Effect of Boron Carbide Filler on Mechanical and Tribological Properties of Polytetrafluoroethylene Based Nanocomposite

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Abstract: Polytetrafluoroethylene (PTFE) is thermoplastic in nature with very attractive properties. It has very low friction coefficient, wide range of service temperature, high flammability resistance and chemical resistance. But its use limited due to low strength and wear resistance. This limitation is overcome by manufacturing composite material of particulate reinforced PTFE. This work deals with use of boron carbide as a filler to improve mechanical and tribological properties of pure PTFE. Numerical analysis carried out with the help of Digimat and ABAQUS software. Digimat software used in order to generate the FE model of the composite RVE and also to calculate homogenized properties of PTFE with boron carbide. For verification of homogenization properties along with Digimat also SwiftComp software is used. The effect of filler content on mechanical properties of PTFE composite are calculated by using Digimate software. Boron carbide with PTFE nanocomposite manufactured by using preforming and sintering process. The mechanical and tribological properties are calculated experimentally by using UTM and pin on disc setup.

IndexTerms – Polytetrafluoroethylene (PTFE), Digimat, Homogenization, Boron carbide, Representative volume element (RVE).

I. Introduction

Polytetrafluoroethylene (PTFE) is a thermoplastic with very attractive characteristics, such as a very low friction coefficient, wide range of service temperatures, high flammability resistance, low dielectric constant and high chemical resistance. Because of these characteristics PTFE is a material of great interest, mainly for the chemical and aeronautical industries. However, its mechanical properties are inferior to those of engineering polymers, which limits its structural applications. The tensile strength of pure PTFE is, on average, 28 MPa and the young's modulus is approximately 0.6 GPa. Thus, to obtain an alternative for structural applications one option is to manufacture composite materials of particulate reinforced PTFE [1]. PTFE is commonly used as a matrix of composite materials for friction units in vehicles, because of its unique antifriction properties, and high chemical and frost resistances. Pure PTFE has limited applications as an engineering material, because of its low wear resistance and cold flow. These limitations can be reduced by adding suitable fillers to a PTFE matrix. The produced PTFE-based composites that are capable to use as the friction units of technical equipment [2].

Boron carbide is the third hardest material after diamond and cubic boron nitride, which possesses low density (2.51 g/cm3), high hardness (3700 N/mm2), high stiffness (445 Gpa), high specific strength, high strength, high shock resistance, high wear and impact resistance, high toughness, has a relatively low fracture toughness, low specific weight, low specific gravity. Boron carbide has high melting point (2450 ºC) as well as high resistance to chemical agents. It is an attractive strengthening agent for aluminium-based composites. One of the special features of boron carbide is that the ability to absorb neutron is considerably high. These features allowed boron carbide to be applied in nuclear industry as neutron absorber materials. Aluminium reinforced boron carbide composite gives interesting features such as high strength and high hardness, good tribological properties due to presence of hard reinforcements. These characteristics have made this composite as a very potential material in engineering field [3].

Nanocomposites can be categorized on the basis of reinforcement and on the basis of matrix. Based on matrix these can be metal matrix nanocomposites, polymer matrix nanocomposites and ceramic matrix nanocomposites. "These nano-metric fillers produce large surface area if homogenously distributed in the matrix; thus, these systems can potentially enhance the interfacial interaction between matrix and filler, resulting in improved mechanical properties of the material [4]. Researchers have reported a considerable amount of enhancement in mechanical and tribological properties, even at very low volume fractions. In our case it is polymer matrix composite because PTFE is act as matrix which polymer in nature and boron carbide act as filler.

II. Problem Defination

The mechanical properties of PTFE based nanocomposite is largely dependent on the filler characteristics as a) size and shape b) concentration of filler c) distribution.Using these factors of nanocomposite mechanical characteristics of PTFE based nanocomposite is calculated. The development of polytetrafluoroethylene (PTFE) with some of the ceramic filler is available but it is not available with boron carbide as filler. Boron carbide is one of the robust material having high hardness, high cross section for absorption of neutron, stability to ionizing radiation. Therefore my work is to develop nanocomposite of PTFE with boron carbide as filler and to find out the mechanical characteristic by experimental as well as numerical method.

