Polymer Composites in sliding bearing applications
Contributions to sustainable construction and future opportunities

By Peter Bakker, Trelleborg Sealing Solutions (UK)

Abstract

Composites for sliding bearing applications have a history of over 60 years, yet these products are often perceived as new and unknown. This can be a barrier to promoting the wider use of composites and to benefitting from their advantages in sustainable construction, protection of the environment and renewable energy.

This paper highlights features of polymer composite materials consisting of woven fabrics for reinforcement, impregnated with thermo set resins such as, polyester, phenol or epoxy as a matrix, and with solid lubricants mixed into the composite for enhanced friction properties and wear resistance.

A selection of applications illustrate the benefits achievable in offshore equipment such as pipe lay towers and heavy lift cranes, civil engineering of bridges and sluices, ship’s propulsion systems, hydro turbines and sea current power generators.

Tribological aspects will be covered, such as low impact on the environment through operation in water without grease or oil. High durability is considered; there is no degradation over time whether exposed to marine environments or submerged in water. Also load capabilities compare to or even exceed conventional metal bearings.

The load capability of composite bearings comes with peculiar characteristics of elasticity. For example, non-linear behaviour at low load turns them progressively stiffer as higher stresses are applied. A set of engineering rules specifically for these materials has therefore been developed by the industry, often based on field testing.

Key properties do not fit within conventional standards for testing that are based on metallic bearings. The future of these materials would benefit from research to clearly define material properties and standards of testing. The paper concludes with a few indications on what these standards may include.

The paper deals with a range of composite materials, not limited to the resin systems applied in Orkot®. Though the practical examples are about Orkot® material, the paper aims to address general issues, such as lack of standards.

Keywords polymer composites; sliding bearings

1 Introduction

The use of polymer composites for sliding bearings in large structures goes back to the middle of the 20th century. Fabric of made of natural fibre, such as cotton, was impregnated with a phenol resin as the matrix. Chopped asbestos fibres were added for strength. The restrictions to the use of asbestos lead to new materials being introduced in the early 1980's in the US and Europe. Since then these asbestos-free products have seen a growing interest by various industries and now have proven track records in particular in applications requiring grease-free operation for protection of the environment. Industries active in environmentally sensitive areas notably hydro power, ocean power, offshore oil & gas and shipping are scaling-up the size of the equipment deployed, thus demanding ever larger sizes of bearings. The bearings have to operate with low friction, be maintenance free and with increasing service life expectations.

Within the context of the SCAD 2013 conference, the technical requirements can be summarised as follows:

- Suitable for use in sea water, rivers, lakes, fully submerged to any depth, in the splashing zone or in the air
- Withstand temperature changes
- Withstand ozone and UV radiation
- Not pose any risk to marine life.
- Available in any size from 25 millimetres up to tens of metres in diameter or flat length
- High load capability comparable to metal bearings
- High resistance to fatigue and creep
- Durable with no chemical degradation for 40 years,100 years for civil engineering
- Low friction without oil or grease.

2 - Fabric reinforced polymer composites main features

Polymer composites are composites using a *thermoset* resin typically polyester, epoxy or phenol as the matrix and have a proven service track record. The reinforcement is a fabric, woven with the threads at a 90 degrees angle (cross ply). For marine applications the fabric is made from synthetic, non absorbing fibres typically polyester. S*olid* lubricants typically polytetrafluoroethylene (PTFE) and MoS_2 micro powders are added to the matrix before curing.

