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Mechanical Response of PTFE-based Nanocomposites

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Abstract: Polytetrafluoroethylene (PTFE), reinforced with Boron Carbide (B_4C) and Molybdenum disulphide (MoS_2) were prepared by Studying the various manufacturing processes and selecting the best suitable for Producing this Composite. Mechanical Properties such as Tension test, Compression test and Hardness (Shore hardness) were done and their results were studies accordingly. The Composition of (MoS_2), Boron, and PTFE compounds were varied with different Percentages so as to get the Optimized Result for Tension Test, Compression test and Shore D Hardness.

Keywords: Polymer-based Nanocomposites, fillers, hardness, Mechanical property

INTRODUCTION

We know that all our industry experts are researching constantly to develop a mechanical material which is best at both Tribological and mechanical strength. Polymers are constantly used in self-lubricating and sliding applications such bearings, bushes, seals, rollers, cams and wheels [1]. Solid lubrication is the best alternative to be used in place of conventional sources we are using since industrial revolution. As they provide various benefits such as ease of design and manufacturability, low cost to design, cleanliness, high temperature capability and long life. Many researches worldwide have tried to add fillers in polymers with various compositions and weight percentages to improve the mechanical properties.

Polytetrafluoroethylene has advanced in various material applications as it has excellent heat resistance, corrosion resistance and best antifriction and self-lubrication properties. This is because it is crystalline polymer. Also this material exhibits properties like chemical inertness, high thermal stability and is nontoxic, non-flammable in nature. These various mechanical properties make it suitable for many applications. However some disadvantages of PTFE make it not advisable to use solely for the bearing applications as a whole material. Pure PTFE exhibits low hardness, strength, and high wear rate, which limits its use in various applications [2]. Many Researchers have used addition of suitable fillers in PTFE matrix to experiment the various results on mechanical and Tribological properties. It is simple and effective method to enhance PTFE filler modification by various kinds of nanoparticles to overcome the PTFE defects and enhance the comprehensive properties. We also know that in polymer-metal bearing applications, the formation of a transfer layer on the metal counter face has a large effect on the wear behaviour. These polymers form a transfer layer which indeed helps in reduction of wear and enhance shielding of the surface reducing abrasive action. Min Chao, Changjuan Guo [3], in his research Al2O3 nanoplatelets were introduced into polytetrafluoroethylene (PTFE) matrix via a cold pressing and sintering method. The effect of mass content of the Al2O3 platelets on the morphology, mechanical properties, thermal conductivity and dielectric properties of the composites was investigated. The results revealed that the Al_2O_3/PTFE nanocomposites exhibited higher thermal conductivities, better thermal stabilities, enhanced mechanical properties with considerable dielectric properties. Compared with pure PTFE, the tensile strength of composites with 5 % by weight of Al_2O_3 increased by 6% (28.12 MPa), suggesting good distribution of Al_2O_3 nanoplatelets and the strong interfacial adhesion between Al_2O_3 and PTFE matrix.

Dao fang Chang, Young Huang in his research [4] used low-density polyethylene (LDPE) rubber and silica (SiO2) particles were employed to modify polytetrafluoroethylene (PTFE) simultaneously. The distribution and dispersion of LDPE and SiO2 particles in PTFE matrix can be adjusted by the wettability of SiO2 particles toward PTFE and LDPE, so as to achieve a simultaneous enhancement of toughness and modulus of PTFE. A unique structure with the majority of PTFE surrounded by SiO2 particles was first observed using maleic anhydride (MAH)-grafted LDPE, resulting in a dramatically increase in Izod impact strength as the rubber content in the range of brittle–ductile transition (4–16 wt.%). Tensile tests were conducted on Instron 5567 testing machine using laboratory dumbbell-shaped specimens with 10 mm dimensions of the working part at 20 mm/min cross-head rate. Specimens of size measuring up the GB/T16420 – 1996 standard were prepared from the moulded board for Izod impact tests. Impact tests were conducted in an impact machine Type ZBC – 4B (Made in China) at room temperature. When the SiO2 content increased in the PTFE matrix from 4 to 16%, the tensile and bending strength increased, while the impact strength decreased. For the SiO2/PTFE composite filled with MAH-grafted LDPE, both the strength and toughness increase with the content of SiO2. Similarly, Johanna Zimmermann-Ptacek, Mark Muggli, Stefanie Wildhack studies the addition of Boron nitride into PTFE as matrix [5].