III. Analysis of PTFE with boron carbide nanocomposite

As analysis process carried out in three stages as a) RVE Generation b) Calculating homogenization properties c) Simulation of FE- model.

3.1 RVE Generation

Digimat-FE is used to generate a realistic representative volume element (RVE) for a large variety of material microstructures (plastics, rubbers, metals, graphite etc). Digimat-FE allows you to describe the microstructure of your composite as well as the material properties of its constituents in order to generate the FE model of the composite's RVE.

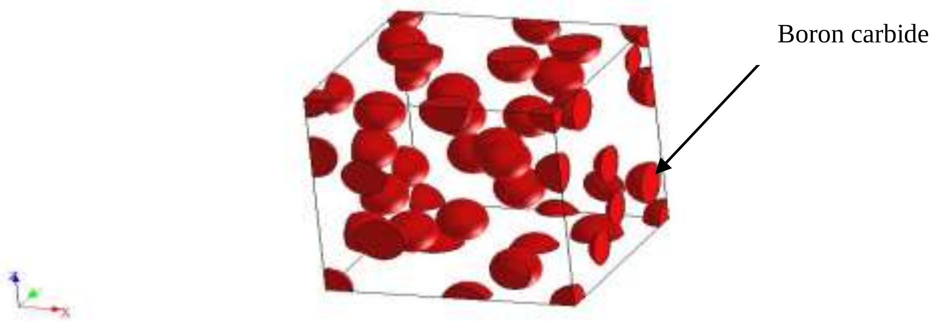


Figure 1: RVE for 10% volume fraction of boron carbide

3.2 Homogenization

It is a process by which the composite specimen is regarded as a body of an effective homogeneous material, whose mechanical behaviour is described by a definitive constitutive law. This constitutive law can be determined based on the detailed fields in the selected RVE through an “averaging” procedure.

Table 1: Properties of PTFE and Boron carbide [5]

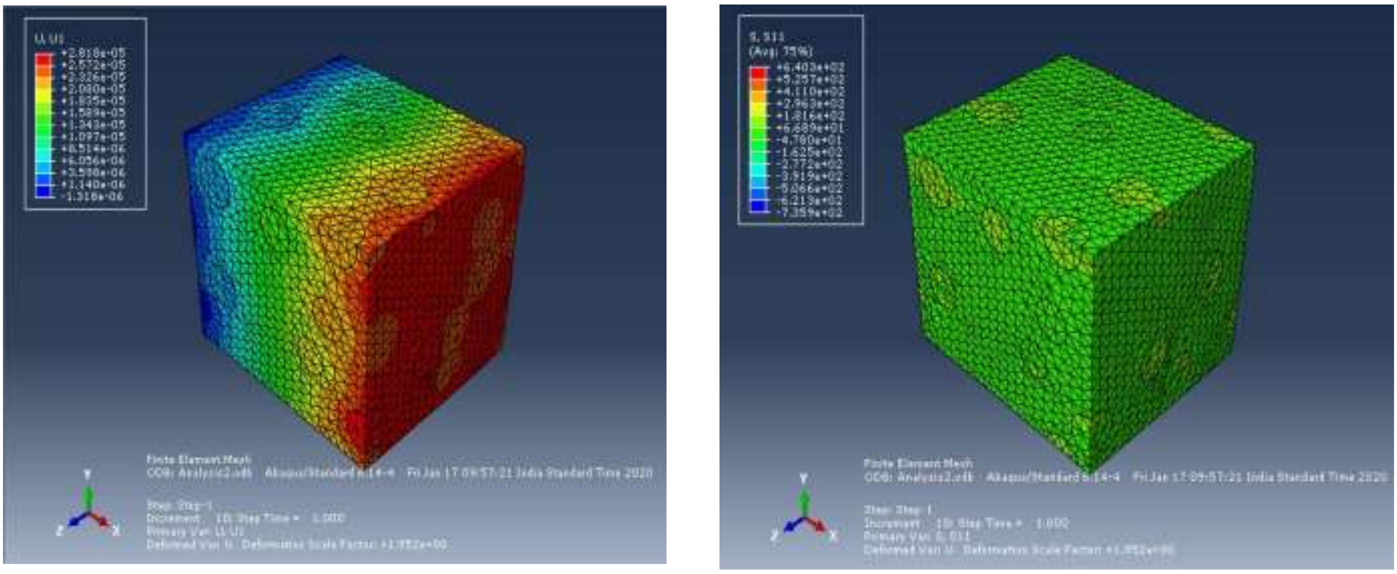
Property	**PTFE**	**Boron Carbide**
Density (kg/m^3)	2200	2510
Young modulus (GPa)	0.6	445
Poisson Ratio	0.41	0.19
CTE (K^{-1})	120E-6	5.54E-6
Tensile strength (MPa)	28	350
Tangent Modulus (MPa)	134	-
Hardening Exponent	0.15	-

