the better values. Indentation is done through a diamond indenter with a square base. Angle between the pyramid faces is $136^0$. Vickers hardness number is obtained by dividing the average load P by the surface of the pyramidal depression. The equation for finding the Vickers hardness number is:

$$VHN=\frac{2P\sin(136/2)}{d^2} = \frac{1.8544P}{d^2}$$

Where, d is the average diagonal length in (mm) .

Table: Hardness values calculated for the composites with different composition (nano Al2O3)

| Variations of reinforcements (wt. %) | Load applied (kgf) | Time (Sec) | VHN (36) |
|---|---|---|---|
| Composition A | 5 | 10 | 36.12 |
| Composition B | 5 | 10 | 39.66 |
| Composition C | 5 | 10 | 43.98 |
| Composition D | 5 | 10 | 49.71 |
| Composition E | 5 | 10 | 50.43 |

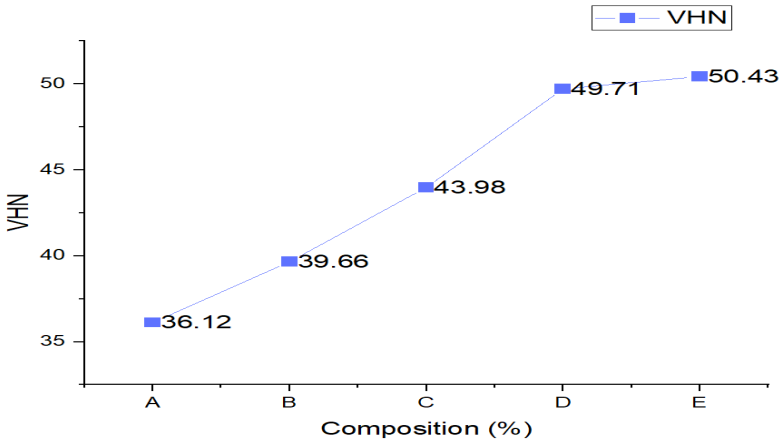



Fig: Hardness values for different composition

Table above table and graph shows the hardness values for the prepared composites with different compositions. Evidentially the table shows the hardness of the composite increases due to the increase in the reinforcement percentage for up to 28.6%. When observed the values of hardness or the percentage increase in hardness for 2.5%, 5%, 7.5%, 10% and 12.5% increase in reinforcements are 0.3%, 9.2%, 18.14%, 27.57% and 28.6% respectively. While observing the hardness values of composites with 10 and 12.5% reinforcement, it can be seen that there is no such drastic increase in the hardness values (27.57 and 28.6%). This may be due to the higher porosity of the composite with 12.5% reinforcement (52%) compared to base matrix UHMWPE (0.21%). The increase in hardness can also be attributed to the secondary phases formed and observed during the microstructural analysis. Intermetallic phases were formed and precipitated and seen at the grain boundaries. Also the pore nucleation is minimum resulting in less void formation leading to increase in hardness up to 10% reinforcements.

With more addition of reinforcement above 10% porosity increases as discussed in the previous section and due to which the hardness is affected. Also the mixture heterogeneity plays an important role in hardness property. Other reason for decrease in hardness may be the interface formed between the base matrix and reinforcement being brittle.

Table: Hardness values calculated for the composites with different composition (nano ZnO)

| Variations of reinforcements (wt. %) | Load applied (kgf) | Time (Sec) | VHN (36) |
|---|---|---|---|
| Composition A | 5 | 10 | 37.05 |
| Composition B | 5 | 10 | 40.29 |
| Composition C | 5 | 10 | 44.33 |
| Composition D | 5 | 10 | 51.98 |
| Composition E | 5 | 10 | 52.63 |

