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# MECHANICAL PROPERTIES OF UHMWPE-CARBON NANO TUBE COMPOSITE FOR TOTAL HIP PROSTHESES

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## ABSTRACT
Total Hip Replacement is the most common artificial joint in human beings. A typical total hip replacement consists of cup type acetabular component, and a femoral component whose head is designed to fit into the acetabular cup, thus enabling joint articulations. Conventionally it was metal to metal pairs for artificial hip joints mainly AISI316 material was used. Later on high density poly ethylene and ultra-high molecular weight poly ethylene are used for socket material. In the present study Ultra High Molecular Weight Polyethylene (UHMWPE) blended with high strength multi-walled carbon nano tubes with varying weight fraction of reinforcement is analyzed for mechanical properties. Composite sheets were prepared and are subjected to Tensile, Compression and Wear test to evaluate the mechanical properties of the composite. The main objective of this study is to compare the mechanical properties of conventional pure UHMWPE material with Carbon nano tube reinforced polymer composite. It is observed that the Young's Modulus in tensile test is increased by 27%, in compression test it is increased by 50% and the wear loss is reduced by 30% with an addition of 5% Carbon Nano tube to pure UHMWPE. It is concluded that addition of Carbon Nano tubes to pure UHMWPE will enhance the mechanical properties of the biomaterial composite.
**KEYWORDS**: UHMWPE, MWCNT, Acetabular cup, Wear, Tensile, Compression

## I. INTRODUCTION
Total Hip Replacement is the most common artificial joint in human beings. Conventionally it was metal to metal pairs for artificial hip joints mainly AISI316 material was used [1]. Sir John Charnley proposed polymer to metal pairs for total hip replacement in early 1960 [2.3]. In United States of America alone over 150,000 artificial replacements for hip are performed per year. In India over two lakhs artificial replacement are performed every year. A typical total hip replacement consists of cup type acetabular component, and a femoral component whose head is designed to fit into the acetabular cup, thus enabling joint articulations. Early days Poly Tetra Fluro Ethylene (PTFE) is used as acetabular cup socket material, but was banned because of high wear rate due to low resistance to friction. The minimum requirement of acetabular cup socket material is bio-stability, bio-compatible, high toughness, high creep resistance, low friction, and low wear [4]. High toughness property eliminates fracture, low creep deformation resist cold flow of acetabula cup socket near femoral head, less co-efficient of friction reduce the friction between socket and femoral head and finally reduced wear which in turn eliminate wear debris generation. Due to this requirement beside Poly Tetra Fluro Ethylene (PTFE), both High Density Poly Ethylene and Ultra High Molecular Weight Poly Ethylene are been presently used for socket material [5, 6]. In many cases artificial joints made of metals are available in the market. However these are concerned on biological response due to wear debris. These wear particles at the contact location of artificial hip joint lead to inflammatory reaction known as Osteolysis [7]. These concerns lead to development of alternative material which enhances the mechanical properties. Hence Ultra High Molecular Weight Polyethylene reinforced with Carbon Nano Tube composite is considered in the present work to enhance the mechanical properties. Sheet made of Ultra High Molecular Weight Polyethylene with different percentage (1%, 3% and 5%) of Carbon Nano Tubes were prepared by melt mixing and compression molding. Tests were conducted to evaluate mechanical properties and the results are compared with pure Ultra High Molecular Weight Polyethylene.

## II. MATERIALS AND METHODS
Multi Walled Carbon Nano Tubes (MWCNT's) are used as filler material along with Ultra High Molecular Weight Polyethylene for the preparation of composites sheet. Multi Walled Carbon Nano Tubes has the dimensions of outer diameter ranging from 8 to 15 nm, length 10 to 50 µm having density of 2100 Kg/m$^3$ (2.1