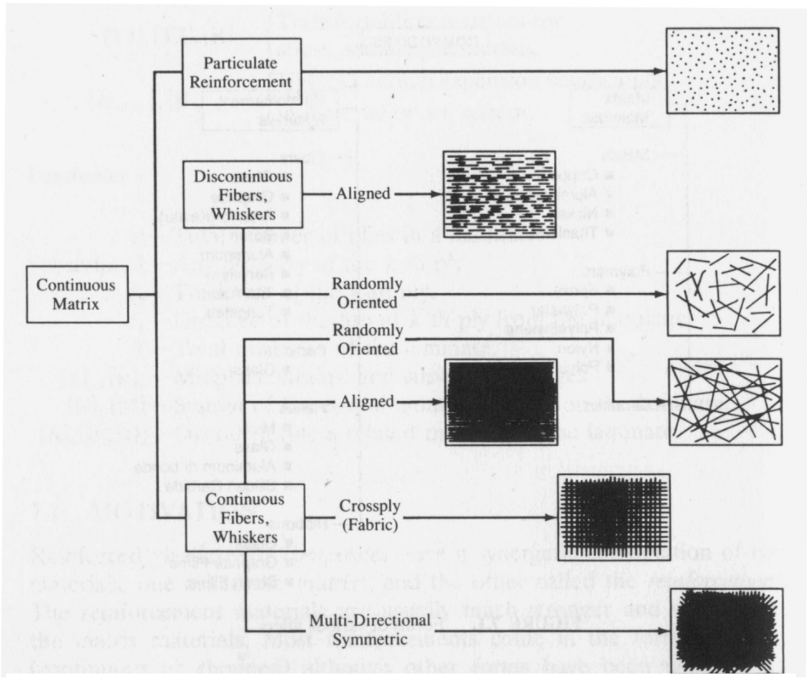


Figure 1 - Reinforced plastics as per Krishnamachari [1]

2.1- Fabric reinforced polymer composites key features, mechanical strength

Prior to curing the fabric and matrix are brought together in a process called wrapping. At the curing, the resin forms chemical bonds turning it into a solid. Contrary to thermoplastic resins, the solidification process of a thermoset is irreversible and makes it durable and resistant to creep. The wrapping process allows for large sizes to be produced though limited in shape; the product has a laminated structure of layers of reinforcement and is therefore either cylindrical or flat in shape. Using the same matrix all the way through one can produce sandwich-type constructions using different fabrics, tailored to stiffness and sliding properties required.

The product is designed to be applied with the *principal load direction perpendicular to the laminate.* The threads are used for reinforcement *not in the direction of the principal load* but in an indirect way and from the undulated shape in the weave, it takes a certain level of compressive strain in the composite for the threads to become stretched and active as reinforcement.

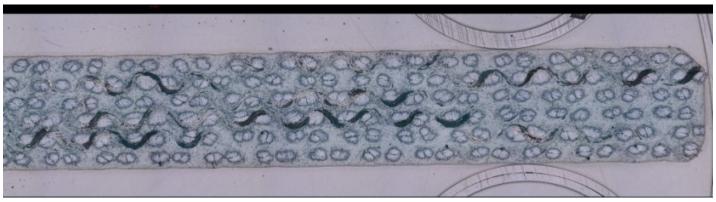


Figure 2 Cross section of Orkot® composite, sample thickness 2.5 mm

Polymer composite bearings take loads comparable to traditional grease lubricated bronze bearings but are relatively elastic with a non-linear, low-modulus at the beginning of the stress/strain curve.

This feature can be put to good use as large steel structures often require bearings capable of adapting to shaft bending and misalignment.

Misalignment from elastic deflection of structural components may also cause edge load statically or dynamically.