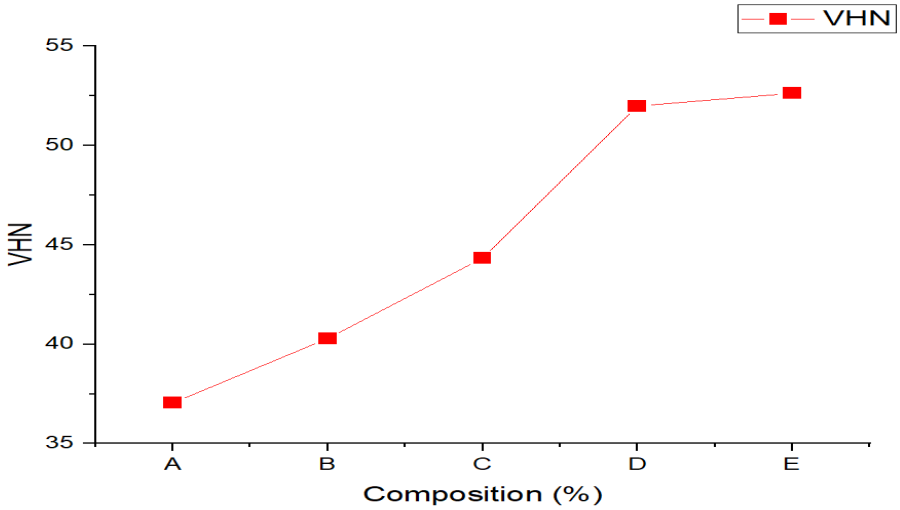


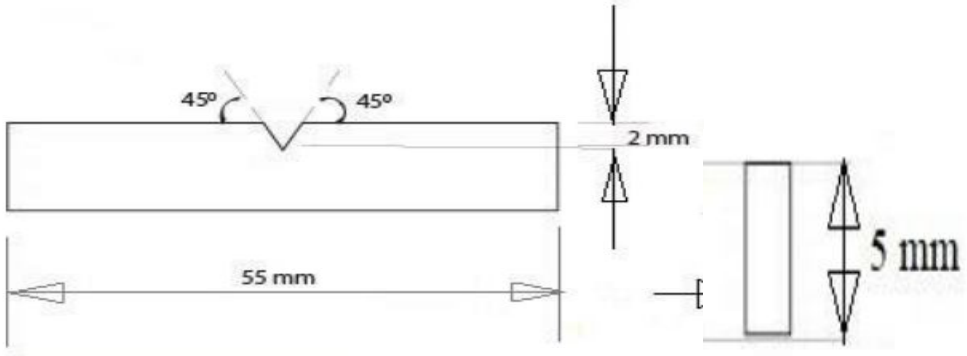

Fig: Hardness values for different composition

The hardness values after the experiments are tabulated in the table. The values of hardness are seen to be increased with the increase in the reinforcement's percentage. Again as seen with the composites with Al2O3 composites the increase in nano ZnO from 10% to 12.5% does not yield much of a drastic increase in the values of hardness. This may be due to the increased porosity in the composite sample with 12.5% nano ZnO which may be due to the pore nucleation at the ceramic particulates site. Also the brittle phase can be seen to be formed at the matrix and reinforcement interphase. From the graph it can be seen that the Vickers hardness number increases with the increase in the nano ZnO. The maximum value reached is at 12.5% reinforcement with an increase of 31.59% as compared to the base matrix (UHMWPE). The percentage improvement values in percentage are 2.8%, 10.64%, 18.79, 30.74% and 31.59%. Rigid nano fillers (ZnO) are responsible for the increased hardness of the composite. The inter particulate distance between the reinforcements will be reduced when more and more reinforcements are added to the base matrix. This may also be the cause for the increased micro hardness number of t6he composites with different composition.

**Impact test**

Charpy impact tester was used to conduct the impact test on the samples prepared using ASTM A370 standard. The figure shows the full dimension of the sample including notch prepared on the sample. Initially the test apparatus is set at 10kgm and e1 reading is noted. Then with the experiments conducted on the samples prepared for the different composition e2 is recorded. Three trials were taken for every composition and the average value is taken at the end and recorded. Equation for calculating the impact strength is:

Charpy impact value e = e1-e2



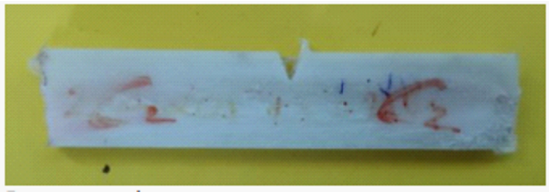


Fig: Specimen dimension and specimen sample for impact test

Table shows the impact strength values of both composites with Al2O3 and ZnO as reinforcements. Initially tests are conducted on the samples of composites with Al2O3 filler and the same procedure is followed for the ZnO fillers also. The graphs are drawn to understand the behaviour of composites in terms of impact strength with respect to the composition.

