Development and Analysis of Polymer Composite Material for Tribological Applications

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Abstract—Polymer composites show good tribological properties in engineering applications, low cost and easy to manufacturing. Regardless of the wear of polymer composites, improvements in material development have been used to improve mechanical properties. Wear is the main parameter that reduces the useful life of the machine or its components. A wear-resistant polymer composite material was analysedcontaining three-element composition composed of a matrixmaterial, reinforcing material, and friction and anti-wear material in particulate form. In this work, a combination containing Polyaryl ether ketone (PAEK) as the matrix, alumina (Al2O3) and boron carbide (B4C) as the reinforcing material and polytetrafluoroethylene (PTFE) as the anti-wear material are prepared according to the ASTM standard. The purpose is to develop and analyse new thermoplastic polymer composite materials to improve the tribological properties of materials, especially wear resistance, to study new polymer composite materials and test their wear and other mechanical properties. If the developed composite material gives challenging results and passes the mechanical tests that will be conducted during this research period, it will be a good substitute for isotropic materials and may also be suitable for some composite materials. Possible application areas: gears, bearings, artificial joints in the medical field, brake pads, clutches, tires, etc.

Keywords: Polymer Composite; PAEK;Wear resistance; Friction; ASTM

I. INTRODUCTION

Today, polymers and their composites are extensively seemed to be a group of important elements due to their top-notch properties which includes resistance to wear, elasticity, density, molding capability, high vibration absorption. There are a huge range of applications along with bearings, gears, brakes, transmission gadgets, sprocket, valve guides, signals, industrial liquid slides / slides containing abrasives and so forth in put on-related conditions. The development of unique materials for tribological surfaces has come to be a pressing call for the manufacturing industry. Polymer composites have the capability to sustain longer in cryogenic & high temperature without softening. Polymer composites have great prospectus for business applications due to ease of customisation with unique fillers. Mechanical properties to the base of the polymer is expanded through adding with solid organic or inorganic lubricants. In immaculate form, just a few polymers can serve the tribological requirements; but, in composition (with addition of suitable additives), polymers are extra fine than metals or ceramics. The tribological application of polymers includes gears, bearing cages, human joints, brakes, tyres. The list doesn't end here. For instance, inside the new microelectromechanical systems (MEMS), polymers (which includes poly (methyl methacrylate) (PMMA) and poly (dimethyl siloxane) PDMS[1] are gaining reputation as building materials over the maximum broadly used materials, Si. Tribological polymers properties strongly affected by means temperature, normal load, the relative speed of the merged surface and the environment. Therefore, to overcome the inefficient polymers, the polymers are modified by way of including the best fillers in accordance with a selected application. Therefore, they're used for a merger of better performance in friction and wear related applications. The composition, usually the manufacturer's key secret, and the final performance may additionally depend upon the formula or matrix recipe and reinforcement or filling materials[1].

Polymers are bad in dissipation of heat generated which leads to the underperformance of tribo properties causing instantaneous strength reduction. To avert this issue, polymers with high tribological properties and advanced temperature structures at excessive temperatures have already come to be the main focus of studies in this place. Therefore, special plastics the Polyaryl-ether-ketone (PAEK) own family is mostly approved to enhance the performance of tribo-materials[2]. It is experimented that PAEK & PTFE mixed together produces great Tribological properties. This Inspired to form combos of PAEK, alumina (Al2O3), Boron Carbide (B4C) and PTFE to improve wear resistance, method performance, as this research has no longer been noted.

