A REVIEW ON WATER LUBRICATION OF POLYMERS

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Abstract: Water lubrication for polymers which is an economical solution has not been completely reviewed from the qualitative perspective. A comparative study on water lubrication of polymers helps to understand the fundamental aspects of tribology relevant to the different applications. The use of water as a lubricating material has been effective after the development of phenolic resins, further to which the advancements in thermoplastics has increased the water lubrication to a greater extent. Most of the researches on water lubrication of polymers reported a positive frictional character and uncertain wear behavior on comparing with air and oil lubrication. From the existing literature in polymer tribology with different parameters such as contact pressure, velocity and composition of materials there is a lack of knowledge in understanding the mechanism involved during the wear process for water lubrication. Moreover, connection between the mechanical properties of polymer under wet condition relating to the water lubricated polymers could give appropriate results of tribological behavior. Exploring the tribo-mechanical characteristic in wet condition aids to choose appropriate material for water lubricated applications.

Key words: Water lubrication, polymers, wear mechanism

1 INTRODUCTION

Simple design and life time operation for tribological consideration has lead to an extensive replacement of metals with polymers in wide range of applications. Equipments and parts made of steels in aqueous environment are susceptible to corrosion. Such intricacy can be eliminated by using polymers and its composites in place of steel. Characteristics such as high shock absorbance and resistant to corrosion has made polymers to enter the engineering industry. Moreover, the material properties in polymers can be altered as per the requirement for corresponding application by using fillers, additives and fibers. Polymer composites substitute metal by having properties like corrosion resistance, light weight, low cost and ease of manufacturing. Usage of polymers in various environments is suitable on considering applications like linear sliding system for sea gate, bearings in nuclear reactors, buoy bearing, rolling mills where aqueous medium is used as a working fluid [1-4]. In a earlier research on six different bearing material including polyamide against steel counter face material the polymer showed better friction and wear characteristic in sea water than aluminium bronze and cast iron[4]. In most cases, water a plasticizer of polymer is used as a lubricating medium. The interest for thermosetting plastics has been turned towards engineering plastics in bearing industry has forced for progressive industrial research on water lubricated bearings. Some notable advantages of the water lubrication are long life, low running cost and clean running. Comparing oil and water lubricated journal bearing the water lubricated bearings provides better cooling which can avoid the frictional heating of the system. Water which is one of the cheap and abundantly available lubricating sources should be studied impending towards the involved mechanisms based on structural and tribological properties. The most suitable application for water lubrication is the marine bearings where sea water has produced better results relative to air. Besides the importance of polymer to be used in corrosive environment, majority of research is based on dry sliding. Limited researches are performed to investigate the friction and wear behavior of polymer on water lubrication [5-8]. Existing studies on the water lubrication of polymers have shown positive and negative tribological characteristic [2-11].

Besides, researches based on water lubrication of polymer to understand both the micro level reactions of material are inadequate. Most existing research on water lubrication of polymers describes the transformation in tribological characteristics from the quantitative responses of the material such as dimensional changes and change in tangential forces [2-8]. Data are required for creating a linkage between the quantitative results and qualitative analysis such as microstructural responses of materials in wet condition could be appropriate. Moreover, tribological behavior for corresponding mechanical properties of material construes the fundamental science of water lubrication of polymers.

2 WATER AS A LUBRICANT FOR POLYMERS

The commonly used engineering plastics PA6, POM and PTFE have been tested for their tribological performance under water lubrication. Results show that the PTFE has better frictional characteristic on comparing with POM and UHM-PE [6]. From the literature it was understood that the enhanced wear performance of PA6 was attributed towards the hygroscopic characteristics of the material [2]. Fillers such as cellulose, wood powder and polyvinyl alcohol are used to alter the hygroscopic property which in turn has an effect on the frictional characteristics of polymers. In common, engineering plastics can have improved tribological properties in water lubricated condition by including additives that improve the hygroscopic properties. Drawing a range of fiction characteristics from different engineering polymers as shown in Fig. 1 it is clear that the range for friction coefficient in dry condition is several folds lesser for PA6 in wet condition and also the range doubles for polyacetal however, PTFE performs better in dry condition. This low friction coefficient for PA6 in wet condition as seen in Fig 1 is due to the better hygroscopic character of PA6 on comparing with polyacetal. However concerning the engineering plastics the wear rate decreases on water lubrication.