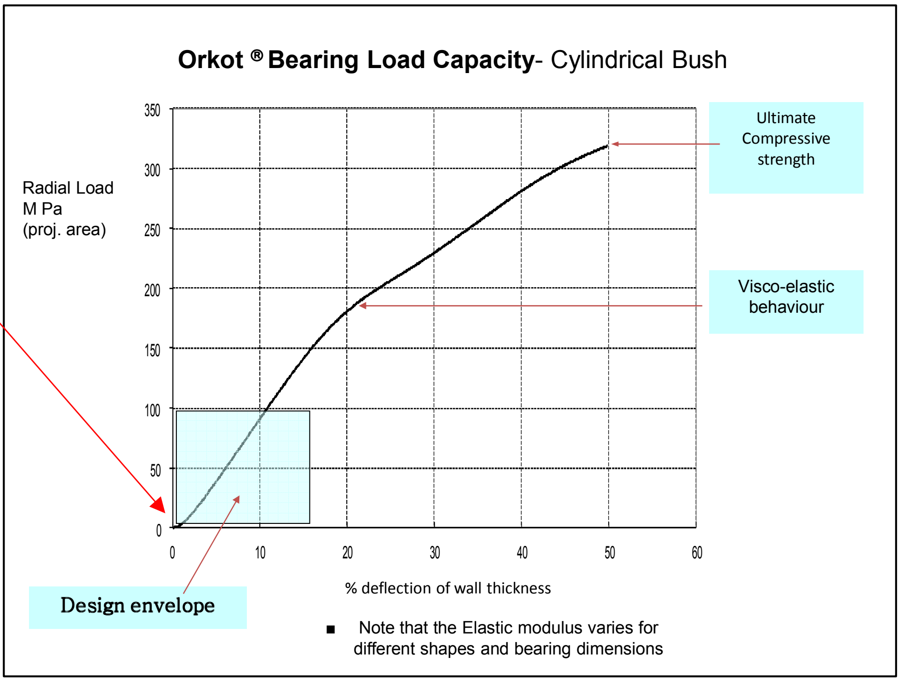


Figure 3 Typical load/ deflection curve of Orkot® composite, Trelleborg Product Information- Hydro Engineering Manual

Bearings capable of self alignment can be significant costs savers at first installation and in maintenance. Polymer composites are tolerant to edge loads though too much elasticity is to be avoided. Once the matrix and reinforcement is decided, the stiffness is further controlled by the bearing thickness and bearing manufacturers will provide recommendations tailored to the applicable load conditions.

2.2 - Fabric reinforced polymer composites key features, friction and wear

The friction and wear properties vary as manufacturers select resins and fillers. Commonly used fillers for marine and hydro applications are MoS_2 and PTFE. The effectiveness of these lubricants can still vary amongst the various brands. Manufacturers issue technical data sheet on coefficients of friction at specified test conditions but seldom do these relate to the application the designer is dealing with.

Also there’s the aspect of friction heat. Inherent to the properties of the matrix the composites have little capacity of storing and dissipating friction heat. Polymer bearings are, in this respect distinctively different from metallic bearings. With polymer composites the friction heat generated is stored in the counter face i.e. shaft and dissipated from there to the surrounding structure. Therefore the admissible P x V in continuous movement of these materials depends on the construction in which they are used. The presence of water as a coolant has a major influence. This complicates the assessment of polymer composites in terms of the friction losses to be expected in operation and more over, what service life to predict.

Several industries and OEM’s with a vested interest in the use of these materials have derived their own set of engineering guide lines based on empirical testing either in a full scale installation or by simulation in a test installation, as close as is feasible to the real situation. Many of these are proprietary documents though some test results have been published, such as, results of tests conducted at the Soete Laboratories of Ghent University [2]. University of Lulea Sweden [3]. B. Moss at Dinorwig Power Station [4].

A summary of friction coefficients for various filled thermosets can be found in ‘Advanced Engineering Design’ [5]. Low friction by PTFE filled polymers is achieved by the low shear strength of PTFE and the transfer of PTFE from the bearing to the counter surface. Friction coefficients can range from 0.20 at light loads down to 0.03 as load increases, for the temperature range up to 100 °C.

The feature of a falling friction coefficient as load increases is actually contrary to what happens in grease or oil lubricated bearings. One can take advantage of this in safety critical applications, as it ensures continuation of movement with low friction under extreme conditions with no risk of bearing seizure.

Polymers filled with solid lubricants feature the ‘availability of lubricant on every square millimetre’, where grease lubrication requires a certain amount of sliding movement to carry the lubricant into the loaded area.

Combined with its high mechanical strength, this makes polymer composites stand-out in applications of high and permanent load conditions where the movement is slow, irregular in time and when low friction is required when there’s only minimal movement.

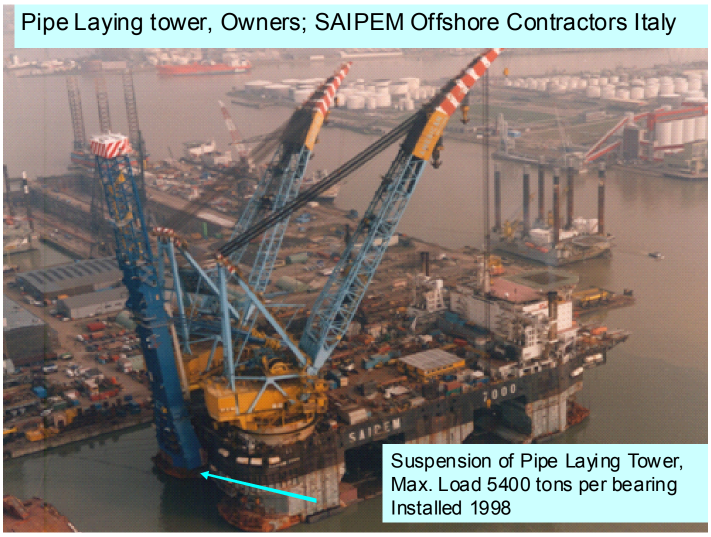
3 - Examples of applications of polymer composites with a long service history