Table: Impact strength values of UHMWPE+nano Al2O3

| Variations of reinforcements (wt. %) | Impact strength in KJ/m2 | Average |
|---|---|---|
| Composition A | 97.06 | 97.06 |
| | 97.09 | |
| | 97.02 | |
| Composition B | 99.14 | 99.2 |
| | 99.19 | |
| | 99.27 | |
| Composition C | 101.63 | 101.7 |
| | 101.68 | |
| | 101.79 | |
| Composition D | 106.32 | 105.6 |
| | 106.63 | |
| | 106.98 | |
| Composition E | 107.12 | 107.3 |
| | 106.98 | |
| | 107.55 | |

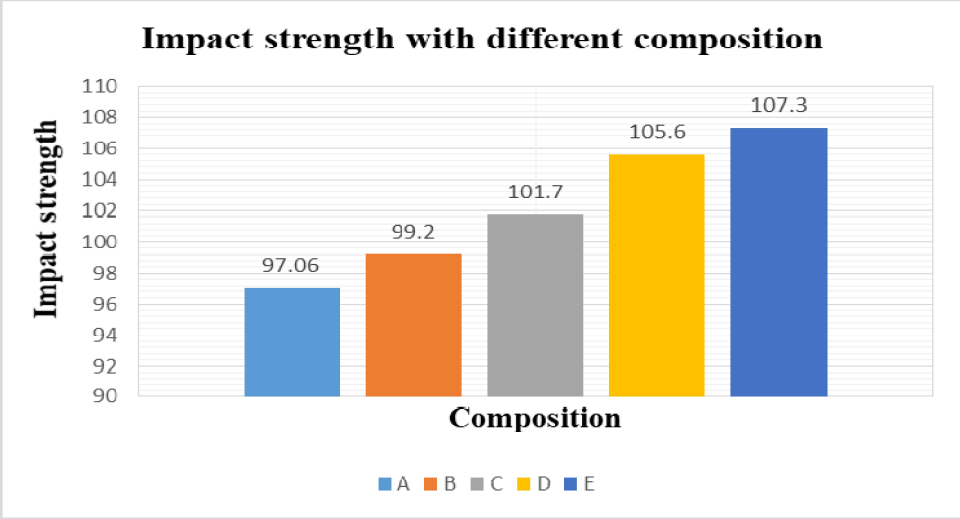



Fig: Impact strength variation for different composition

The values of impact test on the composites with nano Al2O3 as reinforcements is tabulated in the table. The Impact strength or the impact absorption energy of the composites is seen increasing with the increase in the reinforcement percentage. With an addition of 12.5% Al2O3 an increase of 10.5% in the impact strength can be seen from the values obtained. Not much difference is observed between the 10% and 12.5% reinforcement. This may be due to the increase in porosity leading to increased voids which almost decreases the absorption energy by propagating and joining the voids which leads to fracture. The increase in impact energy comparatively to the base matrix is due to the increase in the number of particles per unit area which makes the mixture of matrix and reinforcement homogeneous. This leads to reduction in pores and voids which in turn increases the absorption energy while impacted. Failures due to debonding through matrix phase is reduced which is the effect of nano particle size and increase in number. This in turn reduces the cracking amount at the particles and interphase and hence the impact strength of the composites is increased. The increase in impact strength compared to base matrix is 0.78%, 2.9%, 5.30, 8.80% and 10.25% for 2.5%, 5%, 7.5%, 10% and 12.5% increase in the reinforcements respectively.