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The filler loading in the composite was varied up to a filler volume content of 50%.Follwowing conclusions were made. Mechanical properties can be modified using a wide range of fillers for reinforcement. The fillers can vary in geometry, particle size, and filler–matrix interaction. While the Young's modulus is mainly affected by the filler geometry, intrinsic modulus, and particle size distribution, the tensile strength is strongly dependent on the filler–matrix interaction. Since at filler loadings higher than 30% by volume the mechanical properties decline drastically, the preferred filler content for applications should not exceed 25% by volume. Yu Jianghong, Li chao studied the effects Wollastonite added in PTFE as matrix and found that that the wearing properties and rolling stress is reduced by 17 % and 27.7 % under heavy load conditions [6].

EXPERIMENTAL

Materials: Polytetrafluoroethylene, Boron Carbide and Molybdenum disulphide are the materials used in this investigation. Figure (a) PTFE Nanopowder which is crystalline in nature with white colour, has melting point of about 327 ℃ and density of 2200 kg/m^3.Figure (b) Shows Boron carbide which has second highest hardness of 9.5 to 9.75 on Mohs hardness scale. It has density of around 2200 kg/m^3. The melting point of boron carbide is around 2760℃. Figure (c) shows Molybdenum disulphide in powder form which has melting point of 2375 ℃.

Figure (a)

Figure (b)

Figure (c)

Molybdenum disulphide is excellent lubricating material due to its layered structure and low coefficient of friction. Interlayer sliding dissipates energy when shear stress is applied to the material. The shear strength increases as the coefficient of friction increases [7].

In here PTFE is considered as the matrix material the details of materials and their properties are shown in the table below. All the material formulations are based on the weight percentages calculated in arithmetic progressions. Also Source of the materials is also mentioned in the table.

Table : Date and the source of the materials used in this study

Material	Designation	Form	Mesh Size	Manufacturer
Polytetrafluoroethylene	PTFE	Particles	800	DuPont Co.Ltd
Boron Carbide	B_4C	Particles	1200	Triveni chemicals
Molybdenum Disulphide	MoS_2	Particles	1200	Triveni chemicals

Table 2: Formulations of Composite Blend of PTFE/ B_4C/MoS_2

Composition	Material ID	Weight percentage		
		PTFE	B_4C	MoS_2
PTFE	A	80	0	0
PTFE/B_4C/MoS_2	B	80	5	5
PTFE/B_4C/MoS_2	C	80	10	5
PTFE/B_4C/MoS_2	D	80	15	5

Specimen Preparation: The unique properties of nanoparticles arise from their size reduction. When a particle is reduced down to the nanosize range (usually defined as 1–100 nm), a much larger surface area per unit volume is achieved, and even more importantly, a dramatically increased percentage of molecules or atoms are found to be present on its surface.

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Furthermore, when two or more phases are mixed together to make a nanocomposite, a combination of properties can be obtained, which are not available in any of the individual components, since at this scale, macroscopic material properties are strongly influenced by atomic or molecular interactions.
All these Nanopowders are in their dry condition and handles very carefully with spoon for measuring it into the Digital weighing scale which had accuracy of 0.1 grams. The Particle mixing was done step by step once the Weight of first compound added in the weighing machine stabilized. Respectively, next amount of compound was added until the Total weight was achieved with respect to weight percentage. After that the mixed powders were poured into ball mill mixer for around 20 minutes to get a complete homogenous mixture. Then the mixture was allowed to settle for 10 minutes at room temperature. Since the mesh size was 800 and above there was no need to pass the mixture through the mesh sieve. Thereafter all the mixtures of 4 samples were sealed tightly in a vacuum container.
Then the Mixtures were put into die of 200 mm x 20 mm die and hot pressed with force of 50 Mpa at 300 degrees with a minimum hold time of 10 minutes. The components were naturally cooled down in furnace.

