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Observations on the effectiveness of some surface treatments of mineral particles and inorganic compounds from Armenia as the fillers in polyphenylene sulfide for tribological performance

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Abstract

This is a general study in which a number of minerals and inorganic compounds from Armenia were investigated for their effectiveness as the fillers in polyphenylene sulfide (PPS) for tribological performance. The minerals studied were tuff, bentonite, and travertine, and inorganic compounds MoO_3 and MoO_2. The filled polymer specimens were prepared by compression molding and tested for tribological behavior in the pin-on-disk sliding configuration. The particulate fillers included many variations in terms of the size (micro and nano) and surface treatment. Friction and wear test results revealed that MoO_2 and nano size bentonite particles were effective in improving the wear resistance. The lowest steady state wear rate in this study was observed for PPS + 7% MoO_2 (50 nm) + 5% PTFE composite, and MoO_2-filled composites had generally lower coefficients of friction than that of the unfilled PPS. From the wear plots, filler abrasiveness, and transfer film studies, it was concluded that the abrasion by filler was mostly responsible for the detrimental wear behavior. The wear behavior has been discussed in terms of the abrasion by filler and transfer film uniformity, texture, thickness, and coverage. The effects of particulate size and surface treatment are also included in the discussion. In view of the results reported for these fillers in formaldehyde and dioxolane copolymer (CFD) and the observations in this study, it is felt that the fillers from Armenia with the exception of tuff and MoO_3 have considerable appeal for further investigation using other innovative surface treatments for fillers.

Keywords: Wear; Friction; Transfer film; Mineral deposit; Surface treatment; Size effect; Filler abrasiveness

1. Introduction

This study was done under a CRDF[1] project whose objective was to explore the effectiveness of mineral deposits in Armenia as the fillers in polymer for wear resistance. Since Armenia is very rich in mineral deposits, there is a great potential for the improvement of economy of the country by utilization of these deposits for industrial usage. The minerals are complex mixtures of inorganic compounds and the tribological behavior of such mixtures has not been studied from a fundamental perspective. The study reported herein is general in nature intended to screen a number of mineral deposits for their effectiveness as the fillers in polymers. Whereas this study uses polyphenylene sulfide (PPS) as the base polymer, a parallel study was done at the State Engineering University of Armenia with the copolymer of formaldehyde with dioxolane (CFD-acetal resin). With this as the base study, follow-up studies with select minerals as the fillers will be reported. These will examine the behavior of these minerals on a more fundamental level. Attempts were made to understand the tribological behaviors of PPS composites with five fillers and the results are presented in this study.

Many studies on polymer composites have been done using inorganic compounds as a single filler material. Mineral deposits differ from these compounds because they are a mixture of many compounds usually with one or two of these in large proportions. Since polymer composites filled with single compounds such as CuO, TiO_2, Ag_2S, SiC, Si_3N_4, and Cr_3C_2 have shown increased wear resistance while others

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filled with compounds such as ZnO, SiC, PbTe, and Al_2O_3 decreased wear resistance [1–3], a study with mineral deposits as the fillers is expected to be much more complex.

The tribological behavior of polymer composites filled with minerals would essentially depend upon the constituents in the mineral. The minerals examined in this study are tuff, bentonite, and travertine. The constituents in these minerals are SiO_2, Al_2O_3, $CaCO_3$, MoO_3, MoO_2, MgO, Na_2O, K_2O, etc. A limited number of tribological studies with these compounds as the individual fillers have been reported. For example, Wang et al. [4] reported that the coefficient of friction and wear rate of PEEK were lowered with the addition of nanometer SiO_2 particles. Yang and Hlavacek [5] found that the wear resistance of PVC improved with the addition of Al_2O_3 but decreased with the addition of $CaCO_3$ and SiO_2. The wear resistance of PPS was reported to decrease with the addition of microscale Al_2O_3 particles [3]. With Al_2O_3 particles reduced to nanosize, Schwartz and Bahadur [6] reported that the wear resistance of PPS increased. This indicated that apart from the composition of a filler, its size also affects the tribological behavior. With more than one compound present in the filler material, there could as well be counteracting effects in terms of the wear resistance. This makes the study a lot more challenging.