Ship's steering and stabilising systems
The material selection and allowable wear in this application is decided by the globally operating ships classification societies and polymer bearings have a long track record in these systems. Asbestos-free polymer composites are fitted to the majority of all modern ocean going commercial ships with service intervals of 15 years and beyond. The classification societies also allow double the load capacity compared to bronze, which means ship's designers achieve costs savings at new build. There are also fuel savings for the operator, as the rudder has less resistance when the ship is on course.

Image courtesy Qatar Gas Transport Co.
LNG carrier fitted with seawater lubricated
Orkot composite rudder bearings

Heavy Lift applications on the Offshore Oil & Gas industry
The first high load (80 M Pa) applications for polymer composites were in 1994 and since then the bearings have demonstrated stable mechanical and tribological properties.

Pipe Laying tower, Owners; SAIPEM Offshore Contractors Italy

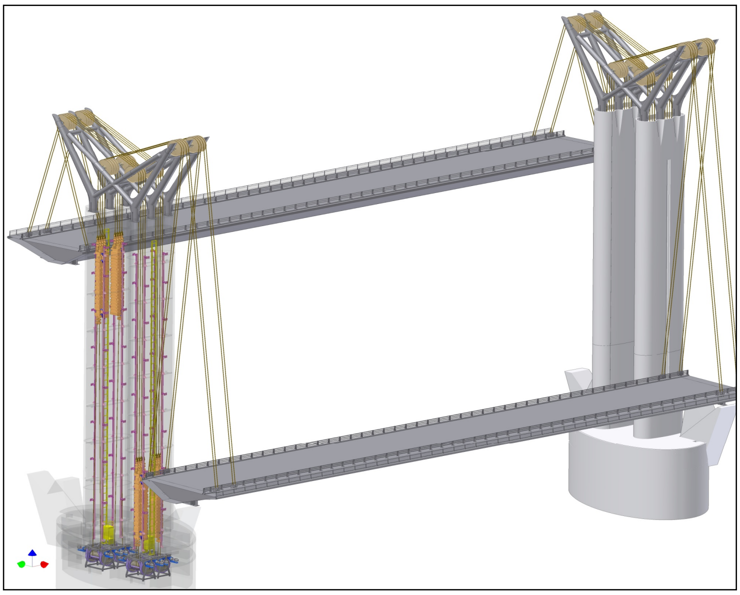


Suspension of Pipe Laying Tower,
Max. Load 5400 tons per bearing
Installed 1998

Image; Pipe laying tower, 135 metres tall with a deadweight 2400 tons, added in 1998 to the existing crane barge to enhance it's operational capabilities in offshore construction and pipe laying. The bearings passed their 10-year examination in 2008 and were declared 'fit for purpose'.

Offshore anchoring of oil rigs and floating objects
Bearings operate permanently submerged, connecting anchor chains to one another and to the anchor. They are under continuous load and subject to small movements.

Applications in civil engineering
Maintenance-free, self lubricating composite bearings fitted on the rope pulleys carrying the counterweights on this suspension bridge, are under permanent load combined with minimal but ongoing movements while traffic introduces movement and vibrations on deck level.