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g/cm$^3$) and the purity was reported to be more than 95% with an ash content of 1.5%. Ultra-high molecular weight polyethylene with molecular weight ranging from 3.5 x $10^6$ to 7 x $10^6$ g/mol (ASTM calculation) is used as base/matrix material. Ultra-high molecular weight polyethylene will be in the form of powder with particle size ranging from 0 - 500µm, with an average size in the range of 135- 150 µm. The density of Ultra-high molecular weight polyethylene powder is 930 Kg/m$^3$. Chemically treated Multi Walled Carbon Nano Tubes (MWCNTs) and Ultra-High Molecular Weight Polyethylene (UHMWPE) was physically blended using Plastic corder machine which is shown in Figure-1 for 30 minutes. The temperature of the compound inside the chamber is maintained at 200$^{\circ}$C. The "dough" obtained after melt-mixing the powder were put in the die. During compaction stage, temperature of the die plates was maintained at 200$^{\circ}$C and raw material was first compressed to 19 MPa (190 bar) for one minute. The die is unloaded to allow recrystallization of the material at 200$^{\circ}$C. Further the die is loaded again to attain a pressure of 19 MPa (190 bar) for five minutes.


***Figure-1 Brabender Machine***

***Figure-2 Hot Press Machine***

Hot Press Machine used for this purpose is shown in Figure-2. Finally die is unloaded and water cooled to room temperature before the composite sheets are removed. The size of compression molded sheets is 150 x 150 x 2mm which is shown in Figure 3.

***Figure-3 Compression moulded Ultra-High Molecular Weight Polyethylene sheet.***

## III. TENSILE TEST

Tests were conducted as per ASTM D 638 standards for polymer. Four groups of materials such as pure Ultra high molecular weight polyethylene and Ultra high molecular weight polyethylene with 1%, 3% and 5% Carbon Nano tube to form composite were considered for testing. Five specimens from each group thus totally twenty specimens were tested. Figure-4 shows the tensile test specimens used for carrying out tensile test. The tensile test specimen which is of rectangular cross section is held by suitable grippers of the Electronic Tensometer. Uniaxial load is applied at uniform test speed of 0.1mm increment on the test specimen through the actuator and the results were noted till the specimen fractures.

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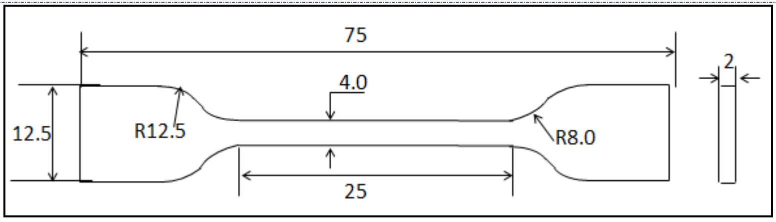


*Figure-4 Ultra-High Molecular Weight Polyethylene and Composite test specimens*

Every sample is measured for the dimensions before testing to calculate the cross section area of sample and gauge length. The measured area is fed to Electronic Tensometer testing machine to perform internal calculation to evaluate strain and stresses. Tests were conducted under the ideal room temperature conditions and the same parameter setting is maintained for all the tests. Load and the displacement (elongation) is recorded using X-Y recorder and strain and stresses were calculated by the software in the Electronic Tensometer testing machine itself. Tests were similarly carried out on all the twenty samples.

## IV. RESULTS AND DISCUSSION

Stress and Strain are extracted from tensile test and plotted as shown in Figure 5. It is observed that both Ultra high molecular weight polyethylene and Ultra high molecular weight polyethylene with 1%, 3% and 5% Carbon Nano tube to form composite behaves as linear elastic – linear plastic material.