Table 2: Homogenization Properties of PTFE with boron carbide

Properties	**SwiftComp**	**Digimat-MF**
Young modulus(Pa)	7.8122E08	7.464E08
Shear modulus(Pa)	2.619E08	2.6626E08
Poisson ratio	0.397	0.40167
Density(Kg/m^3)	2231	2231

3.3 Numerical Analysis of PTFE with boron carbide RVE

The FE model of the composite RVE is further solved by using ABAQUS software. Meshing and mechanical loading of RVE is carried out in Digimat- FE software. Uniaxial loading condition along x-axis with periodic boundary condition is to be considered for loading.



a) b)

Figure 2: Contour plot showing (a) the displacement along x and (b) the stress in x-direction for a filler concentration of 10%.

3.4 Comparison of stress-strain graph for varying filler percentage

Stress- strain response of the PTFE with boron carbide nanocomposites containing 0, 2, 4, 6, 8 and 10 wt. % of boron carbide nano-particle are studied by using Digimat-MF software. The size of the boron carbide nano-particle is kept constant as 100nm. The nature of the graph indicate that as volume percentage of filler increases strength of the nanocomposite also increases. But addition of filler percentages is restricted upto 12 wt. % because coefficient of friction increases drastically.

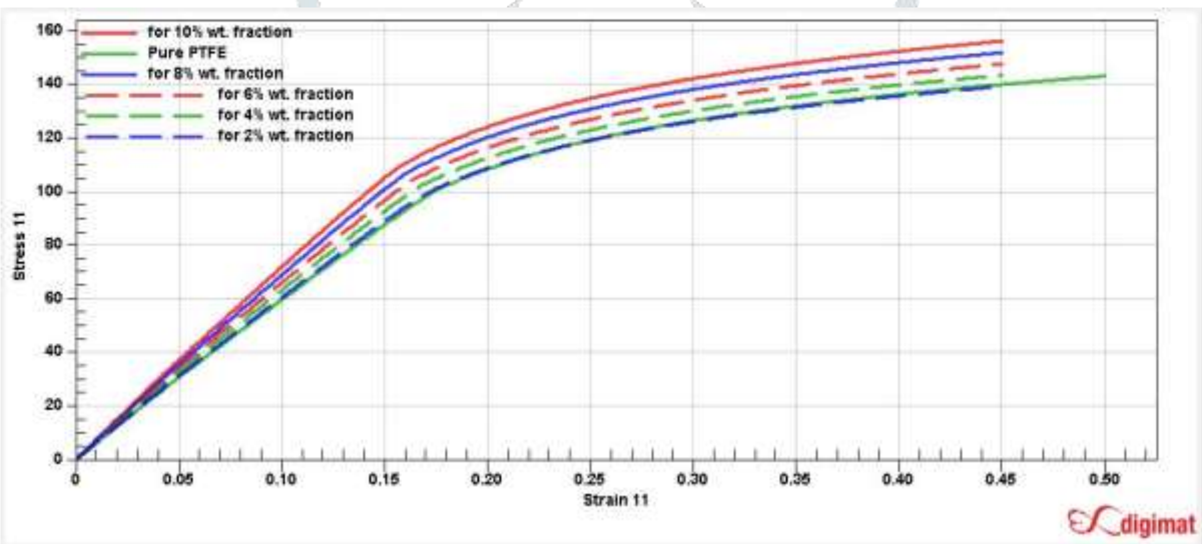