II. LITERATURE REVIEW

Generally, very strong strength combined with high elasticity promote wear resistance in the polymer. Accordingly, given all other materials being stable, some straight thermoplastic polymers have a semicrystalline microstructure that performs better compared to thermosets or amorphous thermoplastics. This conclusion is consistent with the notion that in polymers, surface rigidity is not a material that controls wear resistance[1]. Polybenzimidazole (PBI) is a unique polymer with immense thermal stability. Nonetheless, its capability to form compounds has not been tested due to performance-related problems. Approximately 20-30% was a good PBI content in PEK that provided moderate flow and performance. When these were used together, performance was much better. Compared to a commercial compound based on the PBI-PEEK compound and similar design, the new layers revealed the potential with a much lower tribo-coefficient (μ) ≈ 0.05 and a certain wear rate (K0) ≈ 1 × 10-6 m3 / IN m and with a very high safe range of PV≈ 63 MPa m /s[2]. PEEK and PEKK / carbon fibers produce least wear rate; the UHMWPE system on any metal alloys shows a very high wear rate even though it has a low coefficient of friction[3]. The increased performance of micro-reinforced PEEK matrix composites and nano size ceramic particles of aluminum nitride and alumina is constructs in a simple manner consisting of dispersing ceramic particles into the PEEK matrix following hot pressures at 350˚C and 15 MPa. Hardness of PEEK / AlN compounds is greater compared to PEEK / Al2O3 formulations. With the fraction of the given volume, the density of nanocomposites is greater compared to micro composites[4].The use of polymer composites for surface applications is very widespread. Special reinforcement helps to make them also reluctant to wear. New developments in this use of additional nano-particles, including wear-and-tear tribo-system. This is reflected not only in the laboratory scale, but also in a variety of applications[5].The requirements for learning about the behavior of polymers and their compounds have recently been increased. The results showed that there is a high potential for replacement of normal and bio-reinforced reinforcement. Researchers conclude that thermoplastic materials have the potential to produce a thin film transfer to a metal challenge that helps to reduce the unevenness of the collision. However, at higher temperatures of the interface, the occurrence of plastic damage to the soft surface leads to higher damage. Strengthening the thermoplastic equipment will help to reduce the wear level of materials that can reach the systems of resisting bearings and bear structures and trees. The addition of hard fibers to thermosets can increase wear and tear properties[6]. M. Remanan et.al [7] studied the development and thermo mechanical formulation of individual, binary, and ternary nanocomposites using radiation resistant fillers such as boron carbide (B4C), tungsten carbide (WC)), as well as high-density carbon nanotubes (F-MWCNT) with a high-performance polymer, namely poly aryl ether ketone (PAEK). In this work, a twin screw extrusion mixing process was used to prepare PAEK-based nanocomposites using radioactive fillers such as B4C, WC, and FMWCNT.

III. DEVELOPMENT OF COMPOSITE

Different compositions are developed to minimize the wear, with the help of the fillers and lubricants. The proportion of the elements is varied and their effect are studied. Poly-aryl-ether-ketone (G-PAEKTM 1200P) (800 µm to 900 µm in size make- Gharda Chemical Ltd, Mumbai) used as base matrix, alumina (Al2O3, ≈ 50 µm in size) and Boron Carbide (B4C, ≈ 50 µm in size) as a reinforcements and Poly-tetra-fluoro-ethylene (PTFE, 150P, 30 µm in size) as lubricant for this research. 14 Compositions are developed and the results of samples are studied and compared.

Sr. No.	[PAEK] (% Wt)	PAEK in gm	Alumina (% Wt)	Alumina Gm	Total weight in gm
1	100	500	0	0	500
2	95	500	5	25	525
3	90	500	10	50	550
4	85	500	15	75	575
5	80	500	20	100	600

Table 3. (a) Compositions of Materials (PAEK and Al_2O_3)

Sr. No.	PAEK(%Wt)	PAEK in gm	PTFE(% Wt)	PTFE in gm	Alumina (% Wt)	AluminaGm	Total weight in gm
1-L.	95	500	5	25	0	0	525
2-L.	90	500	5	25	5	25	550
3-L.	85	500	5	25	10	50	575
4-L.	80	500	5	25	15	75	600
5-L.	75	500	5	25	20	100	625

Table 3. (b) Compositions of Materials (PAEK,PTFE andAl_2O_3)

Sr. No.	PAEK(%Wt)	PAEK in gm	Boron Carbide (% Wt)	Boron Carbide Gm	Total weight in gm
1-B4C.	95	500	5	25	525
2-B4C.	90	500	10	50	550
3-B4C.	85	500	15	75	575
4-B4C.	80	500	20	100	600