Tensile Test
Tensile tests were conducted according to ASTM D638 standards and the specimens were sized accordingly. The specimens were grinded and polished with material hardening paste for better results. The tensile tester had load cell of 10kN and all the tests were done at room temperature of 25 degrees. The tests were performed with a constant strain rate of 50mm/min until the specimen was fractured accurately at its neck. In order to test properly, specimens must be held perpendicular to the jaw faces and not tilted on an angle. Specimen misalignment can cause major variations in results, and proper care should be taken to ensure that the specimens are all aligned consistently for each test.

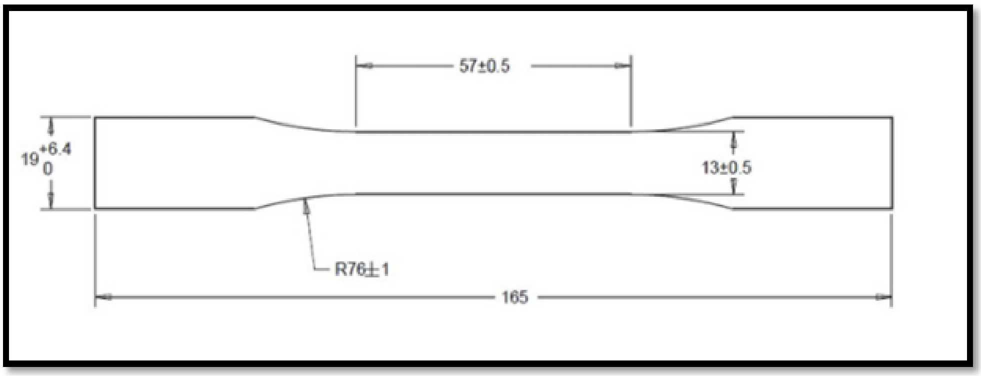

Figure (d) tensile test specimen as per ASTM D638

Shore D hardness
A Durometer gauge or Durometer tester is needed to perform a Durometer hardness test procedure. Durometer devices determine the surface hardness of many different materials, including polymers and elastomers. Each Durometer or hardness tester measures the depth of an indentation in the material caused by a defined force of a given geometric presser foot. The depth of the indentation reflects the hardness of the material. A general distinction is made between static and dynamic methods. In traditional static tests, the test force is applied uniformly with increasing magnitude, while in dynamic testing methods, an instantaneous load is applied.

Izod Impact Test
The impact properties are one of the widely specified mechanical properties of polymeric material. The different weight percentage of nanofiber reinforced composite specimens was tested by Izod impact test machine shown in. The Izod impact test was modified by George's charpy to hold the specimen in a horizontal rather than a vertical position. This is the primary difference between the Izod and the charpy impact test. The Izod impact test differs also in that the notch is positioned facing the striker. The specimen size and shape vary with the Izod impact test according to what materials are being tested. Specimens of metals are usually square, and polymers are usually rectangular being struck perpendicular to the long axis of the rectangle. The impact strength is determined by the loss of energy of the pendulum as determined by precisely measuring the loss of height in the pendulum's swing.
The impact strength is given by I = EI/t J/mm^2
Where EI = Impact energy in joules value obtained from the scale (J) t = thickness of the specimen (mm^2).

RESULTS AND DISCUSSION
All the tests carried out in this research showed that the mechanical properties of the PTFE based Nanocomposite depend on the variety of nanoparticles.

