Development of Bearing Material and High Performance Bearings for Dry Applications Under Harsh Operating Conditions

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ABSTRACT
Among the four types of engineering materials viz. metals, ceramics, polymers and composites, specially fibre reinforced polymers (FRPs) form a very important class of materials because of their special properties such as high specific strength and stiffness, self-lubricity, as well as resistance to wear, impact, corrosion, chemicals, solvents, nuclear radiation, contamination with oils and their capacity to absorb vibrations leading to quiet operation. Such tribo-components fabricated from composites are used in typical situations where either hydrodynamic lubrication is not possible because of frequent start and stops or low PV (pressure-velocity) values.

Polymers also have some limitations such as low thermal stability, heat conductivity and dissipativity. These are overcome to a great extent by selecting polymers with high thermal stability and mechanical properties and by tailoring composites with variety of reinforcements, fillers and solid lubricants. Among the speciality polymers, Polyether-etherketone (PEEK), Polyimides (PIs), Polytetrafluoroethylene (PTFE) etc. are at the forefront in the area of tribology of polymers. Among these, PEEK is the most investigated polymer during last 15 years and numerous composites have been reported having wide spectrum of tribo-properties. Various fibrous reinforcement such as glass, carbon, aramid etc. in various forms such as short and long have been explored along with various combinations of solid lubricants and metallic fillers. Within an Indo-German research project supported by DST and DAAD novel bearing materials and high performance bearings for dry applications are developed.

1. INTRODUCTION

Reliable and predictable performance in adverse operating conditions is a key criterion for material selection in engineering applications. Continuous innovations and advancements in modern technology are placing ever increasing demands on materials for better and reliable performance in harsh operating conditions such as extreme temperature, pressure, corrosive and biologically aggressive environment, nuclear radiation etc. These demands cannot be always met by the existing materials and new advanced composites are called for. Thus tailoring of composites with specific performance expectations followed by characterisation and performance evaluation forms a sound platform to form a successive batch of composites.

Among the four types of engineering materials viz. metals, ceramics, polymers and carbon-carbon composites; polymers and composites, specially fibre reinforced polymers (FRPs) form a very important class of materials because of their special properties such as self-lubricity1, high specific strength, resistance to wear, impact, corrosion, chemicals, solvents, nuclear radiation, contamination with oils, easy processability in complex shapes and, capacity to absorb vibrations leading to quiet operation, etc. Such tribo-components fabricated from the polymers and composites are used in typical situations where either hydrodynamic lubrication is not possible because of frequent start and stops or low PV (pressure-velocity) values. Polymeric bearings are the only solution in the following situations.

[1] They do not need any external lubrication by conventional liquid lubricants and can run in dry condition.

1. where lubrication is a problem (tribological components in inaccessible equipment, for example in nuclear reactors and in hazardous conditions in chemical plants or in vacuum or space)
2. where lubrication is unacceptable because of the possibility of contamination of lubricant with product (plain bearings or gears in food, paper, pharmaceutical and textile industries)
3. where maintenance is spasmodic or impossible (bushes and seals in domestic appliances, toys and instruments)
4. where lubrication is sparse (aircraft linkage bearings)
5. as a safeguard in the event of failure of the lubrication systems (e.g. gears in train)