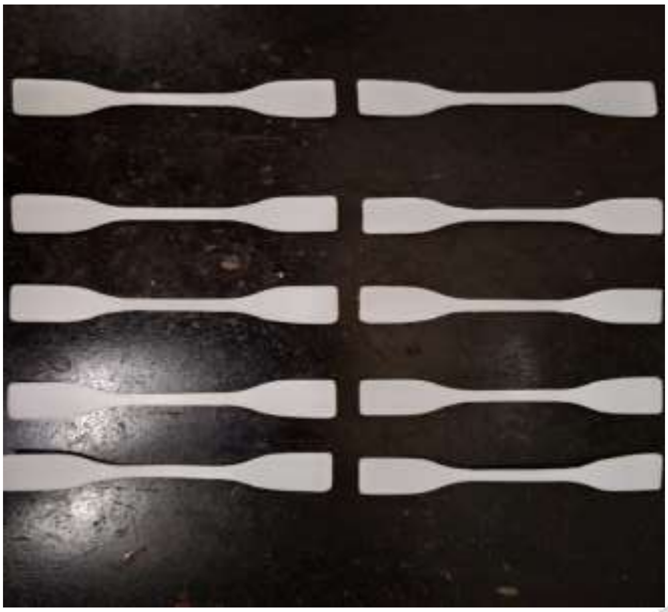
Figure 3: Stress-strain curve for varying filler percentage

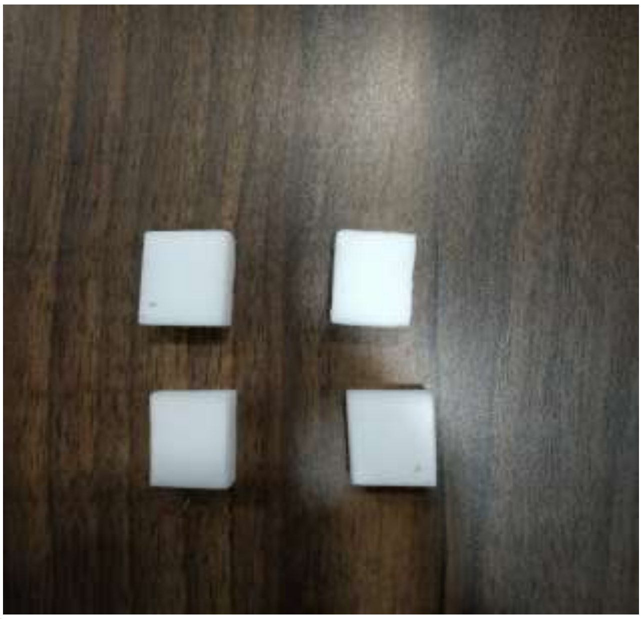
IV. MANUFACTURING OF PTFE COMPONENT AND PREPARATION OF TEST SPECIMENS

To carry out the testing such as tensile test, wear test etc. it is recommended to manufacture bush, according to ASTM-D617. For manufacturing bush following steps carried out.

- Blending: In case of virgin PTFE component raw material used is pure PTFE powder. While in some cases to improve the properties some additives are mixed in PTFE powder and such process is called as blending.
- Preforming: Compacting powdered PTFE material under pressure in a mould to produce a solid object, called a preform that is capable of being handled. Moulding and compaction are terms used interchangeably with preforming for PTFE.
- Sintering: Thermal treatment during which the PTFE is melted and recrystallized by cooling with coalescence occurring during the treatment. The sintering cycle carry out for the formation of bush is 24 hours with maximum temperature rise up to 365˚C.
- Finished Product: If necessary after the sintering process machining operation carry out. Also burr present to the sintered part is removed. Also some resizing operation carry out after the sintering operation.