Table 3. (c) Compositions of Materials (PAEK and B_4C)

Poly-aryl-ether-ketone (PAEK) used as matrix, ceramics as alumina & Boron Carbide as reinforcing filler and PTFE (Polytetrafluoroethylene) used as wear resistant additive are prepared using powders, dry mixing is done using a mixture. After mixing a mixture was placed in twin screw extruder. Alumina, Boron carbide and PTFE powders are used in micro sizes. Compounding temp of 375-395˚C kept for extrusion. Result i.e., the molten material of the twin screw extruder is supplied with a strand pelletizer where the soluble price granules are made and these granules are stored in the oven at 150˚C for two hours to dry. The granules were then placed in an injection molding machine at 375-390 ˚C to produce experimental samples.

Physical Property (density) of Composites

Calculations for density:

$$\rho_{composite} = \frac{(\%\ \text{wt.of Matrix} \times \rho\text{Matrix}) + (\%\ \text{wt.of Reinforcement} \times \rho\ \text{Reinforcement}) + (\%\ \text{wt.of Lubricant} \times \rho\text{Lubricant})}{100}$$

1. $\rho_{composite} = \frac{(100\times1.30)+(0\times4.0)}{100}$

$= 1.30$ gm/cc

2. $\rho_{composite} = \frac{(95\times1.30)+(5\times4.0)}{100}$

$= 1.43$ gm/cc

3. $\rho_{composite} = \frac{(90\times1.30)+(10\times4.0)}{100}$

$= 1.56$ gm/cc

4. $\rho_{composite} = \frac{(85\times1.30)+(15\times4.0)}{100}$

$= 1.71$ gm/cc

5. $\rho_{composite} = \frac{(80\times1.30)+(20\times4.0)}{100}$

= 1.85 gm/cc

1-L. $\rho_{composite} = \frac{(95\times1.30)+(0\times4.0)+(5\times2.2)}{100}$

= 1.36 gm/cc

2-L. $\rho_{composite} = \frac{(90\times1.30)+(5\times4.0)+(5\times2.2)}{100}$

= 1.47 gm/cc

3-L. $\rho_{composite} = \frac{(85\times1.30)+(10\times4.0)+(5\times2.2)}{100}$

= 1.62 gm/cc

4-L. $\rho_{composite} = \frac{(80\times1.30)+(15\times4.0)+(5\times2.2)}{100}$

= 1.76 gm/cc

5-L. $\rho_{composite} = \frac{(75\times1.30)+(20\times4.0)+(5\times2.2)}{100}$

= 1.88 gm/cc

1-B4C. $\rho_{composite} = \frac{(95\times1.30)+(5\times2.52)}{100}$

= 1.36gm/cc

2-B4C. $\rho_{composite} = \frac{(90\times1.30)+(10\times2.52)}{100}$

= 1.42gm/cc

3-B4C. $\rho_{composite} = \frac{(85\times1.30)+(15\times2.52)}{100}$

= 1.48 gm/cc

4-B4C. $\rho_{composite} = \frac{(80\times1.30)+(20\times2.52)}{100}$

= 1.54 gm/cc

Sr. No.	$\rho_{composite}$ gm/cc	Sr. No.	$\rho_{composite}$ gm/cc	Sr. No.	$\rho_{composite}$ gm/cc
1.	1.30	1-L.	1.36	1-B4C.	1.36
2.	1.43	2-L.	1.47	2-B4C.	1.42
3.	1.56	3-L.	1.62	3-B4C.	1.48
4.	1.71	4-L.	1.76	4-B4C.	1.54
5.	1.85	5-L.	1.88		

Table 3. (d) Physical Property (density) of Composites for different compositions

As shown in table no. 4 In addition to the % weight of PTFE, samples were compared. It is observed that density of the prepared composites are increasing with addition of the fillers i.e., boron carbide. B4C compounds have the smallest density in all compounds and alumina compounds have the larger density.