Table: Impact strength values of UHMWPE+nanoZnO

| Variations of reinforcements (wt. %) | Impact strength in KJ/m2 | Average |
|---|---|---|
| Composition A | 98.56 | 98.31 |
| | 98.26 | |
| | 98.09 | |
| Composition B | 100.93 | 101.47 |
| | 101.87 | |
| | 101.45 | |
| Composition C | 105.21 | 105.16 |
| | 105.37 | |
| | 104.89 | |
| Composition D | 108.75 | 108.39 |
| | 108.34 | |
| | 108.09 | |
| Composition E | 109.78 | 109.48 |
| | 109.61 | |
| | 109.03 | |

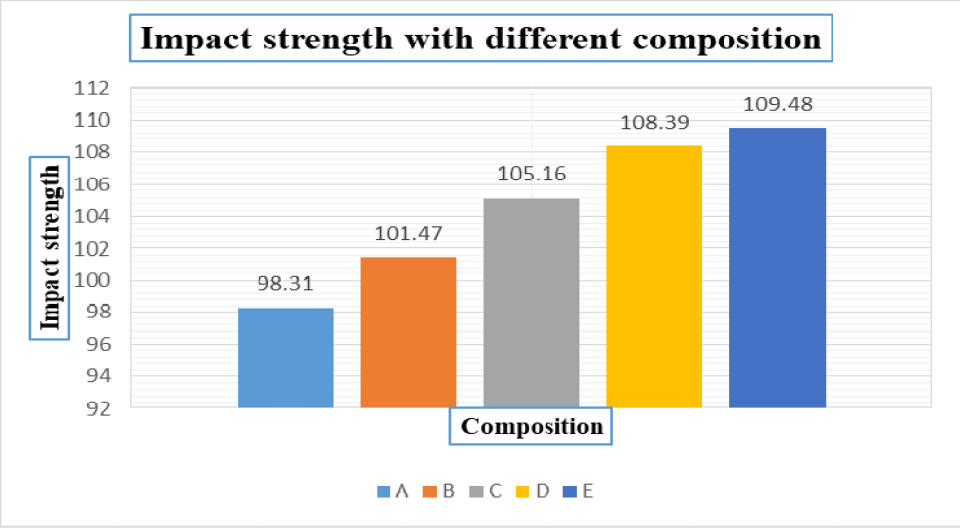



Fig: Impact strengths for different compositions

The impact test results are shown in the table. The values indicate increase in the absorption of energy with the increase in the reinforcement percentage. With the addition of 10% and 12.5% ZnO there is no much difference in the impact strength. Whereas when increment (12.5%) in the percentage of ZnO total shows 12.31 percent increase in the impact strength as compared to the base matrix. Individual increment in the energy absorption values are 2.14%, 5.39%, 8.71%, 11.43% and 12.31% for 2.5%, 5%, 7.5%, 10% and 12.5% increment in the reinforcements respectively. The increase in the impact energy is due to the strength of ceramic particles and the reduced vacant sites due to additional fillers which reduces the pores and voids increasing the impact resistance. No clustering or agglomeration is seen due to which there is no areas where stress can be concentrated, hence increase in the impact strength. The mixture is homogeneous due to which particles are mixed uniformly throughout the matrix and this avoids the pore nucleation which in turn reduces void formation and hence the impact resistance is improved.

**Compression test**

The compression strength of the composites with different composition of Al2O3 and ZnO are measured with the use of FIE make Universal testing machine, Unitek 9450 with a load resolution of 0-50KN. The diameter to length ratio considered was 1:2 (8.02:16.23mm). Test reference standards were taken as ASTM D695-15. Hot compression molding samples of UHMWPE reinforced with nano fillers were considered with their diameter and length to find the Ultimate stress due to compressive load acting on them. The calculations are made based on the below equations:

| Observations | Calculations to be made for every trial |
|---|---|
| 1. Initial gauge length ($l_i$) = 16.23mm | 1. Initial area, $A_i = \frac{\pi}{4} \times D_i^2$ |
| 2. Initial diameter ($d_i$) = 8.02mm | 2. Final area, $A_f = \frac{\pi}{4} \times D_f^2$ |
| 3. Final gauge length ($l_f$) = 9.68mm | 3. Ultimate stress, $\sigma_u = \frac{P_{max}}{A_i}$ |

