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Development and testing of PTFE based Composite Bearing Material for Turbine Pump

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Abstract - In Vertical submerged turbine pumps the long shafts are supported at intervals by transmission bearings. The radial load acting on shaft is taken care by the intermediate bearings. These transmission bearings are lubricated by the flowing liquid through pump. During starting as water level is below line shaft bearing it requires prepublication before start. Selection of the bearing material becomes critical in situations where we don't have pre lubrication water available. Also remote start and stop is difficult. In this scenario pump runs dry during initial start. Our aim is to develop bearing which will take care of dry running. When pumped water is sea water / raw water containing sand/abrasive particles then line shaft sleeve bearing should withstand against wear.

To cater the problems in conventional bearings and to find the appropriate bearing material focus is given on latest trends & Tribological developments in the world. Different PTFE based composite bearing. In this study, composite materials were comparatively investigated under actual load and sliding velocities by using in a Pump. The influence of inorganic fillers MoS2, on the wear of the glass & bronze fabric reinforced epoxy composites under dry & wet running conditions has been checked.

Bronze filled PTFE bearing are found excellent and will serve as an alternative to conventional bearings.

Index Terms— PTFE, Composite bearings, fillers, Vertical turbine pump.

I. INTRODUCTION

In recent times there has been a remarkable growth in the large scale production of fiber and fiber reinforced epoxy matrix composites because of their remarkable properties. These are used in structural applications as in aerospace, automotive and chemical industry on account of their good combination of properties. Fibers reinforced polymer composites are used for producing number of mechanical components such as gears, cams, wheels, brakes, clutches, bush bearing and seals. Considerable efforts are being made to extend the range of applications. Such use would provide economical and functional benefits to both manufacturers and consumers. Various researchers have studied the Tribological behavior of PTFE. Studies have been conducted with various shapes, sizes, types and compositions of fibers in a number of matrices. In general these materials exhibit lower wear and friction when compared to pure polymers. An understanding of the friction and wear mechanisms would aid in the development of a new class of materials so as to counter the challenges faced by Pump Industries.

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Micro friction studies guide us to understand how the composite material behaves and translate lubrication through shear layer phenomenon. The nanotechnology helps us to decide the behavior of composite material under various operating loads and applied condition. It guides us to decide the limiting operating conditions and properties to improve for particular application. Study of physical properties of composite is also a challenging job for a designer.

II. NEED OF COMPOSITE BEARING IN VERTICAL TURBINE PUMP

In vertical turbine/submersible pumps the impeller is submerged in to water. The rotation to the impeller / impeller shaft is given by the motor which is mounted on the ground floor. To connect the driving shaft to impeller shaft we require intermediate shafts to transfer power from motor to impeller shaft. The length of the intermediate shafts changes from site to site condition depending upon the water level. Thus pump length changes from 3m to 50 m long depending upon the water table in the earth. So we require connecting no of intermediate shaft to connect the both driving and impeller shaft. Due to manufacturing constraint and the operating critical speed of the shaft we require supporting the shaft in between at different span with the help of sleeve bearings. Also initially the bearings above water level require pre lubrication / dry running capability to carry away generated heat. If the pump is used with rubber bearing with clear potable water during starting we need to give pre lubrication to rubber bearing. If pumps are under frequent start and stop due to requirement of water demand and sometimes due to power cut it is difficult to supply pre lubrication to line shaft bearing during each startup. This is true as rubber has no dry running capability so needs water lubrication all the time. PTFE based composites due to its inherent capability of formation of share film phenomenon it can withstand dry running for 1 to 2 minutes till water is delivered by pump to bearings. To cater the problems in conventional bearings latest technology on development of PTFE based composite material which will work in dry and wet condition. Different types of fillers that improve tribological properties of PTFE. Self lubricating bearing material used in presence of lubricating and at normal operation condition will definitely lead the conventional bearings in terms of performance and life.