2. NOVEL FIBRE REINFORCED TRIBO-COMPOSITES

Polymers also have some limitations such as low strength as compared to metals, low thermal stability, heat conductivity and dissipativity. These are overcome to a great extent by selecting polymers with high thermal stability and mechanical properties (speciality high performance polymers) and by tailoring composites with variety of reinforcements, fillers and solid lubricants. By a judicious choice of matrix, reinforcement, fillers and processing technology, the desired performance can be achieved. Among the speciality polymers, Polyether-ether-ketone (PEEK), Polyimides (PIs), Polytetrafluoroethylene (PTFE) etc. are at the forefront in the area of tribology of polymers [1]. Among these, PEEK is the most investigated polymer during last 15 years and numerous composites have been reported having wide spectrum of tribo-properties. Various fibrous reinforcement such as glass, carbon, aramid etc. in various forms such as short and long have been explored along with various combinations of solid lubricants and metallic fillers [1,2]. However, literature on fabric reinforced tribo-composites is very sparse [3,4]. Apart from formulating the composites, various other methods in combination are also used for enhancing the tribo-performance of materials. These include; control and design of bulk properties (molecular weight, microstructure, entanglement density etc.), development of IPN (interpenetrating network), structural modifications by plasma treatment, ion implantation, photo polymerisation, physical and chemical vapour deposition and silicone modification etc. After reviewing the literature on the property (tribo) enhancement by various techniques, it was observed that the efforts for tailoring the composite's surface and bulk simultaneously are not yet reported. In fact, tribology is a science of two interacting surfaces in relative motion and surface properties are very important and decisive for friction and wear behaviour, while bulk properties such as load carrying capacity, resistance to creep, compression, cracking, fatigue etc. are more important for the bearing body. Since the requirements on the surface and bulk are different, both the parts should be designed simultaneously. Such composites containing solid lubricants on the working surface of the bearing along with the network of the reinforcement in the bulk are to be tailored. Such efforts are not yet reported and the proposed project aims at the optimisation of both surface and bulk with different properties.[2] Such efforts if successful will offer a composite with very good friction and wear properties along with very good mechanical properties.

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[2] In conventional methods, PTFE, a solid lubricant is dispersed uniformly in the body of fibre reinforced composites. This leads to two potential problems through tribological performance is improved. First, PTFE, expensive material is not required in the bulk since its its utility is only on the surface. When it is in the bulk, being of very low surface energy material, it reduces mechanical properties especially ILSS of a composite drastically.

Literature also indicates that though the bi-directionally (BD) reinforced (fabric) polymers are very significantly superior than the continuous fibre reinforced composites from the specific strength and processability point of view, little efforts have been made to explore their potential [1,4]. The proposed research will thus be very vital in this area and will explore the potential of carbon fabric reinforcement in PEEK for enhancing various properties.

3. COMPOSITE FORMULATION AND SPECIMEN FABRICATION

Within the research work various tribo-composites using high performance engineering thermoplastic polymer (PEEK) and carbon fabric reinforcement were fabricated whereby a PTFE modification was applied to design the surface for the better tribological properties. A new hybrid carbon-PEEK fabric with bi-directional (BD) reinforcement made of commingled hybrid yarn was selected for fabricating the composites while PTFE was used as a solid lubricant to be incorporated on the surface. Table 1 shows an overview of the fabricated and testes variants.

Table 1: Fabricated and testes tribo-composite variants

No	name	Additive („solid lubricant “)		
		type	customary labelling	amount [g/cm²]
1	T_{A5}	PTFE	830/5+10 mm, opened	0,615
2	T_{B2}	PTFE	830/15+20 mm, opened	1,54
3	T_{C5}	PTFE	815/5 mm, opened	1,54
4	T_{D5}	PTFE	803/10 mm, opened	1,54
5	T_{F5}	PTFE	851/5 mm, natural, bundled	1,54
6	T_{E6}	PTFE long fibre	Type FG12 natural	0,615
7	T_{W2}	PTFE wool	803/60	0,923
8	T_{W3}	PTFE wool	803/60	1,23
9	T_{W4}	PTFE wool	803/60	1,54
10	T_{W5}	PTFE wool	803/60	1,54*
11	$T_{W5/5}$	PTFE wool	803/60	1,54
12	G_5	graphite	---	1,54
13	M_5	molybdenum sulphite	OKS 100**	1,54
14	T_{P5}	PTFE powder	Du Pont	1,54

The manufacturing of composites made of commingled hybrid yarn consisting of reinforcing carbon fibres and high-temperature PEEK matrix is performed using a HT-autoclave (Fig. 1 and 2) or a HT-press. Thermoplastic composite material components with maximum dimensions up to a length of 3.5 m and a diameter of 1.5 m can be realised with these technologies at the ILK. Commingled hybrid yarns have a high potential for a homogeneous distribution of reinforcement and matrix filaments over the yarn cross section [5]. The desired ratio of fibre to matrix can be achieved by variation of the number of yarns during the hybrid yarn production. Uni-directional and bi-directional carbon fibre reinforced PEEK composite specimens were fabricated from commingled yarn with Torayca T300 J fibres.