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Tensile Test: Mechanical properties can be modified using wide range of fillers to use as reinforcements. In this research the use of Boron carbide and Molybdenum sulphide was manufactured which resulted in tensile strength in the range of 15 to 30 Mpa. Though addition of Boron carbide which is used to increase the hardness of the nanocomposite greater than 5 % wt tends to reduce the tensile strength thereafter the same results are shown in figure (e1) and (e2). Nominal Tensile strength of Pure PTFE was found to be at par with the standard values carried out in the research. The following graphs of load vs displacement show the behaviour of addition of fillers in the PTFE matrix. If well dispersed in the polymeric matrix, the nanometer phase offers a major specific surface area enhancement of the interfacial interactions with the matrix compared to conventional reinforcements, and consequently improves the physical properties of the material [8-14]. While the young's modulus is mainly affected by the filler geometry, intrinsic modulus, and particle size distribution, the tensile strength is strongly dependent on the filler-matrix interaction.

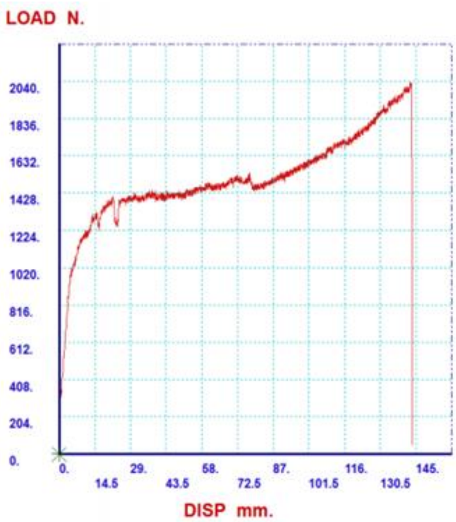

Figure (e1)

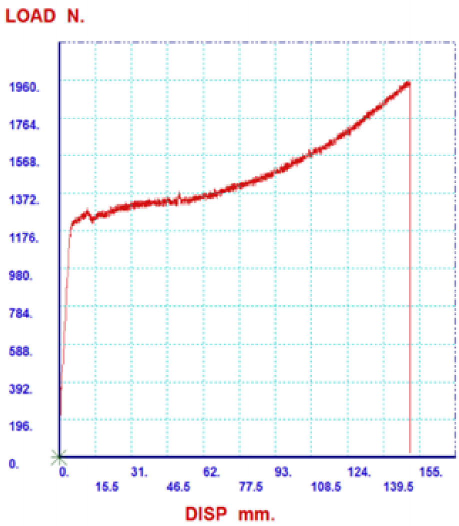

Figure (e1)

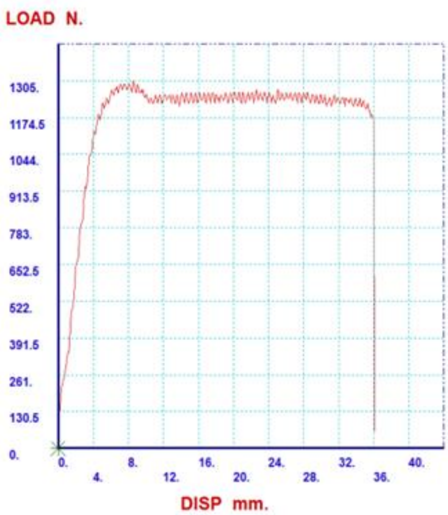

Figure (e1)

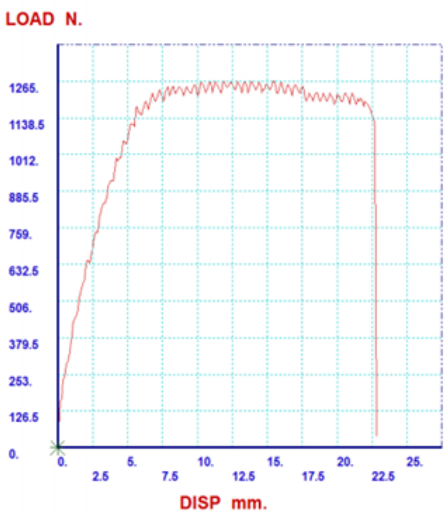

Figure (e1)

As shown in above figure (e3) and (e4) the tensile strength is decreased due to the boron carbide filler attributes, as the filler engages with the matrix to form a hard nanocomposite which makes it slightly brittle.