III. MICRO STUDIES FOR COMPOSITE MATERIAL

Micro friction studies guide us to understand how the composite material behaves and translate lubrication through shear layer phenomenon. PTFE means a Hydrocarbon compound with ethylene as base Polymerization of a simple polymer such as PE (Polyethylene) uses a single monomer (ethylene) and joins these together to form Polyethylene

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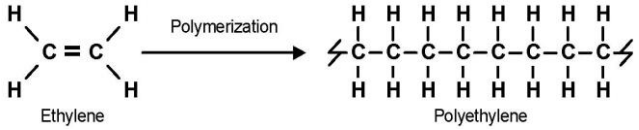
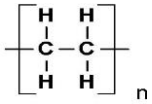
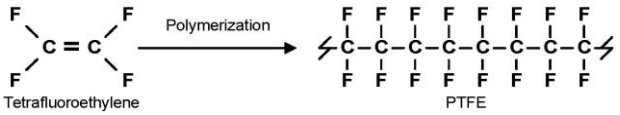
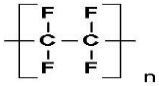


The polymer therefore consists of repeated units of:



and this is a 'shorthand' notation for the polymer structure. PTFE is also a homopolymer and the reaction to form PTFE from tetrafluoroethylene is and the repeated units are:





The extended chain structure is preferred structure when low friction and wear are desired.

The PTFE chain is very different, the fluorine atom is much larger than the hydrogen atom and as a result the chain is no longer flat it is forced into a spiral shape with the fluorine atoms packed tightly around the central C-C bonds. These fluorine atoms then provide a protective sheath for the weaker C-C bonds and the result is the exceptional chemical resistance property of PTFE.

In real life, the fluoro-polymers are highly resistant to chemicals and do not dissolve in most solvents. The only materials that will attack this range of materials are molten or dissolved alkali metals, such as sodium in liquid ammonia, which will extract fluorine from the molecule to leave a black (carbon) surface finish. In addition, at elevated temperature some fluoropolymers can be attacked by fluorine, some fluorine related compounds, alkali earth and alkali metal oxides and carbonates.

IV. COMPOSITE BEARING AND FILLERS

A composite consists of two or more dist materials than when combined creates a material that is stronger, tougher and more durable than the individual material. Polymer composite are fully molded materials. A base resin is blended with filler and then molded together under specific heat and pressure. The molding of blended resign allows the thermoplastic to flow around filler creating a fairly homogenous material.

There are several reasons for adding filler materials to polymers to make composites.

- To increase the polymer load carrying capacity.
- To help lower friction coefficient and wear rates.
- To increase the composites thermal conductivity.
- To increase dimensional stability.
- To take Dynamic stresses and tangential frictional stresses.

Following fillers are used to improve properties of PTFE based composite bearing.

Glass Fiber:- Glass in the form of short fibers is the most widely used filling material. The most popular compounds are 15% or 25% glass (by weight). It is sometimes combined with graphite or MoS2. Glass has little effect on most of the electrical properties of Teflon. It resists acids and oxidation, but it can be attacked by alkali.

Carbon:-Typical carbon filler is high-purity coke powder. It is often used in combination with graphite in concentrations of 25% to 35% by weight. Compounds of Teflon and carbon have excellent wear resistance, both dry and in water. They are compatible with most chemicals and can carry heavy loads under rubbing contact.

Graphite: - This crystalline form of carbon is used alone or in combination with glass or amorphous carbon. A typical compound is 15% graphite by weight. Addition of graphite helps to reduce the wear of soft metal mating parts and improves frictional and wear properties when mixed with other fillers. Like other forms of carbon, it serves well in corrosive environments.

Bronze: - Round or irregularly shaped bronze particles are often used at 60% by weight or 55% with 5% MoS2. Compounds of bronze and Teflon are creep resistant and easily machined. They deliver good wear performance, low friction and relatively high thermal conductivity.

MoS2:- MoS2 used in concentrations of approximately 5% by weight in compounds with glass or bronze. MoS2 can increase surface hardness and lower coefficient of friction and wear rate. Molybdenum disulphide adds to the hardness and stiffness of polymer and reduces friction. It has little effect on its electrical properties. It is quite non reactive chemically and dissolves only in strong oxidizing acids. It is normally used in low percentage and together with other fillers. Compounds containing molybdenum disulphide need special attention during performance and sintering.