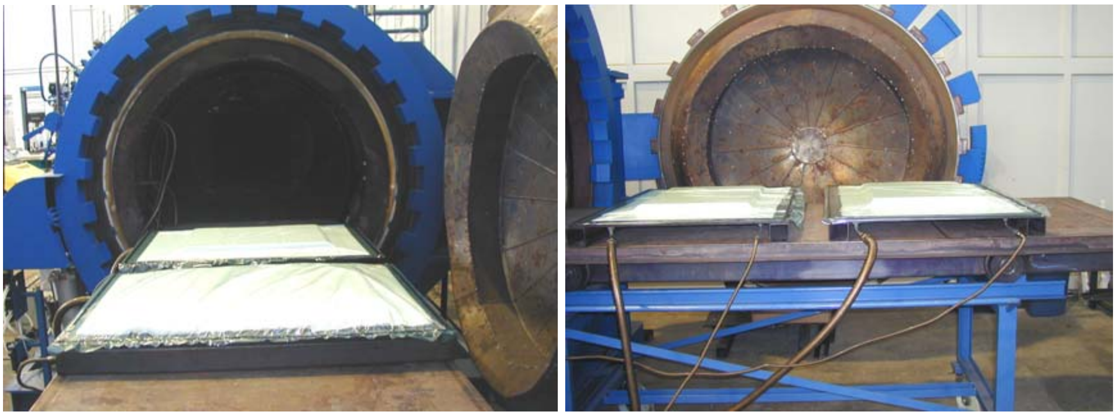

Fig. 2: Figure 1: High temperature autoclave

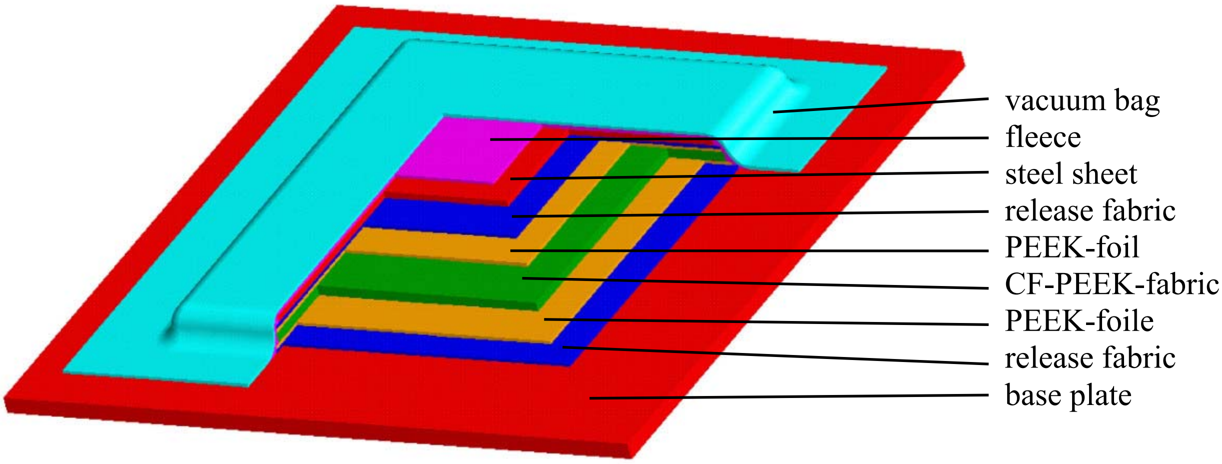

Fig. 3: Lay-up for autoclave process

4. MECHANICAL CHARACTERISATION

For the investigated bearing materials, the carbon fibre reinforced PEEK is applied especially in the form of multi-axial reinforced textile composite, where the single layer is reinforced with uni-directional rovings or with bi- and multi-directional fabrics. To fully exhaust the high potential for high-performance bearings of textile reinforced composites, it is essential to arrange the textile reinforcement of the single layers according to the occurring main stresses. Therefore a broad knowledge of the structural mechanical interconnections and the basic anisotropic material behaviour is required at first. To characterise the property profile of anisotropic textile reinforced composites, the basic thermo-mechanical material data of the single layers are determined in material adapted test methods. Further failure coefficients, which are needed for the application of novel failure criteria, have to be determined in special testing techniques. The experimentally measured material data are the basis for the calculation of the so called material specific characteristic functions, which characterise the anisotropic property profile of textile reinforced plastics.