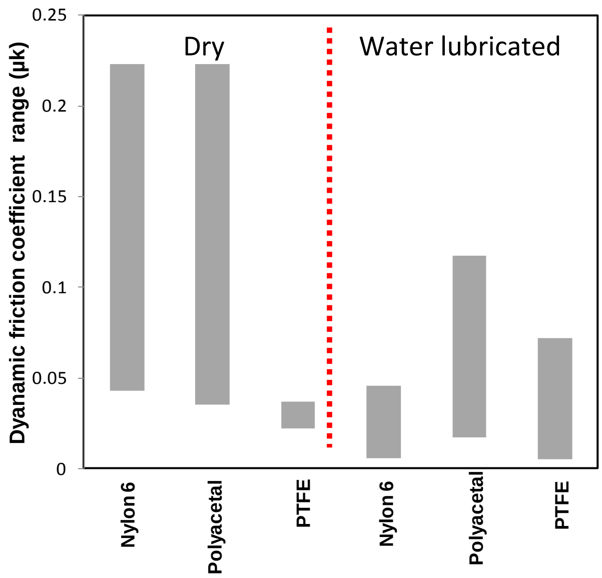

Figure 1 shows a significant difference in frictional characteristics between dry and water lubrication [2]

On using water lubrication the co-efficient of friction decreases to a specific value and then tends to be constant but in case of dry sliding the tendency overturn by having a rapid increase in the beginning of sliding and reaches a specific point from where the coefficient of friction grows in a constant rate. On the whole more data are required to characterize the wear mechanism in water lubrication of polymers few of the observed quantitative data and its mechanisms from various researchers are tabulated below in Table 1 [12-17]. In a study by Lancaster et al it was mentioned that water lubrication has enhanced the tribological property of both the engineering plastics and the high performance polymer [18]. The study clearly shows that the dynamic friction coefficient decreases and the wear rate increases for high performance polymer. Yamamoto in his experiments on understanding the tribological behavior of PPE and PPS again steel counterface has shown better friction properties but the wear resistance was found to be reduced. Moreover, traces of ferrous Sulphide (FeS) transfer layer were found on the steel surface which is due to the sulfur from PPS [17]. The difference in the tendency of the friction behavior of dry and water lubricated polymer composites is clearly explained by Jia [13].

Table 1 showing various researches in polymers against steel counter material on water lubrication

Research	**Polymer**	**Influence of water lubrication**		**Involved mechanisms**
		Friction coefficient	Wear rate	
Feng et al	FEP coating	Decreases	Increases	Scuffing
Yamamoto et al	PEEK & PPS	Decreases	Decreases	Plastic deformation
Hu et al	M-POM	Decreases	Decreases	Adhesion
Zohng et al	PEEK composite	Uncertain	Decreases	Micro cutting
Xiong	UHMWPE	Decreases	Increases	Abrasive wear
Chauhan et al	Vinylester composite	Decreases	Decreases	Fiber exposure
Yijun et al	PI-CNT composite	Decreases	Increases	Abrasion

3 VARIOUS MECHANISMS IN WATER LUBRICATION OF POLYMERS

Water lubrication has advantages and disadvantages on its own explained from the involved mechanism and wear mode. Water lubrication in polymers-metal contacts can act as a cooling agent to reduce the frictional heating thus hindering the normal thermo-mechanical behavior like softening of polymers. Water absorption of polymers and plasticization are the two most common phenomenon occurring in a water lubrication. Absorption leads to changes in structure at the surface level by swelling and it also changes the elastic modulus and strength wherefore altering the friction and wear behavior. Positive effect of wet sliding of polymers has reduced in the induced shear stress. The positive or the negative effect of water lubrication is determined by the dominating mechanism involved in the sliding process. The reduction in shear stress and cooling effect influences positive wear characteristics. However, Zhu et al explain that the reduction in shear strength due to water absorption, and the difficulties in the formation of transfer layer can decrease the wear resistance [7]. Polyimide composite have also produced better friction and wear behavior with water lubrication on comparing with dry sliding. The obtained wear rate from water lubrication was ten times less than dry sliding. Even in this case the decrease in wear rate is explained by the swelling due to absorption of water molecules which also decreases the shear strength [8]. Similar results were reported for UHMWPE against ceramic (Al2O3) in water lubricating condition has shown better tribological performance on comparing it with saline and dry conditions [12]. For which Xiong et al explains from the view point of reduction in shear strength as a consequence of water absorption for having better frictional characteristic.

The transfer layer which acts as an effective lubricant in dry sliding has been removed in most of the water lubrication. Similar results were reported by Yijun et al on polyimide with carbon nanotubes where no transfer layers are present on the steel surface. However in the same research dry sliding a considerable amount of transfer film was found [14]. Transfer layer which aids to the positive tribological characteristics in a polymer – metal contact has been hindered in water lubrication. The transfer layer is removed together with the water as wear debris. Similar effect was observed by Zohng et al on testing PEEK composites on steel counterparts where no trace of transfer film was present in the counterface material and was collected as wear debris from the lubricating water [5].