V. DESIGN CONSIDERATIONS FOR SLEEVE BEARINGS

Following are the factors to be considered while designing the plain sleeve bearing.

1) Wear rate
2) Friction coefficient
3) Operating pressure
4) Load and velocity
5) Temperature

We will consider the effect of above factors on PTFE filled composite bearings.

Wear rate: The wear resistance of PTFE is generally increased by the incorporation of fillers. Resistance to compressive loads increases with addition of fillers but impact resistance reduces. An optimum percentage of filler which will improve wear performance without seriously modifying the mechanical properties of the bearings. The fillers can be added from 25% to 40 % by volume are used. The prediction of wear properties is an extremely difficult task and one can provide only general guideline. Attempts to specify the performance by specifying K factor based on PV values only give the idea of performance of bearing.

Friction Coefficient: Many factors affect the coefficient of friction of journal bearing and one most important of this is bearing pressure. The effect of filler concentration and type of filler will decide the coefficient of friction. Generally the coefficient of friction for filled PTFE is in between 0.1 to 0.15.

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Operating Pressure: The load limit value represents the maximum static load that the bearing can support and from it the projected bearing area can be calculated. For dynamic condition bearing length can be decided to surface velocity and PV rating.

Load and Velocity: The influence of load and velocity on the wear and friction of bearing

Temperature: When the ambient temperature of the bearing is raised, the performance capability is reduced. For example, an increase in wear rate of approximate 5 times at 200 deg than measured at 25 deg. In order to retain bearing performance it is necessary to increase the bearing area. The useful temperature range for continuous use of TEFLON compound is extremely broad. Teflon is one of the few polymeric materials that can be used in a cryogenic environment. At upper end they can be used up to 260 deg. Thus at higher temperature the PV limit is lower.

VI. FACTORS AFFECTING POLYMER COMPOSITE WEAR AND TRANSFER

Load / Stresses: In order for a polymer composite to function as a solid body lubricant it must be able to support the load and the tangential stresses induced by sliding. It has been observed that there are two regimes of polymer film wear and composite wear dependent on load/stress. Essentially low loads to mild wear but high loads can cause wear. The sever wear regime is characterized by brittle fracture or severe plastic deformation. The mild wear regimes is characterized by the deformation of the Shear layer at the composite surface, the deformation of a thin transfer film and a delimitation type of wear process of the shear layer.

Contact Area: Contact area is important from two points of view. First the contact areas will determine the projected contact stresses. If the load cannot be reduced, one way of reducing stress is to increase the projected contact area; this lowers the stresses and promotes sliding in the mild regime of wear. However a large contact area and lower stresses can cause other problems.

The effect of contact area is on transfer film formation. If the area of contact becomes too large instead of the transfer flowing across the metallic counter face surface, it will have a tendency to build up the form ridges which can cause high localized stresses and higher adhesion. This will lead to higher friction and the severe wear. Thus it is important to design a part with correct match up of load and contact area.

Sliding Speed: The sliding speed can have a couple of effects on polymer composites. The high sliding speeds can produce high temperatures due to friction heating. This may cause the polymer or the polymer composite additives to degrade. However in some cases higher temperature might be beneficial to the lubricating process. It could help to have some molecular relaxation temperature which in turn could provide greater mobility to the polymer molecules.

As we know the polymer are composed of molecular chains. In order to develop a surface shear film and a transfer film, the molecular chain must have time to reorient. If one slides too fast over these un-oriented chains, instead of reorienting they will fracture, leading to the production of large wear particles and high wear. Thus it is important to choose sliding speed for each particular polymer to ensure the beat result.

Counter face Topography: The material counter face that slides against a polymer composite is very important in determining the friction and wear characteristics of that composite. If the counter face is too rough it can abrade the composite and not allow a shear film or transfer film to form. The effect of counter face material type and surface roughness on the wear rate and friction coefficient are noted as, the smoother the counter face the lower the wear rate. It is also found that over polishing tend to polish away the softer matrix material of the metal and hard particles protruding above the surface. The surface finish or material type did not initially affect the friction coefficient.