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| | |
|---|---|
| 4. Final diameter ($d_f$) = 15.89mm | 4. Fracture stress, $\sigma_f = \frac{P_f}{A_i}$ |
| 5. Maximum load ($P_{max}$) = 7.26KN | |
| 6. Load at fracture ($P_f$) = 6.640KN | |

With the calculated values the table is made to show the corresponding ultimate stress values for the composites as shown below:

Table: Compressive strength values for different composition

| Composition | Peak Load (KN) | Breaking Load (KN) | Compressive strength (30.256MPa)(MPa) |
|---|---|---|---|
| A | 7.260 | 6.640 | 33.19 |
| B | 7.620 | 7.620 | 49.68 |
| C | 8.520 | 8.440 | 63.19 |
| D | 8.940 | 8.515 | 79.08 |
| E | 8.980 | 8.517 | 81.32 |

It can be seen from the above table that the compression strength of the composite is increased with the increase in Al2O3 percentage. Al2O3 reinforced UHMWPE composites have shown better compression strength as compared to the UHMWPE alone. Almost non uniform rate of increment is observed in the composites as the amount of reinforcement is increased from 2.5 to 12.5%. The increments in compression strength values for every increment in the reinforcement is 8.85%, 39.11%, 52.12%, 61.74 and 62.8% for an increment of 2.5%, 5%, 7.5%, 10% and 12.5% respectively. A random increase in the compression strength is observed until 10% addition of nano AL2O3 after which at12.5% the increment in the compression strength is almost equal or very near to the compressive strength at 10%. After 10 or 11% increase in the reinforcement leads to agglomeration of AL2O3 in matrix may have happened but throughout the matrix the reinforcement potential is not disturbed. The increase in compressive strength may be attributed to homogeneity in the mixture with very less number of voids or pores. The densification is obviously increased when the compacting pressure is increased hence increasing the compacting pressure. The decrease in the compressive strength after the 10% addition may be attributed to the faster nucleation and propagation of cracks (through the voids and pores present due to high porosity) and may be due to the agglomeration or clustering of AL2O3 grains at the matrix and reinforcement interface. Increase in the compression strength is mainly due to the high elastic modulus of UHMWPE but after the addition of 10% of Al2O3, due to the brittle nature of ceramic particles the compressive strength is seen decreasing.

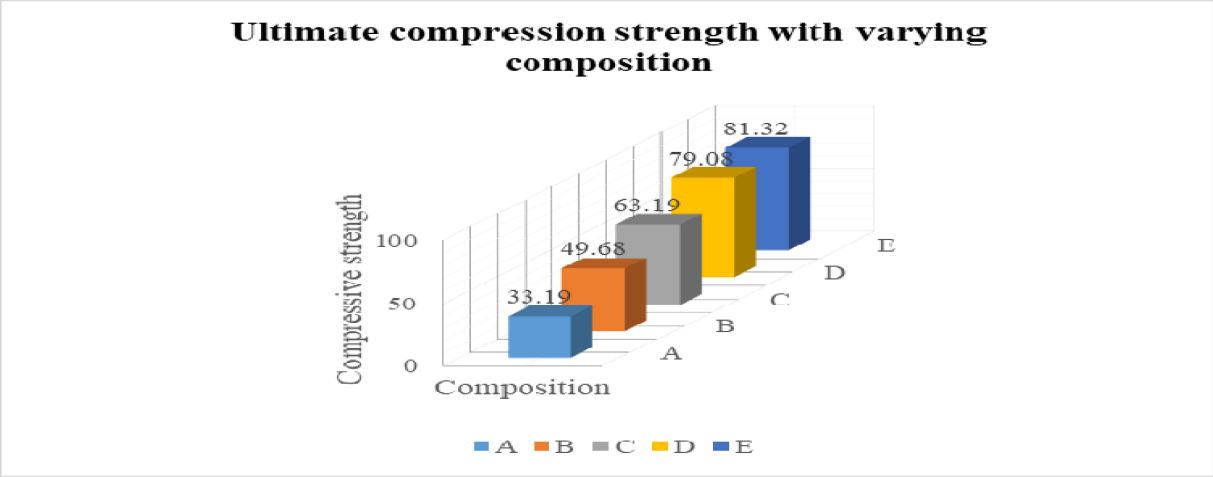


Fig: Ultimate stress variation with varying composition

In the similar way the compressive strength of UHMWPE composites with ZnO nano reinforcements is found out and the values are listed below for the analysis.