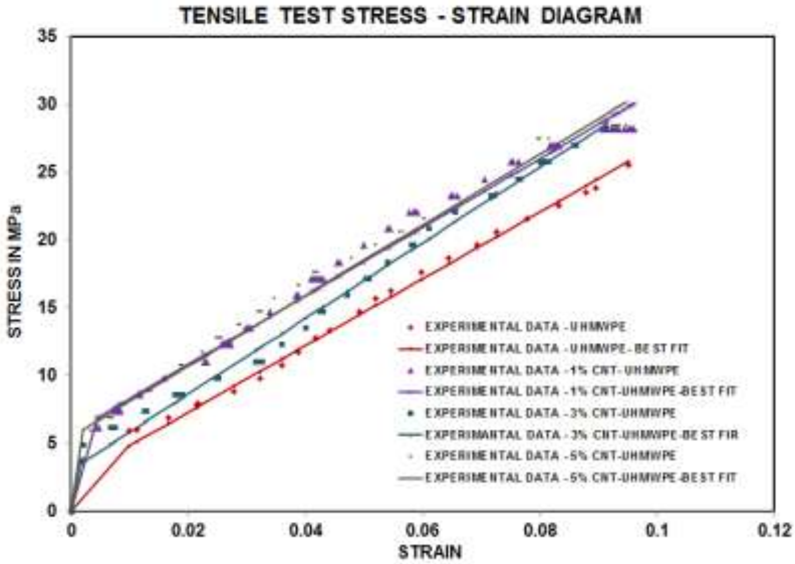


*Figure-5 Stress vs Strain Diagram*

Experimental data is used to fit the best curve as shown in figure 5. It is known that the Young's Modulus of the material depends on slope of the linear elastic behaviour of the stress strain curve. It can be observed that the slope is less for pure UHMWPE material where as it increases as the quantity of Carbon Nano tube increases in composite material. Figure - 6 shows the Young's Modulus variation with respect to different material. Young's Modulus is evaluated using the slope on linear elastic curve as per ASTM D 638 standards. Young's modulus of pure Ultra High Molecular Weight Polyethylene is found to be 661MPa. Whereas Young's modulus of composites is found be increased by 2 times with 1%, 3.6 times with 3% and 3.7 times with 5% addition of filler material. Yield strength of the composites specimen is observed to be increased by 5%, 9% and 13%. Multi-Walled Carbon Nano Tubes have excellent tensile properties which when added to polymer by melt mixing method helps homogeneous distribution of filler material leading to increased crystallinity which in turn enhances the toughness of material there by reducing the ductility or strain to failure there by enhancing the Young's modulus and Yield strength property of composite material.

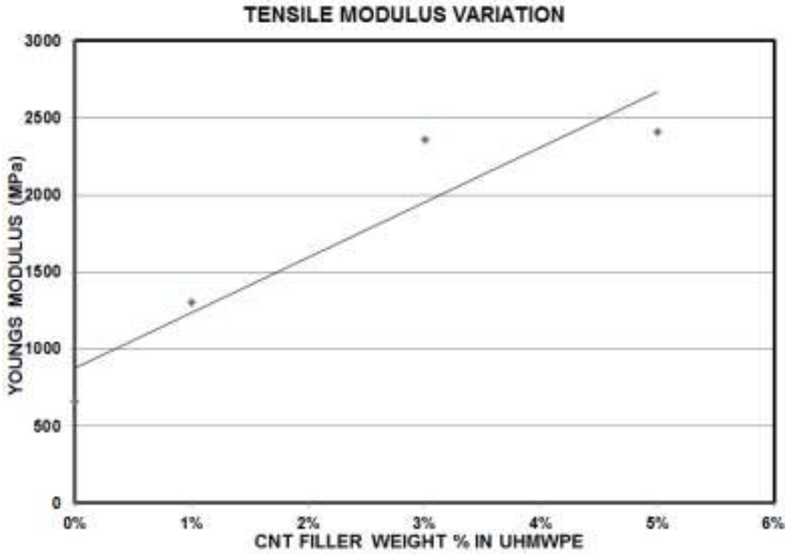


***Figure - 6 Young's Modulus variation***

Figure: 7 shows the SEM images of the tested fractured specimen. Fractured surface is inspected using SEM machine for all the composite material test samples. At fractured surface, images shows the pulled fibre like appearance which is due to ductile nature of the material. It can be observed that fibre like appearance is high in pure UHMWPE material and subsequently reduces for other material as weight percentage of Carbon nana tube increases. It indirectly says that composite material behaves as brittle material as the filler material quantity is increases.

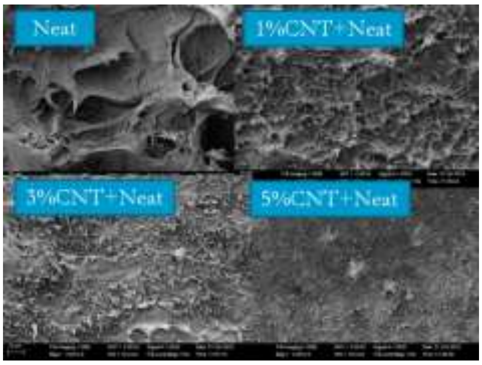


***Figure-7 SEM images of tested sample***

Figure - 8 shows the strain to failure variation for different material. For polymer composites it is good to understand the behaviour of material (either ductile or brittle) under tensile load. It is observed that, pure Ultra High Molecular Weight Polyethylene samples experience 1.5% strain to reach break point. But strain to failure for composites decreases by 93%, 95% and 96% for composite material compared to UHMWPE alone material.