Temperature and Molecular Relaxations: Most polymers possess molecular relaxations at certain temperatures various molecular segments are freed up and give capability for movement. The transition temperature is the temperature above which the movement of main chain in the polymer obtains its greatest degree of freedom and thus the polymer obtains a great deal of plasticity above this temperature.

One method for determining the temperature at which relaxation occur in polymer is a technique called tensional braid analysis. The relaxation effects occur with PTFE. PTFE has a couple of relaxations that occur below ambient temperature. At lower temperature the friction and wear properties of PTFE are not as exceptional as they are at or above ambient temperature.

Temperature can affect the lubricating properties of the additives in polymer composite. Additives might desorbs gases at certain temperature or even decompose. Temperature can also affect bonding between the additives and the polymer matrix.

VII. MANUFACTURING OF BRONZE FILLED PTFE COMPOSITE BEARING

It has been observed that introduction of fillers could greatly change their tribological behavior. Such change on tribological behavior of the bulk composite material is directly related to the change of tribological properties of the corresponding transfer film formed during the friction process. Choosing exact combination and percentage of fillers is critical to know different behavioral and mechanical properties of composite bearing. Considering pump application and the properties of conventional rubber bearing we have chosen three different combinations of composite bearing material.

1] 35% glass filled PTFE.
2] 55% Bronze + 5% MoS2 + PTFE
3] 35% carbon filled PTFE

Glass filled PTFE bearings worn out by 0.2 mm as compare to 0.01mm in bronze filled PTFE. Glass filled PTFE bearing loses its hardness in case of dry running. Hardness decreases to 48 Shore D from 65 Shore D in case of these bearings. As compared to this for Bronze filled bearing hardness decreases with a marginal change to 64 from 65 shore D scale.

The material matrix breaks for glass filled PTFE. The matrix for bronze filled PTFE is stable and shows no wear. Carbon filled and glass filled bearings face fitment issues and dimensional stability is not good. Although coefficient of friction for glass filled and carbon filled PTFE is less due to dimensional stability and thermal stability bronze filled PTFE bearing works to be superior for mechanical performance.

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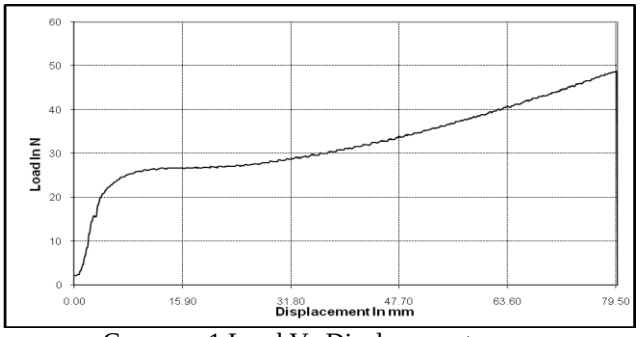
Different combinations of bronze filled PTFE are prepared and the specimen is tested for properties as below. Following is a sample report of testing of specimen. We have compared this strength and hardness with conventional rubber bearing for following blends and it seems to be well within range. From this report it is clear that the manufactured bearing blend is suitable for pump bearing operation. Properties are shown in table no.1.

Sr. No.	Type of blends	Tensile Strength	Elongation	Hardness	Sp Gravity
		PSI	%	Shore D	
1	40% Bronze Filled	2500	175	60±5	2.9 - 3.2
2	60% Bronze Filled	2000	140	65±5	3.8 - 4.0
3	55% Bronze+5% MoS2	1500	80	65±5	3.5 - 3.8

Table no. 1 Properties for Bronze filled Composite bearing



Curve no.1 Load Vs Displacement curve

For applied load we have tested the specimen of different combinations and checked the tensile strength and elongation of material with Tensometer as shown in curve no.1. The density of the blend was checked by checking the weight in air and checking the weight in water. Comparison will give us the density of blend. Hardness is measured with Shore D SCALE to ensure proper hardness.

Following steps are essential for manufacturing of composite sleeve bearing.