IV. EXPERIMENT AND RESULTS

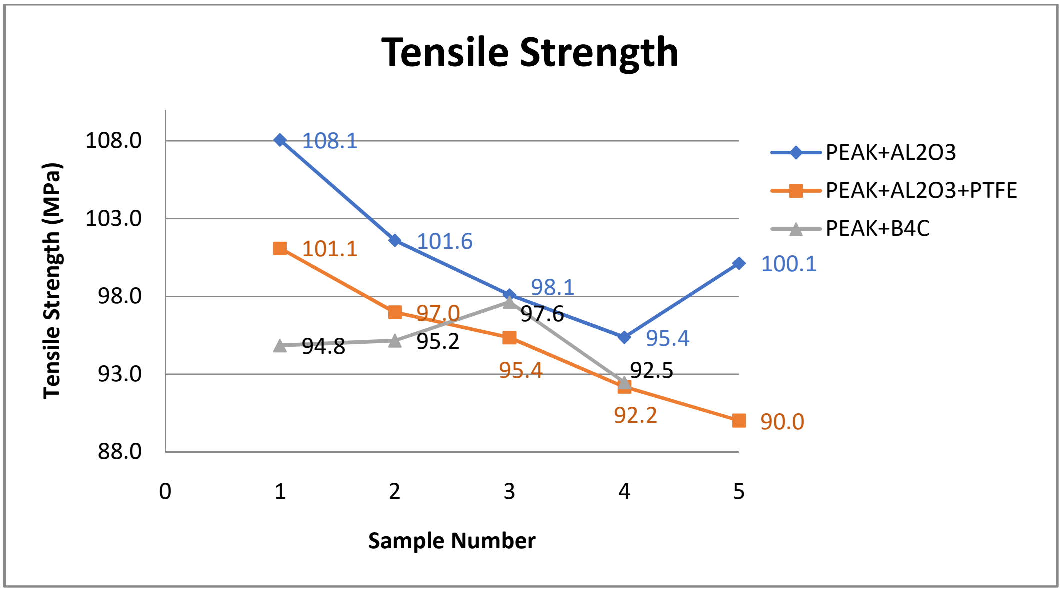
Mechanical Properties of Composites

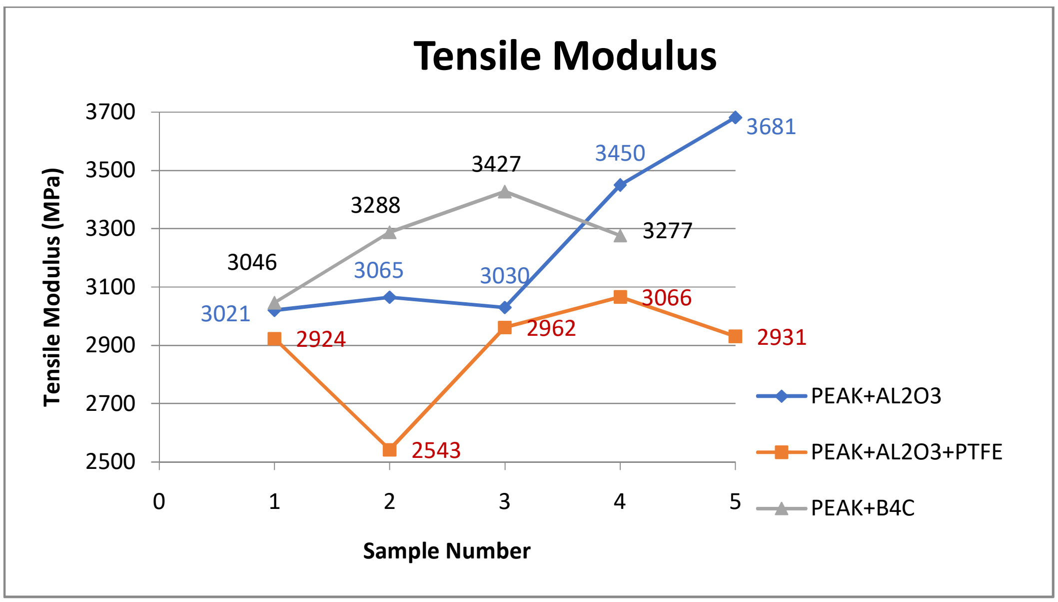
4.1 Tensile Testing-

Tensile testing is performed according to ASTM D638 (Type-V) standard and results are shown below:

