Wettability and soil friction of the wollastonite fiber filled UHMWPE composites

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Adhesion and friction of soil to soil-engaging components of agricultural machines decrease their working efficiency and working quality and increase their energy consumption considerably. The adhesion of a solid surface against soil is related to its wetting ability by water. The contact angle of water on the solid surface is used as an expression of its wetting ability. It was shown that ultra-high molecular weight polyethylene (UHMWPE) is a material with significant anti-adhesion and anti-friction properties against soil. The abrasive volume rate of UHMWPE was two times that of the hardened and low-tempered steel-45 although UHMWPE had lower mass-lost rate than carbon steel, ceramic and enamel coating against free-abrasive simulating soil [1]. The free-abrasive wear resistance of UHMWPE can be improved by filling some content of inorganic particles or fibers in the matrix of UHMWPE to form the composites. The wollastonite fibers have been used as the reinforcement of such polymer materials as PA6-PP [2], PMMA [3], and phenolphthalein poly(ether ketone) [4]. Ma *et al*. [5] conducted the statistical analysis of the experimental condition effects on the free-abrasive wear of UHMWPE. Tong *et al*. [6, 7] demonstrated that the wollastonite fibers could improve the sliding wear property and free-abrasive wear resistance of UHMWPE. It was shown that the UHMWPE composite containing wollastonite fibers of 10 wt% gave the highest abrasive wear resistance.

The wollastonite fiber reinforced UHMWPE composites were prepared and their wettability by water and the soil friction of the composite containing wollastonite fibers of 10 wt% were examined in this work. The lower cost of the wollastonite fibers, which can decrease the cost of the composites, was also a factor considered.

Powdered UHMWPE of a molecular weight of 2.5×10^6 was used for preparing the composite. The needle-shaped wollastonite fibers used as reinforcement had an aspect ratio of 15:1 and a constitution of SiO_2, 50.9 wt%; Al_2O_3, 0.25 wt%; TiO_2, 0.05 wt%; CaO, 43.9 wt%; MnO, 0.10 wt%; L.O.I, 0.5 wt%; FeO, 0.55 wt%; and MgO, 0.1 wt%. In order to improve the combining strength of the wollastonite fibers with UHMWPE, the fibers were modified with the silane–titanate combined modification method. The modifying agent was vinyltriethoxysilane for silane modification. The modifying procedure was that wollastonite fibers were dispersed in water to become a slurry mixture and then silane was added into the mixture, simultaneously stirring for 15 min and then drying at 100 °C for 60 min. The modifying agent for titanate modification was NT-105. The modifying procedure was that the titanate was dissolved in toluene solution and then the solution was sprayed onto the wollastonite fibers by stirring for 15 min, followed by drying at 80 °C for 60 min. The procedure of the silane–titanate combined modification of the wollastonite fibers included the above silane modification and then the above titanate modification. The silane–titanate combined modification can obviously elevate the contact angles of water on the wollastonite fiber surfaces [6], indicating that the modification can improve the combining strength of the interface between the wollastonite fibers and UHMWPE matrix. The preparation procedure of the test specimens was that the mixture of UHMWPE powder and the wollastonite fibers was filled into a mould and pressed into the testing specimens on a hydraulic press under 100 MPa and, then, sintered in a stove at 190 °C, followed by hot-pressing under 20 MPa.

The surface of UHMWPE and its composites for contact angle tests were grounded using metallographic papers (the last, $8^{\#}$) and cleaned with acetone and distilled water. The advancing contact angle θ_A and the receding contact angle θ_R of distilled water on solid surfaces were measured at 23 °C by the sessile drop method as shown in Fig. 1.

The soil friction behavior of UHMWPE composite containing a wollastonite fiber content of 10 wt% was examined. The pure UHMWPE and the hardened and low-tempered steel-45 were taken as comparison materials. The specimens for soil friction had a half ball with a diameter of 11 mm. The soil used for friction tests was black soil taken from Changchun, which had moisture content of 15 db%, 18 db%, 21 db%, and 24 db%, respectively, and a cone index of 100 kPa. The particle size distribution of the black soil is listed in Table I. The soil surfaces were prepared through by cutting with a steel wire of 0.2 mm diameter. The soil friction tests were run on Universal Micro-Tribometer (UMT-2), using its ball-on-disc sliding mode. A small soil bin was attached to the disc which was driven by a motor to rotate, as shown in Fig. 2. A half ball was slid against soil.

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TABLE I Particle size distribution of soil used for soil friction tests

Size (mm)	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001
wt%	2.48	11.15	31.68	8.45	18.96	24.92

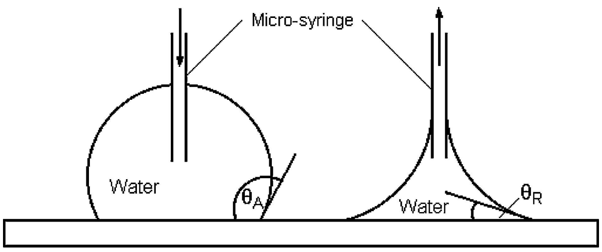

Figure 1 The sessile drop method for measuring advancing contact angle (θ_A) and receding contact angle (θ_R).

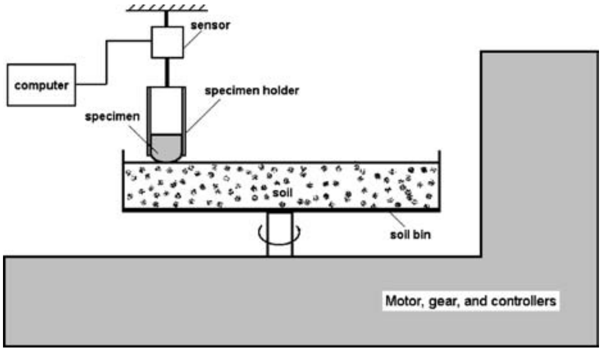

Figure 2 Schematic diagram of the ball-on-disc apparatus for measuring apparent friction coefficient.