1] Weighting of Raw materials

2] Mixing of Composite Powders

3] Molding of composite powder in Press

4] Baking / Sintering of molded parts in Oven

5] Machining of Bearing and groove preparation

6] Inspection and testing for tensile strength.

Firstly, PTFE and the fillers were mixed mechanically. After mixing, the uniform mixture was pressed in a mold at 75 Kg/cm2 under room temperature for about 2 min to prepare cylindrical samples. After extruded from the mold, the samples were moved into an oven coupled with a temperature controller. The sintering process was carried out in the oven in atmosphere under a given temperature modulation procedure Plate no. 1 shows an electric motor driven mixer. This powder is mixed thoroughly for 30 min to form homogeneous mixture.

Plate no. 2 shows bronze filled barring after compaction. These bearings are then baked and machined to form required sleeve bearing shape.

Plate no.1 Motorized Mixer for blending powder

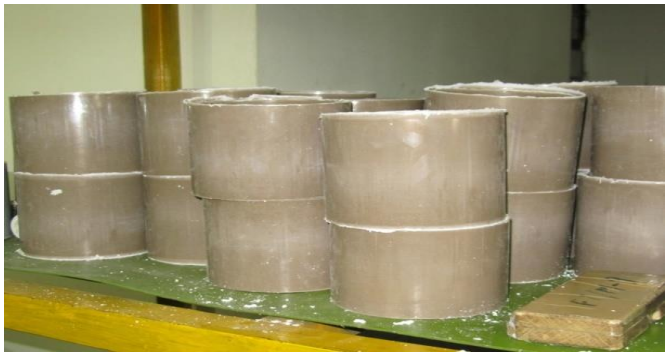


Plate no.2 Bronze filled PTFE bearing after compaction

VIII. TESTING OF VERTICAL TURBINE PUMP WITH PTFE BEARING

Experiment details

We have selected vertical turbine VT250 for trial testing of rubber and composite bearing. This pump had been already installed with rubber bearings and faced problem of bearing failure due to frequent start and stop. We have already changed the bearings twice in a year to restore the pump. Due to frequent start-stop, pre-lubrication supply for rubber bearings was every time not possible & leads to failure of rubber bearings due to dry running.

We have taken this as an opportunity to check performance of composite bearings to address and resolve bearing failure problem & check dry running capability of composite bearing.

Step 1:

We have decided to re-test the pump with existing rubber bearings to know the loss in efficiency & vibrations of the pump. Pump performance test readings with worn out rubber bearings are as follows. It is observed that loss of efficiency is almost 4% and vibrations are on higher side up to 4.5 mm/sec peak to peak, indicating the bearings and shaft sleeves are worn out.

Step 2:

Pump was fitted with new Bronze + MOS2 + PTFE bearings and new shaft sleeves. Performance testing with new bearings was carried out to know efficiency and mechanical running of pump. It is observed that increase in pump efficiency is around 4% and vibrations are normal up to 1.5 to 2.1 mm/sec. which well within limit.

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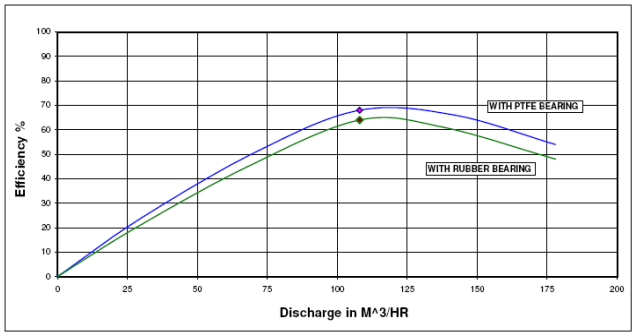
Step 3:

Pump was dismantled after 8 hours test and bearing condition for scoring marks were observed. It was decided to measure weight of bearing before test and after test to know loss of material due to wear. Following are the test report.