Shore D hardness test

Below table (3) shows the comparative hardness values of the PTFE-based Nanocomposite. It can be seen that addition of Boron carbide filler materials into PTFE matrix caused a significant improvement in the hardness which is up to 4 % increase compared with that of pure PTFE matrix. In particular, composite 4 displayed the maximum hardness, which is due to the synergistic effect of Nano-Boron carbide rigid particles. Moreover, from the figure, the addition of Nano-Molybdenum sulphide into PTFE matrix (composite 4) also caused a significant improvement in hardness.

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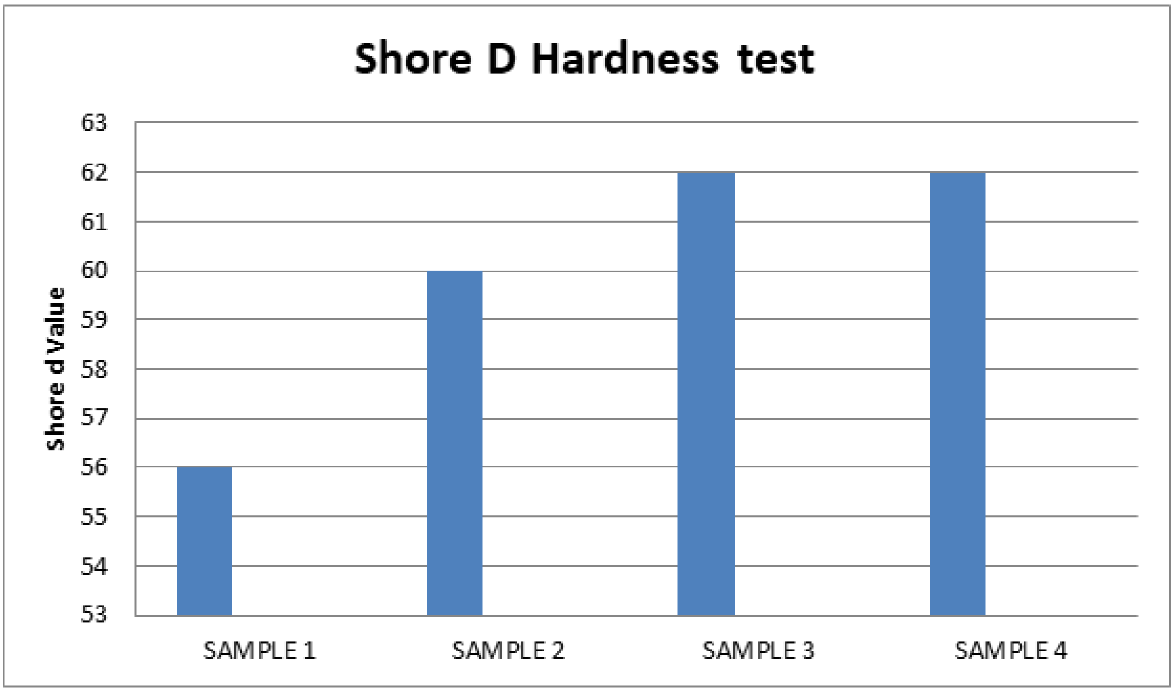
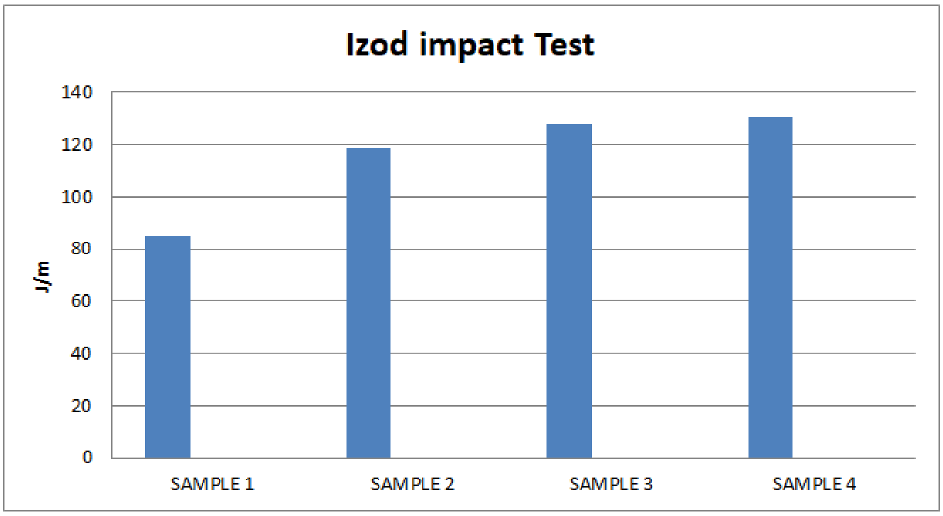
Table 3: Shore D hardness test experimental results.