Sr. No.	**Tensile Strength MPA**	**Maximum Load KN**	**Breaking Load KN**	**Tensile Modulus MPA**
1	108.07	1.101	1.078	3021
2	101.60	1.035	0.994	3065
3	98.10	1.000	0.872	3030
4	95.37	0.968	0.961	3450
5	100.13	1.018	0.934	3681
1-L.	101.10	1.027	1.005	2924
2-L.	96.97	0.988	0.964	2543
3-L.	95.35	0.969	0.774	2962
4-L.	92.17	0.942	0.925	3066
5-L.	90.00	0.914	0.864	2931
1-B4C.	94.83	0.964	0.930	3046
2-B4C.	95.15	0.970	0.843	3288
3-B4C.	97.63	0.998	0.977	3427
4-B4C.	92.47	0.941	0.918	3277

Table 4.1 (a)The average testing results of tensile test fordifferentcomposition





As seen from table 4.1 (a) for tensile strength addition of alumina particles in PAEK matrix decreases tensile strength but in case of addition of PTFE leads to more decrease in tensile strength. In case of addition of Boron carbide particles in PAEK matrix tensile strength deteriorates significantly and further increase in B4C tends to increase in tensile strength up to 15 weights % of B4C but beyond that it decreases significantly as compared to alumina.

Addition of alumina in PAEK matrix increases young's modulus (E), however in case of addition of PTFE in PAEK matrix decreases young's modulus (E). Addition of Boron Carbide increases young's modulus (E) up to 15 weights % of B4C beyond that it decreases.

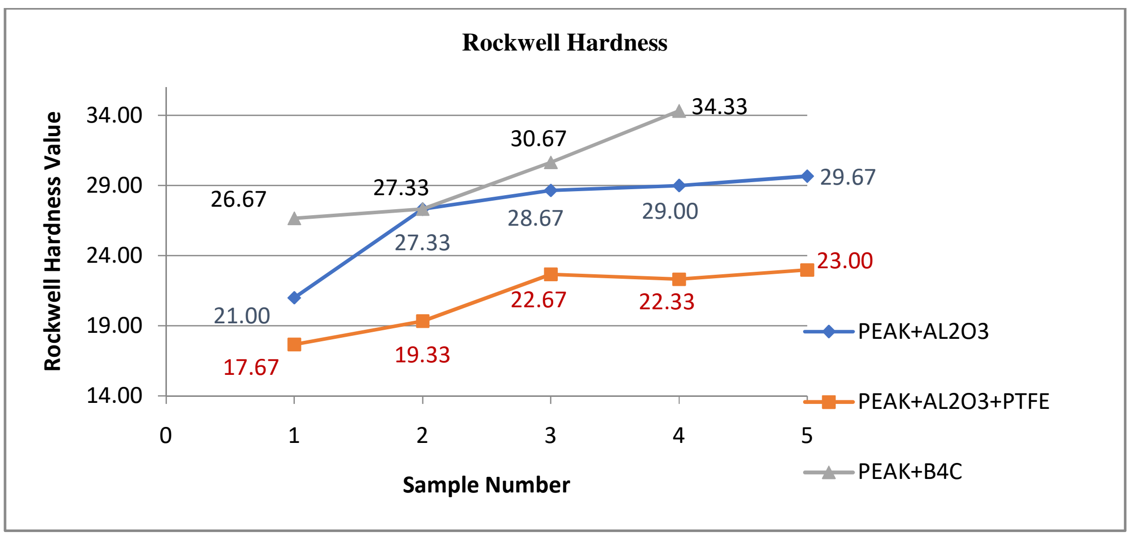
4.2 Rockwell Hardness Testing

Rockwell superficial hardness testing is performed according to T-scale in which 1/16˝ ball indenter is used and applied load is 15 Kg.