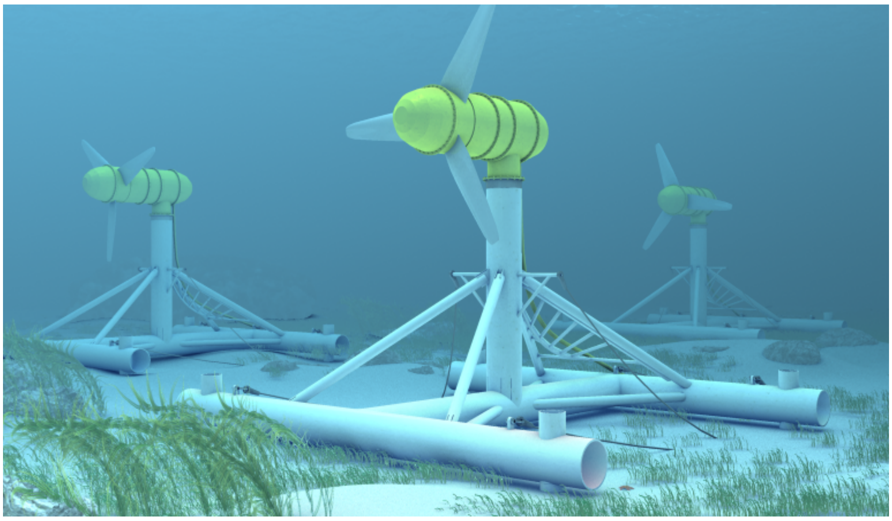
Courtesy Eiffel France and city of Rouan.

Applications in Hydro Turbines

Polymer composite bearings were introduced into hydro power turbines to fulfil the demand for grease-free bearings to stop pollution of downstream water. Since the early 90's, hundreds of existing power plants have been upgraded in the US, Canada, Europe and South America. New plants, for example, in Asia and Africa, are routinely fitted with polymer composite bearings right from the start.

Image courtesy Alstom Hydro
Upper casing of a Francis turbine for Three Gorges China, 700 MW at 70 rpm. Orkot bearings fitted to the guide vanes and control mechanism.
Commissioned 2005

New developments in renewable energy



Artist impression courtesy Voith Hydro

Water lubricated polymer composites are fitted in ocean power generation. These are hydrodynamically operated bearings and reference is taken from design and service experience gained in propeller shaft bearings for commercial and military ships, where these materials have been used for over 30 years.

4 – Conclusion

Polymer composite bearings can bring substantial contributions to longevity of constructions exposed to severe climate conditions. Also, they contribute to protecting the environment. Both aspects are amply covered by proven track records in a variety of industries.

There is however a challenge, as the wider use of polymer composite bearings depends on building confidence amongst designers, end-users and supervising authorities. This would be helped greatly by establishing design standards, not only those carefully kept and guarded by a few specialist companies, but standards readily accessible to the mechanical engineering society.

The use of woven fabric reinforcement made of low-modulus yarns causes these materials to be non-linear in their elastic properties. Also, referring to the load/deflection chart, fig. 3, it can be seen that the suitability of the material cannot be judged on the ultimate compressive strength alone. Additional information such as the recommended design envelope and a submission of system stiffness by the manufacturer are needed.

Trelleborg Sealing Solutions has, for many years, established a standard sample shape and size used to monitor the consistency of material properties over daily production as well as over dozens of years of manufacturing. Using such a standard across the industry will allow for a like-for-like comparison of material stiffness and strength as can be seen for many years with metals.

The author calls upon the international engineering community to establish engineering standards or codes of practice for the use of polymer composites. Trelleborg is committed to progress in this field and welcomes any initiative that may come from this conference.

The author

Peter Bakker is a bearing specialist and Product Line Director at Trelleborg Sealing Solutions. He is based at the Trelleborg manufacturing facility in Rotherham, England, where Orkot® polymer bearings are produced. With a background in mechanical engineering, he joined the company in 1992. His responsibilities include technical advice to users, including tribological and strength aspects of Orkot® Composite Bearings as part of Trelleborg global operations.

References
[1] Krishnamachari S.I. Applied Stress Analysis of Plastics 349 VNR New York, 1993

[2] Van Paepegem, W. and Samyn, P. Large scale evaluation of constrained bearing elements made of thermoset polyester and polyester fabric reinforcement, ASME, Journal of Tribology 2006

[3] Ukonsaari,J. Lulea University of Technology. An oscillating steel shaft loaded on lubricated journal bearings with water and an environmentally adapted lubricant, 22nd IAHR Symposium on hydraulic machinery and systems, 2004 Stockholm-Sweden

[4] Moss, W.O. and B. Hatem, First Hydro UK. Testing greaseless bearings in service. HRW March 2000

[5] Van Beek, A. Advanced Engineering Design 251-254 TU Delft, 2009