IX. TESTING RESULTS

1] After trials of different composite we have selected Bronze + MoS2 + PTFE as a sleeve bearing material for VT Pumps. The hardness of bearing with different % of bronze powder was checked. With 55% Bronze powder hardness of composite was found to be near to 65-70 shore D. Addition of Mos2 has improved the lubrication property of this composite blend. The coefficient of friction is also improved by addition of MoS2 leading to less friction and improved wear life for sleeve bearing.

2] We have compared the mechanical performance of VT pump with rubber and composite bearing. Results are as follows.



Curve no. 2 Comparison of pump efficiency with PTFE Composite & Rubber bearing

Curve No. 2 shows Mechanical efficiency has improved by 4 % due to change in bearing material and less frictional coefficient of friction for composite bearing as compare to rubber bearing. We have compare bearing wear by weight loss method. Table no 2 and 3 shows that wear rate is considerably less in composite sleeve bearings compare to rubber bearing.

For composite bearing

Weight of bearing before test	Weight of bearing after test	% loss of material.
636.73 gm	636.64 gm	0.00012

Table no. 2 Weight loss comparison for Composite bearing

For rubber bearing

Table no.3 Weight loss comparison for Rubber bearing

Weight of bearing before test	Weight of bearing after test	% loss of material.
640.15 gm	639.84 gm	0.00048

3] Composite bearing has passed the test of dry running for 40 sec which is most important for VT pump application. Normal rubber bearings required to pre-lubricate before pump start. This will increase man hours and requirement of lubrication water @ 30 lpm for 5 min before start. During this test no smoke or jamming of pump was observed. Pump was free and easy to rotate by hand after dry run test. During strip test we opened the pump to see any scoring marks and dimensional changes due to thermal expansion during dry running test. Following dimensions shows negligible change in dimension.

Table no 4 – Dimensions of bearing after dry running test

Dimension of bearing before test	Dimension of bearing after test	% Change.
50.24 mm	50.23 mm	Negligible

There are no significant scoring marks and dimensional change observed on composite bearing after 8 hours and dry running test.

4] Due to higher Pressure and Velocity rating of composite bearing the bearing life is improved by more than 3 times than rubber bearing. PV rating for composite bearing is in the range 10000 to 13000 psi-fpm.

5] Saving in Manufacturing cost Rubber bearings are mould in bronze shell as rubber cannot be fitted directly in housing due to its elasticity nature this leads to costly manufacturing process. As rubber bearing molding requires specialized dies cost towards development of dies is high. Machining and final surface finish requires grinding operation.

Composite bearings are easy to manufacture. Very few processes are required as compare to rubber bearing. Various compositions and properties can be easily achieved by addition fillers and changing matrix of composite. Die cost is less as compare to rubber as die do not come in contact with furnace. Machining is easy and surface finish can be achieved with conventional machines. Table no 5 shows the comparison of manufacturing cost for rubber and Bronze filled bearing.

Cost of Rubber bearing with shell	Cost of Bronze filled Composite bearing.
3000 Rs	2500 Rs

Table no. 5 Cost comparison for rubber & composite bearing

6] Saving in operational cost Due to use of composite bearing the life of bearing has improved considerably almost 3 times than normal rubber bearing. No pre-lubrication is required for the pump, saving water quantity and power required for lubrication of pump. Test pump is not opened for last 22750 hrs so there is saving in scheduled maintenance and cost of spare parts like sleeves and rubber bearing.

- Normal life of rubber bearing is observed nearly 8000 hours.
- Labor cost saving due to no maintenance for 5 years is equal to Rs 60,000.
- Cost of spares saved each year is Rs30, 000 so for five years saving is 1, 50,000.
- Total saving for five years of operation is approx. Rs 2, 10, 000.
- Considering cost of composite bearing payback period is hardly 16 month.

Dry running test: Dry running test was conducted by closing the suction valve and allowing pump to run dry for 40 sec. During this test no smoke or jamming of pump was observed. Pump was free and easy to rotate by hand after dry run test.

During strip test we open the pump to see any scoring marks and dimensional changes due to thermal expansion during dry run test. Following dimension.