Three readings are taken for each sample and the results are shown below.

Sr. No.	Reading 1	Reading 2	Reading 3	Average
1	22	20	21	21.00
2	28	27	27	27.33
3	28	29	29	28.67
4	29	30	28	29.00
5	28	31	30	29.67
1-L.	18	19	16	17.67
2-L.	20	19	19	19.33
3-L.	23	22	23	22.67
4-L.	24	22	21	22.33
5-L.	23	24	22	23.00
1-B4C.	27	26	27	26.67
2-B4C.	27	28	27	27.33
3-B4C.	30	31	31	30.67
4-B4C.	35	34	34	34.33

Table 4.2 (a)The Average Rockwell testing results



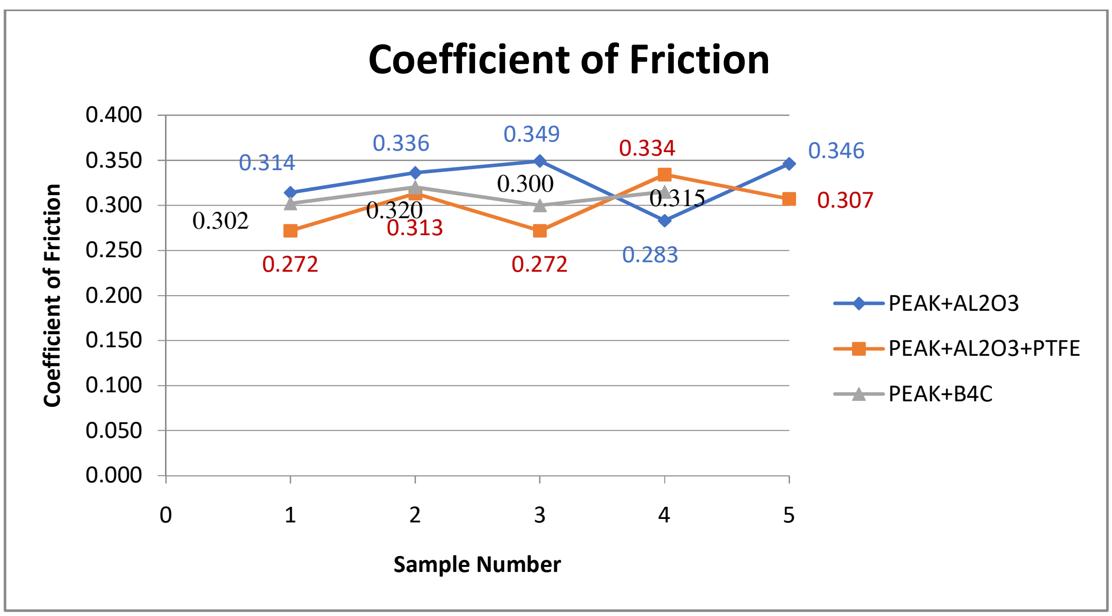
Significant variation in the Rockwell hardness values are observed on addition of alumina and B4C in PAEK matrix but addition of PTFE in PAEK matrix slightly lowers the Rockwell hardness values.

4.3 Wear Testing

A pin-on-disk is used to characterize friction force, frictional coefficient, & wear rate between the two components. Test conducted on DUCOM TRIBOMETER. Equipment mainly consists, a sleeve arm is attached to the pin, a disc up to 165 mm wide and 8 mm wide, electric sensor (proximity sensor), LVDT sensor for measurement of wear and computer software (WINDUCOM 2006),In this testing the stationary disk displays a rotating pin while loading it regularly. Tribostudies are performed using a pin on disk configuration on the tribometer.