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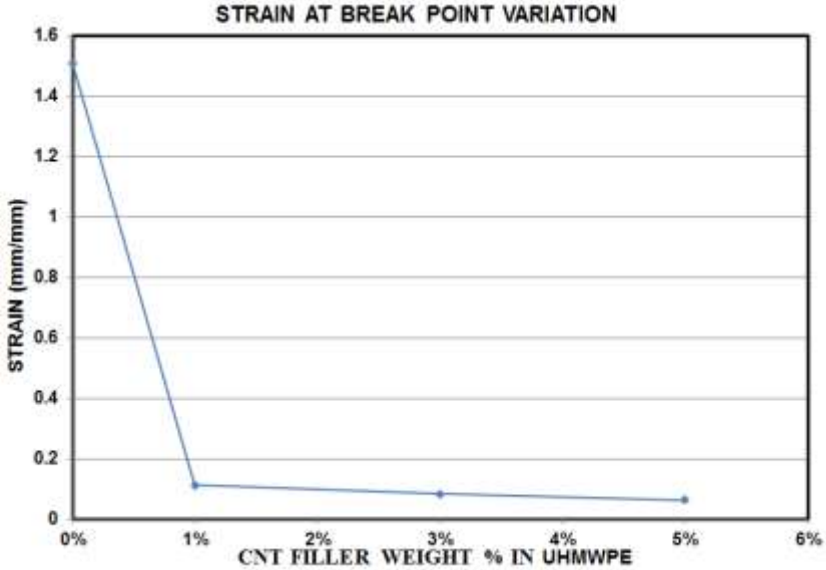


***Figure - 8 Strain to Failure Variation***

CNT addition to UHMWPE will increase the toughness of the composite material which in turn makes material less ductile which is evident with above curve shown in figure 8 and SEM images.

## V. COMPRESSION TEST

Compression tests were carried out as per ASTM D638 standards for polymer. Compression test specimens were prepared as per standard. To avoid buckling, sample of dimension 10mm x 10mm x 2mm thick in considered for the testing. Compression test specimen is of rectangular cross section (10 x 2 mm) which is held with suitable grips between holders of the electronic tensometer. Five specimens from each group thus totally twenty specimens were tested. Uniaxial load at a uniform rate is applied on the test specimen through the actuator till the specimen fails in the manner similar to the tensile test.