Table: Compressive strength values for different composition (Nano ZnO)

| Composition | Compressive strength (30.256MPa)(MPa) |
|---|---|
| A | 41.09 |
| B | 56.28 |
| C | 70.85 |
| D | 84.89 |
| E | 90.16 |

From values in the table and from the figure above it is seen that the compressive strength of the composite is increased drastically with the increase in the reinforcement percentage. The highest increment in terms of percentage is from 12.5% nano ZnO with 66.4% as compared to the pure UHMWPE (30.256MPa). The percentage increase in the compressive strength is 26.38%, 46.25%, 57.30%, 64.36% and 66.44% for 2.5%, 5%, 7.5%, 10% and 12.5% increments in the reinforcements respectively.

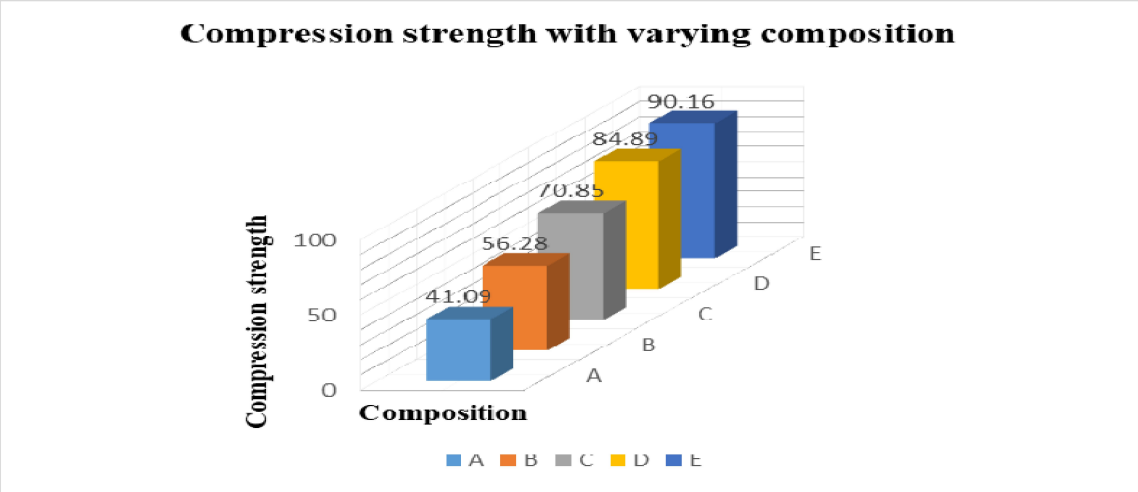


Fig: Ultimate stress variation with varying composition

It can be seen that after the addition of 10% nano Zno the compressive strength decreases. When load bearing devices are considered the application of the material can be evakluated with its compressive behavior as the material undergoes compressive load. Submicroscopic cracks are formed when the compressive load is applied on the UHMWPE composite due to deformation of the samples. While the composite is subjected to stress the submicroscopic cracks in the matrix are occupied by ZnO nano particles. Along with this the chain mobilization deformation occurring due to frictional force of the particles is restricted due to the presence of stiff and rigid nano fillers. This leads to increased compressive strength in the composites due to an increased stress bearing capacity. Hence due to the addition of ZnO nano fillers the compressive strength of the composite is seen increasing. The reduced compressive stress after 10% addition of nano ZnO particles are attributed to the decrease in effectiveness of the stress transfer between the reinforcement and the matrix which is due to the decrease of inter-particle distance when more loading of reinforcements is done which leads to agglomeration or clustering inside the composite system.

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