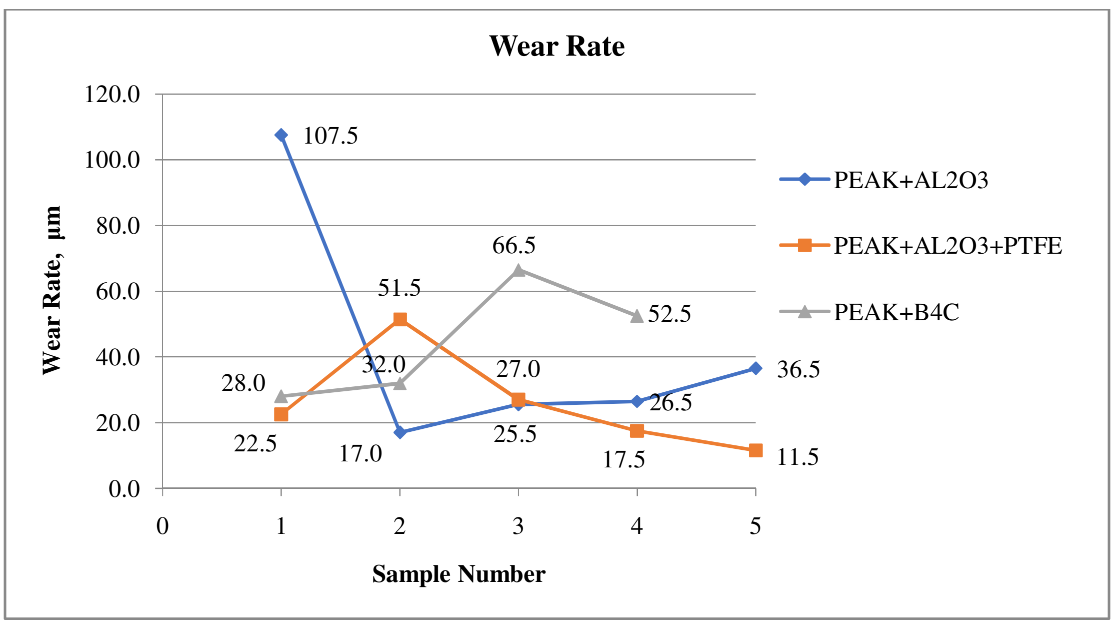
Sr. No.	Sample	Readings			Average	Average of two close values
		1	2	3		
1	100%PAEK	0.278	0.322	0.306	0.302	0.314
2	95%PAEK+5%Al_2O_3	0.341	0.284	0.331	0.319	0.336
3	90%PAEK+10%Al_2O_3	0.34	0.358	0.254	0.317	0.349
4	85%PAEK+15%Al_2O_3	0.223	0.286	0.28	0.263	0.283
5	80%PAEK+20%Al_2O_3	0.353	0.393	0.34	0.362	0.346
1-L.	95%PAEK+5%PTFE	0.242	0.273	0.272	0.262	0.272
2-L.	90%PAEK+5%PTFE+5%Al_2O_3	0.196	0.342	0.284	0.274	0.313
3-L.	85%PAEK+5%PTFE+10%Al_2O_3	0.272	0.353	0.272	0.295	0.272
4-L.	80%PAEK+5%PTFE+15%Al_2O_3	0.335	0.32	0.334	0.33	0.334
5-L.	75%PAEK+5%PTFE+20%Al_2O_3	0.46	0.302	0.312	0.358	0.307
1-B4C.	95%PAEK+5%B4C	0.281	0.43	0.324	0.345	0.302
2-B4C.	90%PAEK+10%B4C	0.291	0.349	0.236	0.292	0.32
3-B4C.	85%PAEK+15%B4C	0.288	0.313	0.637	0.413	0.3
4-B4C.	80%PAEK+20%B4C	0.31	0.321	0.301	0.311	0.315