The tensile test specimen and wear test specimens are prepared with reference to ASTM-D4894 and ASTM-G137.





a) b)

Figure 4: Finished a) tensile test specimen and b) wear test specimen for pure PTFE

a) b)

Figure 5: Finished a) tensile test specimen and b) wear test specimen for PTFE with 10% boron carbide

V. Experimental testing of test specimens

Wear testing carried on pinon disc setup according with ASTM-G99. Testing perform on two specimens from each category.

Table 3: Wear test readings for pure PTFE specimen

Specimen	W1	W2	T	W.R= (W1-W2)/T
1	2.050	2.040	906	0.000011
2	2.155	2.143	906	0.0000132

Therefore average wear rate of pure PTFE is 0.0000121 gram/ second.

Table 4: Wear test reading for PTFE with 10% boron carbide specimen

Specimen	W1	W2	T	W.R= (W1-W2)/T
1	2.255	2.251	906	0.0000044
2	2.279	2.273	906	0.0000066

Therefore average wear rate of PTFE with 10% boron carbide is 0.0000055 gram/ second.
Where,
W1- Initial weight of sample in gram.
W2- Final weight of sample after wear in gram.
T- Time for 1000 rev. in seconds.
W.R- Wear rate in gram/ second.

Tensile testing carried on UTM according with ASTM-D618. Testing perform on five specimens from each category.

Table 5: Tensile test readings for pure PTFE specimen

Spec-imen	(w)	(t)	(IR)	(FR)	(GL)	A= w*t	L	T.S= L/A	% E = (FR-IR)/GL*100
1	6	1	272	400	46.3	6	147.15	24.525	276
2	6	1	290	442	52	6	156.96	26.16	292
3	6	1	280	422	49	6	147.15	24.525	289
4	6	1	285	430	50	6	137.34	22.89	290
5	6	1	280	405	47	6	142.24	23.707	265

Therefore average tensile strength of pure PTFE test specimen is 24.3614 MPa.

Table 6: Tensile test readings for PTFE with 10% boron carbide specimen

Spec-imen	(w)	(t)	(IR)	(FR)	(GL)	A= w*t	L	T.S= L/A	% E = (FR-IR)/GL*100
1	6	1	274	350	49.5	6	196.2	32.7	153
2	6	1	280	365	50	6	189.62	31.6	170
3	6	1	278	357	48	6	206.01	34.33	164
4	6	1	282	367	49	6	196.2	32.7	173
5	6	1	280	361	48	6	189.62	31.6	168

Therefore average tensile strength of PTFE with 10% boron carbide test specimen is 32.652 MPa.
Where,
w- Width of test specimen in mm.
t- Thickness of test specimen in mm.
IR- Initial Reading in mm.
FR- Final Reading in mm.
GL- Gauge length in mm.
A- Area of gauge length in mm^2.
L- Load in N.
T.S- Tensile strength at break point in MPa.
%E- Percentage Elongation.

VI. Conclusion

This paper discuss about polytetrafluoroethylene based composite. The effect on mechanical and tribological properties of PTFE due to use of filler as boron carbide has been studied. Following conclusion can be drawn:

a. Both experimental and numerical results shows same trend.
b. Due to addition of boron carbide as a filler, mechanical properties such as tensile strength, compressive strength are increase up to specific range, while percentage of elongation decreases.
c. The composite material obtained had a tensile strength of 32.652 MPa, which corresponds to approximately 1.34 times the strength of pure PTFE.
d. % elongation for pure PTFE is average 282, while due to addition of 10% boron carbide % elongation reduced up to 42% that is 165.
e. Due to addition of boron carbide wear resistance to be increases. For 10% addition of boron carbide wear rate reduced up to 54%.

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