The apparent friction coefficients, μ, were recorded automatically and stored in datum and in graphical files in computer in real time.

Surfaces can be divided into the low energy surface and the high energy surface according to their surface tensions. The tension of a low energy surface is less than 0.1 N/m. Many polymer materials have a low surface tension, such as, polytetrafluoroethylene (PTFE), polypropylene (PP), polyethylene (PE), and polystyrene (PS), whose surface tension is 0.0239, 0.0301, 0.0357, and 0.0407 N/m at 20 °C, respectively. The tension of high energy surfaces ranges from 0.2 to 5.0 N/m. Metals and inorganic non-metals are high energy materials. The surface tension of water is 0.0728 N/m at 20 °C. The high energy surfaces can adsorb water molecules to become the low energy surfaces even when the relative humidity of the atmosphere is less than 0.6%. The water film adsorbed on high energy surfaces becomes thicker as the relative moisture of the atmosphere is increased. As a result, the surface tensions decrease and the contact angles of water on it increase. Therefore, the wettability of the high energy surfaces is mainly dependent on the amount of water molecules adsorbed on them. The equilibrium contact angle of water on a high energy surface is zero if the surface is clean, such as TiO_2, $BaSO_4$, SnO_2, tin, and gold [10]. It was shown that the enamel coating, alumina coating, and hardened and low-tempered steel-45 have an advancing contact angle of 29 °, 82 °, and 71 °, respectively, and their receding contact angles were zero [1], which were, in fact, the equilibrium contact angles when they are clean. Fig. 3 illustrates the advancing contact angles (θ_A) and receding contact angles (θ_R) of water on the surfaces of the UHMWPE composites. It can be found that θ_A and θ_R of water on the composite surfaces were decreased as the fiber content was increased. But, θ_A and θ_R of the composites filled with wollastonite fibers by combined modification were kept above 90 ° and 70 °, respectively, when the fiber content was less than 10 wt%. This showed that the silane–titanate combined modification of wollastonite fibers can improve the hydrophobic ability of the composites, which was because the combined modification can increase the contact angles of water on the wollastonite fiber surfaces [6] although the wollastonite fiber material had a high surface energy.

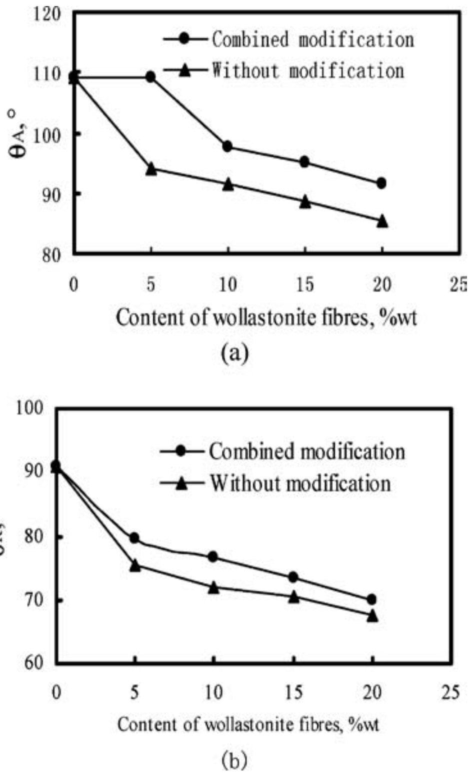

Figure 3 The effects of wollastonite fiber contents on: (a) advancing contact angle θ_A and (b) receding contact angle θ_R of water on the UHMWPE-matrix composites.

The UHMWPE-matrix composite with wollastonite fillers of 10 wt% was used only to compare to the pure UHMWPE and the hardened and low-tempered steel-45 in soil friction property since the composite had the best abrasive wear resistance [7]. Fig. 4 illustrates the apparent friction coefficients (μ) of UHMEPE, UHMWPE-matrix composite with wollastonite fillers of 10 wt% and the hardened and low-tempered steel-45 versus soil moisture contents from 15 db% to 24 db% under the normal load 2 N at the sliding velocity 6.3 mm/s. It can be found that the composite had nearly the same friction coefficient as UHMWPE and much lower friction coefficient than the hardened and low-tempered steel-45. This was because the θ_A and θ_R of the UHMWPE-matrix composites were kept above 90 ° and 70 °, respectively, when the fiber content was less than 10 wt% for the wollastonite fibers with

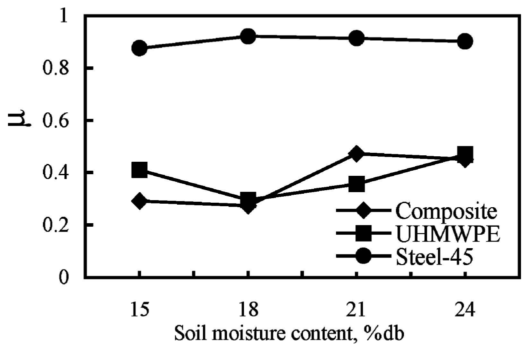

Figure 4 Apparent coefficients of friction of three materials against soil with varied moisture contents.

the combined modification. Therefore, the UHMWPE composite containing the wollastonite fibers of 10 wt% had a better combination of anti-friction and anti-abrasion against soil.

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