Table 4.3 (a)Coefficient of friction readings for different composition



Sr. No.	Sample	Readings (Micrometres, µm)			Average (µm)	Average of two close values
		1	2	3		
1	100%PAEK	137	106	109	117.33	107.5
2	95%PAEK+5%Al_2O_3	66	24	10	33.33	17
3	90%PAEK+10%Al_2O_3	20	46	31	32.33	25.5
4	85%PAEK+15%Al_2O_3	24	11	29	21.33	26.5
5	80%PAEK+20%Al_2O_3	34	39	61	44.67	36.5
1-L.	95%PAEK+5%PTFE	19	26	55	33.33	22.5
2-L.	90%PAEK+5%PTFE+5%Al_2O_3	52	20	51	41.00	51.5
3-L.	85%PAEK+5%PTFE+10%Al_2O_3	26	19	28	24.33	27
4-L.	80%PAEK+5%PTFE+15%Al_2O_3	19	16	29	21.33	17.5
5-L.	75%PAEK+5%PTFE+20%Al_2O_3	14	9	28	17.00	11.5
1-B4C.	95%PAEK+5%B4C	81	29	27	45.67	28
2-B4C.	90%PAEK+10%B4C	26	38	54	39.33	32
3-B4C.	85%PAEK+15%B4C	25	76	57	52.67	66.5
4-B4C.	80%PAEK+20%B4C	49	99	56	68.00	52.5

Table 4.3 (b)Wear rate for different composition



From pin-on-disk wear testing and samples 1 to 5, as weight % of Al_2O_3increases the wear rate decreases but beyond 15 weights % of Al_2O_3 wear rate increases. Also, coefficient of friction increases due to addition of

Al_2O_3 except at15 weight % of Al_2O_3, because the coefficient of friction of alumina (Al_2O_3) against steel is high as compared to pristine PEAK polymer. For samples 1-L to 5-L, coefficient of friction increases and wear rate decreases except for sample 2-L (90%PAEK+5%PTFE+5%Al_2O_3). For samples 1-B4C to 4-B4C, the wear rate decreases up to 10 weight % of B_4C but beyond 10 weight % of B_4C the wear rate increases. Also, the values of coefficient of friction fluctuate between 0.292 to 0.413. From comparison between samples 1 to 5 and 1-L to 5-L, the wear rate decreases for samples 1-L to 5-L due to addition of PTFE except for sample 2-L. Also, the coefficient of friction decreases due to addition of PTFE. From comparison between samples 1 to 5 and 1-B4C to 4-B4C, the reinforcement of alumina (Al_2O_3) gives better wear resistance than Boron Carbide.

The range of coefficient friction for automobile brake pads is 0.3 to 0.6. From the above discussion, sample no. 5-L have low wear rate i.e., approximately 10 times less wear than the pristine PAEK (Polyaryletherketone) polymer and the value of coefficient of friction is 0.358. The sample 5-L (75%PAEK+5%PTFE+20%Al_2O_3) is best composition among all the compositions and which is suitable for automobile brake pads. Hence it is a potential alternative asbestos free brake lining composite (75%PAEK+5%PTFE+20%Al_2O_3) material.

V. CONCLUSION

1. The sample no. 5-L (75%PAEK+5%PTFE+20%Al_2O_3) have low wear rate i.e., approximately 10 times less wear than the pristine PAEK (Polyaryletherketone) polymer and the value of coefficient of friction is 0.358. The sample 5-L (75%PAEK+5%PTFE+20%Al_2O_3) is best composition among all the compositions and which is suitable for automobile brake pads. Hence it is a potential alternative asbestos free brake lining composite (75%PAEK+5%PTFE+20%Al_2O_3) material. Addition of lubricant PTFE decreases coefficient of friction (μ). Relatively fine size particles give good results for friction material.

2. **a)** For tensile strength, addition of alumina (Al_2O_3) decreases tensile strength, addition of Boron Carbide significantly decreases tensile strength as compared to alumina and addition of polytetrafluroethylene (PTFE) leads to more decrease in tensile strength.

b) Addition of alumina (Al_2O_3) and Boron carbide increases young's modulus (E), however in case of addition of PTFE in PAEK matrix decreases young's modulus (E).

c) Addition of alumina and B4C in PAEK matrix but addition of PTFE in PAEK matrix slightly lowers the Rockwell hardness values.

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