Izod Impact Test

The impact behavior of Boron carbide fibers and Molybdenum supplied fibres was experimentally investigated using notched Izod impact test specimen. The impact property of a nanocomposite material is its capacity to absorb and dissipate energies under impact or shock loading. The neat PTFE material has very low impact resistance reinforcement with the Boron carbide and Molybdenum sulphide increasing its impact strength significantly. The impact energy level of the composite depends upon several factors such as the nature of the composite, geometry, Fiber arrangement and Fiber matrix interface. The matrix de-bonding and Fiber pullout are important failure modes observed in the Fiber composites due to impact loading. The load is transferred through shear and when the shear force exceeds the Fiber matrix interaction force, the Fiber matrix de-bonding takes place. The Fiber fracture will be pre-dominating when the stress level exceeds the Fiber stress and then the fractured Fibers are pulled out of the matrix. The fracture energy recorded in an impact test reflects the integrative force of the sample over the range of sample deflection.

Table 4: Impact test experimental results.



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CONCLUSIONS:

The present work investigates the performance of PTFE-matrix based Nanocomposites. Different parameters which affect the mechanical properties are studied in this research. Most of the investigations include finding of suitable fillers to increase the mechanical properties of the Nanocomposite.

Various Physical and Tensile Properties of the PTFE based Nanocomposites exhibit superior advantages over virgin PTFE material especially in cost, environmental aspects and working applications. The physical and mechanical properties of the PTFE based Nanocomposites are observed. The results found good agreement within the range in the literature.

Based on the experimental results and discussion, it is concluded that:

- The PTFE based Nanocomposite was successfully prepared by Compression moulding and sintering.
- The Tensile Strength of Nanocomposite sample B showed good range of tensile strength which is at par in field of Nanocomposites. As the weight percentage of Boron carbide and molybdenum disulphide was increased above 5 % the tensile strength gradually decreased.
- The impact Strength of the PTFE based Nanocomposite was measures by IZOD testing and as the percentage of fillers increased, the impact strength of the samples increased from 30 % to 50 %. It showed that sample number 4 had highest impact strength of 50% of the current virgin PTFE.
- The Hardness value, which is most important in sliding applications, was also increased from 4 % to a maximum of 8 % with respect to virgin PTFE.

All these mechanical properties show that addition of fillers such as Boron carbide and Molybdenum Disulphide increase the Tensile Strength, Impact strength, and Shore D hardness of the whole Nanocomposite.

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