RESULTS AND DISCUSSION

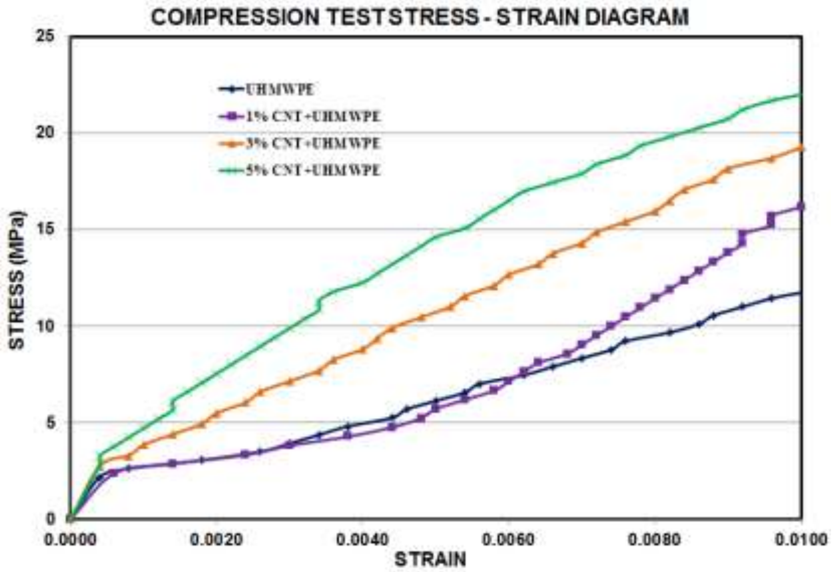


***Figure - 9 Stress - Strain Curves***

Figure - 9 shows the stress versus strain diagram which is the output from compression test. Due to ductile behaviour of UHMWPE material specimen will have fracture after high load and strain or sometimes no fracture. Hence the observations are made till 1% strain. It is observed that at 0.2% strain, UHMWPE pure material is stressed to 2.5MPa whereas for 5% MWCNT with UHMWPE composite material is stressed to 7.5MPa. This behaviour shows that UHMWPE material strength is enhanced by adding the Carbon Nano tube as filler material. From the compression test carried out strain to failure is extracted as shown in Figure-10. Modulus of pure Ultra High Molecular Weight Polyethylene is found to be 1400 MPa. Modulus of composites with 1%, 3% and 5% addition of multi walled Carbon Nano tube filler material is found to be increased by 42%, 72% and 98% respectively when compared to pure Ultra high molecular weight polyethylene. It is observed that, pure Ultra High Molecular Weight Polyethylene samples experience 5% strain to reach break point. But strain to failure for composites is observed to be decreased by 40%, 44% and 59% with 1%, 3% and 5% addition of multi walled Carbon Nano tube filler material compared to pure Ultra high molecular weight polyethylene. Due to same reason explained in tensile test section, the compression strength is also enhanced in composite materials.

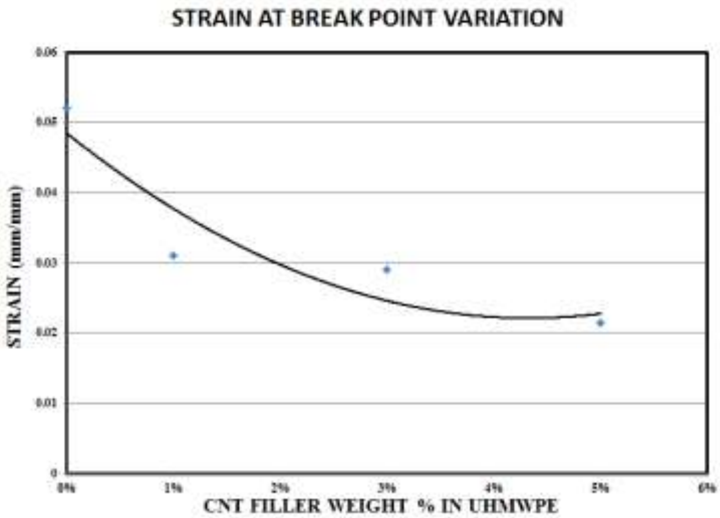


***Figure-10 Strain to Failure Variation***

## VI. WEAR TEST

Wear test was carried using Pin on disc machine. This test is a sliding friction test under dry conditions at ambient temperature. Test is carried out as per ASTM G 99 standards. The specimen's surface with dimensions 10mm x 10mm makes contact with rotating disc. Test was carried out for 30 minutes at a constant speed of 279 rpm with a track diameter of 114 mm for different (5N, 10N, 15N, 20N, 40N and 60N) loads. Weight loss method is adopted to study the wear characteristic of the material. Specific wear rate K is calculated from the relationship

K = Volume of Wear / [Applied Load x Sliding Distance]

Where, Sliding Distance = (2 x $\pi$ x radius of wear circle)

UNIT of specific wear rate, K is $(mm)^3$/ (N-m)

## VII. RESULTS AND DISCUSSION

From the Figure 11 it is observed that, wear of pure polymer and composite material varies with quadratic variation with increase in load. At lower load up to 20N the wear loss is observed to be minimal and it increases as load increases. The wear loss is high in pure Ultra high molecular weight polyethylene and as filler material is added to Ultra high molecular weight polyethylene the wear loss reduced with increase in Carbon Nano tube content. This filler addition leads to increase in toughness of the polymer. At a load of 60 N the wear loss pure Ultra High Molecular Weight Polyethylene is found to be 0.0014g. But wear loss is observed to reduce by 34%, 41% and 66% with 1%, 3% and 5% filler addition and can be concluded that for 5% of filler addition the wear quantity is reduced significantly compared to others.