2. Experimental details

2.1. Materials

PPS was used as the base polymer because of its high temperature capability that was considered necessary for the sliding conditions used in this study. It had been supplied by the Phillips Chemical Company in powder form.

Table 1
Chemical constituents of mineral deposits

	Tuff	Bentonite	Travertine
SiO_2	63.5	60.40	0.40
Al_2O_3	16.7	16.27	0.02
$CaCO_3$	–	–	99.0
TiO_2	0.20	0.82	–
Fe_2O_3	2.20	5.51	0.10
FeO	0.98	0.61	–
MnO	0.40	0.14	–
CaO	2.65	2.78	–
MgO	2.10	3.45	0.50
Na_2O	3.84	2.23	–
K_2O	4.40	0.56	–
P_2O_5	–	–	0.05
H_2O	1.00	6.74	–
SO_3	–	–	0.10

Table 2
Mechanical properties of mineral deposits

	Tuff	Bentonite	Travertine
Density (g/cc)	2.50	2.60	2.40
Compressive strength (MPa)	11–35	20–60	50–150
Moisture absorption (%)	20.0	11.0	1.5–10.0
Porosity (%)	15–48	–	3–4
Thermal stability (°C)	1200	550	600
Thermal conductivity (W/m K)	0.29	0.32	0.42
Mohs hardness	4–6	3	3–4

The chemical compositions of the mineral deposits are listed in Table 1 and their properties are given in Table 2. The mineral tuff is a complex mixture of large percentages of SiO_2 and Al_2O_3, both of which are abrasive materials. It has relatively low density, moderate compressive strength, high thermal stability, low thermal conductivity, and high hardness. It has a large porosity and high moisture absorption characteristic. It is known to consist of volcanic glass fragments and its structure is shown in Fig. 1.

Similar to tuff, bentonite also contains high percentages of SiO_2 and Al_2O_3 along with Fe_2O_3 (Table 1). Its hardness is lower than that of tuff and the material is fairly hygroscopic. It is a soft clay mineral composed mainly of montmorillonite ($Al_2O_3 \cdot 4SiO_2 \cdot H_2O$), which is hydrous aluminum silicate.

Travertine is basically mineral calcite ($CaCO_3$) and it contains very small fractions of the compounds such as MgO, SiO_2, Fe_2O_3, etc. as well (Table 1). It has high compressive strength and its moisture absorption is much lower than that of tuff.

In addition to the above minerals, the inorganic compounds MoO_2 and MoO_3 from Armenia were also studied.

2.2. Surface treatments

The mineral particles were treated as follows in order to modify the particle surface for enhanced bonding with

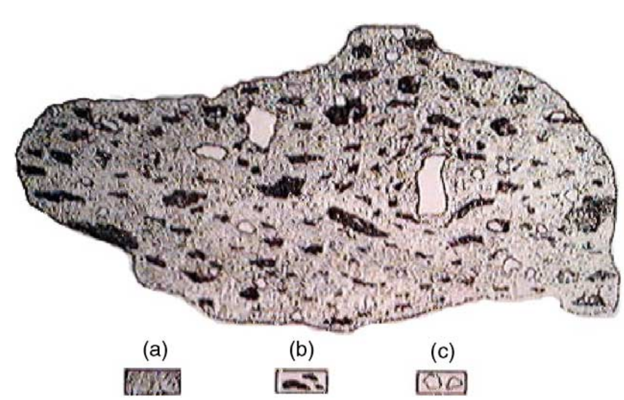

Fig. 1. Structure of tuff; (a) bulk fragmentary-ashes, (b) embedded black glass fragments, and (c) other rock fragments.