Analyzing the surface topography it was reported that the surface damage is caused by scuffing in the water lubrication however in dry sliding micro cracking is the dominant mechanism [13]. In a research by Chen *et al* shows the severity of topographical change in the polymer surface lubricated with sea water on comparing with pure water. The severities in the form of furrows are explained as an abrasive wear through ploughing however the development of mechanisms is not clearly explained. Microstructural details of the worn surface provide evidences of the damage mechanism undergone with respect to the absorption property. All such explanations for tribological behavior of polymers under water lubrication were focused on quantitative and hence an explicit qualitative measure is also required to completely understand the fundamental aspects of tribology.

4 INFLUENCING PARAMETERS IN WATER LUBRICATION

Apart from the material used in water lubrication the quality of the used water has significant effect on the friction behavior of the material. Researchers have proven that even with the difference in water quality a change in the wear behavior exhibits. Prehn *et al* while using PEEK with high volume carbon fibers observed that samples tested with tap water produced better results relative to the samples tested on demineralized water [6]. In such a cases, wear debris might act as a potential contamination on reducing the wear rate of the material. However, such negative effects can be avoided by adopting a continuous supply of water and an effective water recycling system.

The friction characteristics of the polymer in water lubricated condition does also depends upon the counter material where steel tested in sea water has high friction coefficient relative to pure water due to the corrosion of steel by sea water. However, the use of stainless steel in sea water has significantly reduced the friction coefficient due to the corrosion resistance property. Similar results were reported by Chen et al where polymer (PEEK, PHBA and PI) sliding against GCr15 steel showed appreciable results with pure water on comparing with sea water [19]. However, when GCr15 replaced with stainless steel produced better tribological results. It was also reported by Craig *et al* that the friction coefficient reduces in sea water on comparing with pure water for PTFE coated bearing material [2]. The increase in wear rate in salt water was termed as indirect corrosion by Wang et al in his studies on PTFE sliding against steel the decrease in frictional characteristics was attributed to the increase in lubricity of the medium by means of green rust [20].

5 POLYMER TRIBO-MECHANICAL CHARECTERISTICS IN AQUEOUS ENVIRONMENT

Tribo-mechanical characteristics which is the linkage between tribological behavior and mechanical properties of the material in a medium aids to provide the fundamental understanding about undergone wear process. Polymers absorb moisture even from the atmosphere thus in case of polymer in aqueous environment to maintain the clearance within the tolerance range where expansion of polymer is critical [11]. Apart from the dimensional instability the water absorption also changes the mechanical property of the polymer material. Thus polymers used in water lubrication applications are pretreated or alloyed for having low water absorption. Water which is a good plasticizer of polymers, changes the mechanical properties. Even with exposure of polymers to atmospheric humidity the material undergoes significant change in the creep behavior [9]. Not only with the pure polymer but also with composites the mechanical behavior strongly depends on the hygroscopic nature of the matrix material. In general exposure of polymers to aqueous atmosphere reduces the interface bond strength of the polymers and affects the shear strength and the modulus of the material. Studies have proven that the water immersed epoxy vinyl ester composite has increased flexural strength and interlaminar shear strength from the structural perspective [10].

In all cases on investigating water lubrication of polymer metal contacts, it was found that the frictional properties have been enhanced however the wear property degrades. Cohen et al describes that this behavior is due to the surface modification of polymers and Tanaka explains the same theory from his experimental results [2]. In a research by Feng et al on testing FEP coating against steel counterface with the water lubrication showed considerably reduction in friction co-efficient but the wear rate was increased by two times on comparing with dry sliding [16]. When results exist for positive wear performance of water lubricated polymers, negative tribological characteristics occur by weakening of matrix in a polymer composite [16]. The penetration of water molecules on the composite tends to loosen the filler and thus removing it from the matrix for having increased wear rate. It is understood from the literature that the deformation behavior of polymer depends on the hygroscopic property of the material thus the wear mechanisms vary significantly from material to material in wet condition. Theories relating structural changes on the surface level to tribological behavior of the material in wet condition have to be explored.

Design of materials or pre-treatment of polymer itself are done on improving the absorption property of the material by adding fillers of wood cellulose. The appropriate method on polymer material development would be a holistic approach where tribological fundamentals of the involved mechanism in relation to the absorption properties provides a way to design tailor made materials. Understanding the significant change in the mechanical properties, in wet condition (water immersed) might be appropriate to relate the mechanical properties with the tribological behavior of the water lubricated polymers. Thus future work is aimed at characterizing mechanical properties of water immersed polymers and tribological testing of the same.

6 CONCLUSION

From the review it is clear that the frictional behavior has been improved in water lubrication and the wear rate decreases in most cases and increases in some cases. Understanding the tribo-mechanical characteristics of the material in wet condition (water immersed) briefs the connection between material properties influencing the tribological behavior of the water lubricated polymers and its composites. More research on understanding the involved wear mechanisms from the microstructural perspective are required in the tribology of water lubricated polymers.

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