Within the presented investigations, the material behaviour of single-layered carbon textile reinforced thermoplastics like PEEK were characterized in uni- and multi-axial tests.

The basic characteristic values of PEEK-CF and PA-CF at room temperature are compared in Table 2 with the values of carbon fibre reinforced epoxy resin. In Fig. 4 the material specific characteristic functions of UD fibre reinforced PEEK are illustrated in polar diagrams.

Table 2: Experimentally determined characteristic material data

	E_1 [GPa]	E_2 [GPa]	ν_{12}	G_{12} [GPa]	σ_{f1} [MPa]	σ_{f2} [MPa]	τ_{f12} [MPa]	ε_{f1} [%]
PEEK-HTA (UD-layup)	138	11,3	0,24	8,6	1388	87	-	0,98
PEEK-HTA (BD-woven fabric)	66	-	0,036	8,0	343	-	-	0,7
PA-HTA (UD-winding)	-	-	-	-	-	10,9	33,9	-
EP-HTA (UD-winding)	135	8,2	0,29	4,5	1620	60	70	1,1
EP-HTA (BD-woven fabric)	72	-	0,033	3,9	812	-	97	-

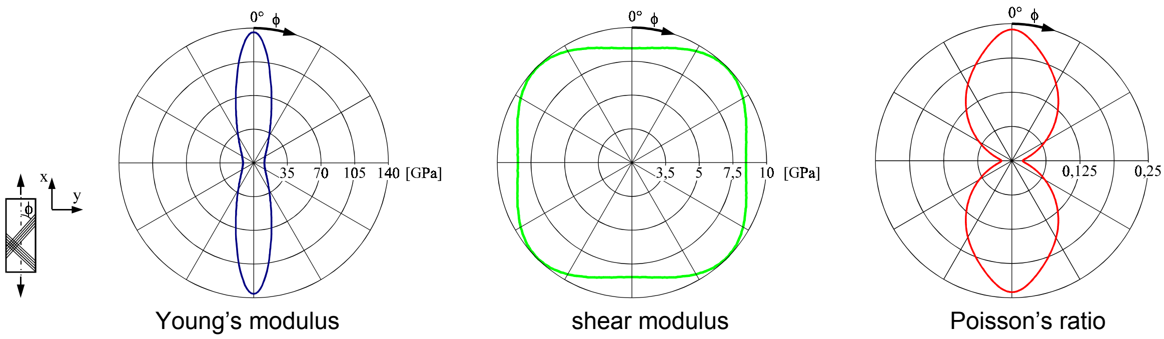

Fig. 4: Directional elastic material data of UD-PEEK-HTA

5. SLIDING TESTS ON FABRICATED CARBON FIBRE REINFROCED PEEK

Within experimental studies at the Industrial Tribology Machine Dynamics and Maintenance Engineering Centre (ITMMEC) and the Institut für Leichtbau und Kunststofftechnik (ILK) the friction and wear performance of the fabricated composites with and without PTFE surface were evaluated in the adhesive wear mode to investigate extent of enhancement in properties. Afterwards performance analysis, failure studies and worn surface analysis were carried out to enrich the understanding of mechanisms. This investigations enable to the formulation and tribo-performance evaluation of bearings under wide range of operating conditions.

At the tribology laboratory of ILK (Fig. 5) selected tribological tests like pin to disc and block to disc tests were performed on the fabricated material. Within the tests the friction and wear behaviour of the fabricated material depending on different operating conditions were investigated. Further tests in reciprocating and abrasive wear modes will be performed at the Indian institute.