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Table no. 6 Dimensional comparison

Dimension of bearing before test	Dimension of bearing after test	% Change.
50.24 mm	50.23 mm	Negligible

X. CONCLUSION

From above results it is observed that fillers Bronze and MoS2 combined with PTFE provide excellent bearing properties. 55% Bronze + 5% Mos2 + 40% PTFE is suitable for pump application. Other combinations can be used for higher loads and big size pumps. As these bearings hardness is near to rubber bearing, PV rating higher than rubber bearing this bearing life will be more which is validated by performance test of pump. The influence of inorganic filler MoS2, on the wear of the bronze fabric reinforced epoxy composites under dry & wet running conditions has proven best results. It was observed that the dimensional stability is more in case of Bronze filled PTFE & lower coefficient of friction due to influence of MoS2. With above analysis we have recommended Bronze filled PTFE for actual use of bearing in VT pumps.

Future scope:

Bronze filled Composite bearing are now proven for clear water. These bearings show remarkable life with clear water. These bearings can be used in different pump applications and loads. Following are the scope for future work,

- These bearings need to be tested for different liquid with abrasive environment
- For sea environment need to find exact composite bearing which will take care of sand particles and also suit for resistance against corrosive environment.
- Composite bearings which are made of PTFE have a unique property of dry running. These bearings need to be tested for different temperature which will decide the working range for liquid operation.
- Resonance of these bearings needs to be analyzed for limiting the operating speed of pumps

REFERENCES

[1] A. J. Stepanoff, John Wiley and Sons "Centrifugal and Axial flow pumps" - Theory, Design & Application - 2nd edition 1957.

[2] Stephen Lazarkiewicz and Adam T. Troskolanski, Pergamon Press Ltd. - "Impeller pumps" - 1st edition 1965.

[3] Val S. Lobanoff and Robert R. Ross, Gulf publishing Company - "Centrifugal Pumps design and application" - 2nd editions 1995.

[4] Robert L. Fusaro & team from NASA - "Self lubricated Polymer Composite and Polymer transfer film lubrication" - 1st edition 1990

[5] B. Suresha & Team - Journals of Minerals & Material Characterization & Engineering USA "The role of fillers on Friction and Slide Wear Characteristics in Composite System"

[6] Yanchun Han & team – "Micro friction studies of filled PPS / PTFE composite blends"

[7] Mr. Seiji Yamajo and Mr. Fumitaka Kikkaw - "Development and Application of PTFE Compound Bearings" dynamic positioning conference, by - 1st edition 2004

[8] Yunxia Wang and Fengyuan Yan - "Tribological properties of transfer films of PTFE-based composites" named paper published in science direct 1-st edition 2006

[9] H.Bongers - "The dynamics of rubber bearings" 1st edition 2000

[10] Augusto E. Barton Martinelli - "Rubber bearings for precision positioning systems" by - 1st edition 2005

[11] Keith Laskey, PhD, Thordon Bearings, "Non-metallic pump bearings" by 1st edition 2008

[12] J. Bijwe, - "Wear failures of reinforced polymers, in: Failure Analysis and Prevention" by vol. 11, ASM Handbook, ASM International, OH, USA, 2002

[13] K. Friedrich - "Wear models for multiphase materials and synergistic effects in polymeric hybrid composite, in: Advances in Composite Tribology, Composites Materials" 1993

[14] K. Friedrich, J. Mater. - "Fretting fatigue failure of polyester resin and its glass fiber mat composites", Sci. 21 (1986) 1700-1706.

[15] P. Rehbein, J. Wallaschek,- "Friction and wear behavior of polymer/ steel and alumina/alumina under high frequency fretting conditions, Wear" 216 (1998) 97-105.

[16] J. Bijwe, S.K. Sharma - "Wear studies on solid lubricated polyimide composite, in: Proc. of the LAWPSP Sym"., IIT Mumbai

[17] Kirloskar Brothers Limited - "Rotodynamic Pumps" Published in 2001

[18] web: http://pump-magazine.com

[19] American standard for vertical turbine pumps – "ANSI B58.1-1971 (AWWA-E-101-71)"

[20] American Petroleum Institute " API 610 – ISO 13709: 2009 (E)

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