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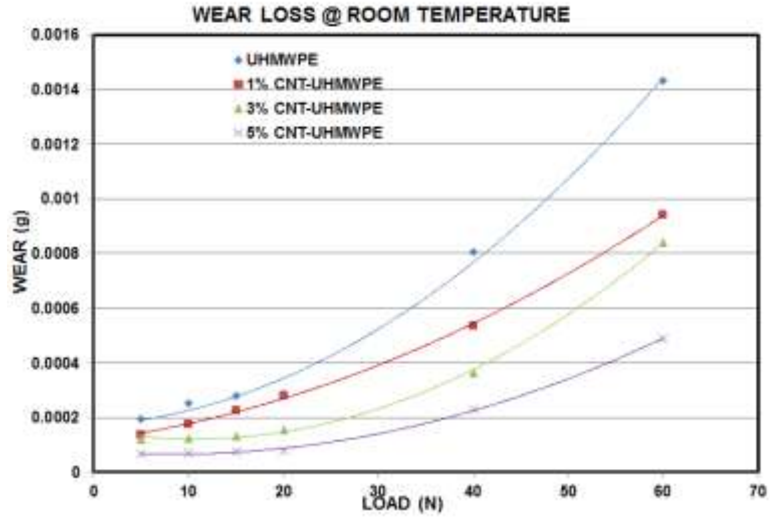


*Figure-11 Plot of Wear Volume*

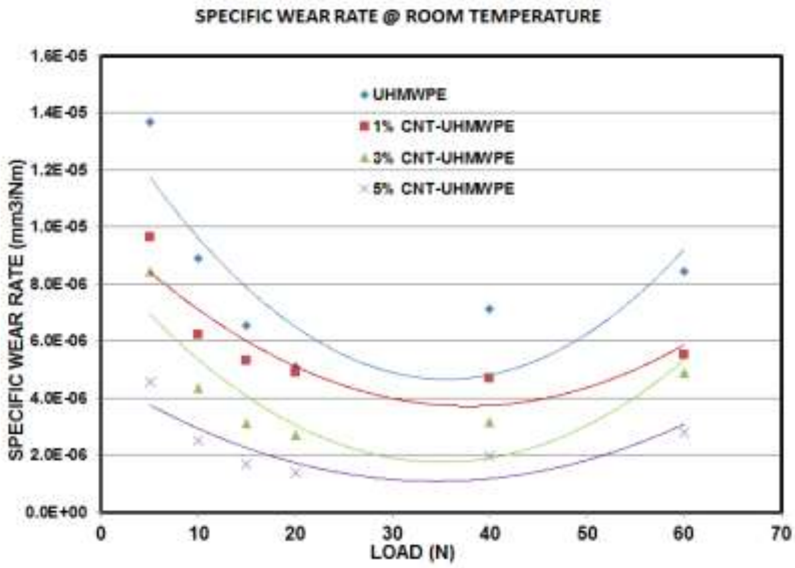


*Figure-12 Plot of Specific wear rate*

Figure 12 shows Specific wear rate versus Load. While calculating the Specific wear rate from the mathematical equation only wear volume and applied load are the variables. Specific wear rate decreases with the increase in load up to 20N, further it increases with the increase in load. This behaviour is purely depends on type of material. For UHMWPE and MWCNT UHMWPE composite materials the wear loss is minimal when load is less i.e. till 20N. So since wear loss and applied load are only variables in equation, the specific wear rate decreases with increase in applied load but the wear loss increases significantly when applied load is above 20N due to which the specific rate increases. It can be concluded that for any load condition wear quantity is reduced with increase in filler percentage. And by 5% CNT addition wear loss is reduced by 73% compared to pure UHMWPE alone material at 15N load condition

## VIII. CONCLUSION

The tensile strength increases significantly compared to pure Ultra high molecular weight polyethylene. Tensile modulus and compression modulus increases drastically in composites and at the same time strain at failure is reduced considerably. Addition of Carbon Nano tubes increases the wear resistance to composites, hence wear volume for 5% CNT composite reduced by 66%. Thus concluding that addition of Multi Wall Carbon Nano Tube as filler to pure Ultra High Molecular Weight Polyethylene Mechanical Properties of Composite Material will be enhanced.

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