Fig. 5: Tribology laboratory

To determine the friction and wear rate of the modified CF-PEEK composites the tribology test stand was adapted according to DIN 50 322 bzw. der DIN ISO 7148 (Fig. 6) with following parameters:

Friction partner	ring from steel 100Cr6	
	hardened und annealed HRC 59 ± 1	
	grided contact surface R_a = 0,2 ... 0,3 µm	
Specimen	modified CF-PEEK with PTFE	
	relativ velocity:	v = 0,5 m/s
	normal load:	incrementally F = 50...250 N
	temperature:	T_P = 23 °C
	loading time:	t_B = 100 h

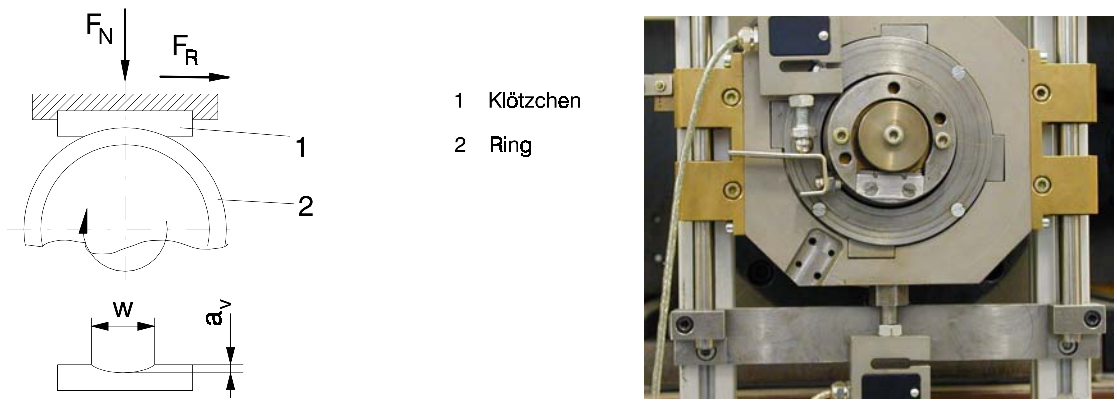

Fig. 6: Pin-Ring testing facility

Fig. 7 shows first results of tribology tests on one selected CF-PEEK composite for different material orientations. The material shows a clear influence of the fibre orientation on the wear behaviour, where the 45° fibre orientation results in the lowest coefficient of frition.

Further results will be presented in the lecture.

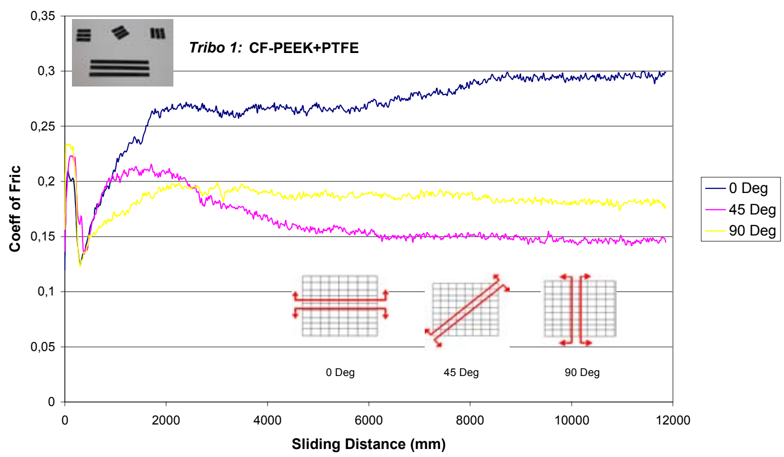

Fig. 7: Tribological behaviour of CF-PEEK with PTFE powder in dependence of the fibre orientation

6. CONCLUSION

It was concluded from the investigations that the inclusion of PTFE in carbon fibre PEEK composites definitely and significantly improve the tribological performance of the material. The blended composites did not show any scuffing problems.

The investigation demonstrates that modified carbon fibre reinforced PEEK with textile fibre architecture is a very interesting material for tribological applications at harsh conditions. Currently, within the cooperation of ITMMEC and ILK sliding bearings for complex applications are designed and tested.

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