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High Performance Synthetic Paper Used for Color Printing Based on Ultrahigh Molecular Weight Polyethylene/SiO_2 by Using TIPS Method

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ABSTRACT: The production of traditional cellulose paper not only consumes lots of timber, but also brings about some environmental issues. Therefore, it is being increasingly replaced by synthetic paper. In this study, ultrahigh molecular weight polyethylene (UHMWPE)/SiO_2 synthetic paper with high application performance was prepared by the thermally induced phase separation method using mineral oil as diluent. The corresponding properties of synthetic paper, including surface morphology, overall porosity, tensile strength, thermal stability, acid and alkali resistance, whiteness, and inkjet print effect were investigated respectively. The results show that the overall porosity of UHMWPE/SiO_2 synthetic paper is above 45%, and the tensile strength exceeds 4.3 MPa. UHMWPE/SiO_2 synthetic paper also presents light weight, as well as good resistance to heat, acid and alkali. Meanwhile, the average whiteness of the samples is up to 91.8%. The sample K-50, which contains 31.5 wt % SiO_2, takes on the best print performance caused by its dense surface and higher SiO_2 content. It is indicated that UHMWPE/SiO_2 synthetic paper has good market prospects in the color printing. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2015**, *132*, 41529.

KEYWORDS: membranes; polyolefins; porous materials; properties and characterization; synthesis and processing

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INTRODUCTION

Cellulose paper, which is traditionally made from wood pulp, has many negative impacts on the environment. Raw cellulose fibers are extracted from plant sources and suspended in baths of water, which leads to deforestation and wastewater. Moreover, during the process of paper production, about 30 wt % of the initial fibers are washed off as sludge. In Europe alone, eleven million tonnes of sludge is produced annually.[1] Synthetic paper, however, is made from thermoplastic polymers, and used for writing and printing in the form of a membrane. Synthetic paper, fabricated from virgin or recycled thermoplastic polymers, is usually produced by an almost totally clean method that does not produce sludge.[2] In addition, it can meet the requirements of light weight and good resistance to weather, acids, and corrosion. Thus it is increasingly replacing cellulose paper.[3,4]

Many thermoplastic polymers are suitable for synthetic paper preparation, such as polyethylene (PE), polystyrene (PS), polyvinyl chloride, polyester (PET), and polypropylene (PP). As a new type of engineering thermoplastic, ultrahigh molecular weight polyethylene (UHMWPE) is an attractive material due to its excellent properties, such as high strength, good toughness, chemical resistance, and low-temperature resistance. In addition, UHMWPE is a polymer featured of non-toxic, low moisture uptake, low density, and wear-resisting.[5–7] It is an ideal raw material for making synthetic paper after being processed to membrane. However, UHMWPE exhibits poor liquidity because of its ultrahigh molecular weight (typically more than 1.0×10^6 g/mol). Therefore, it is difficult to be processed into membrane using routine methods.

Phase separation methods, including non-solvent induced phase separation (NIPS)[8,9] and thermally induced phase separation (TIPS),[10,11] are employed mainly to fabricate porous membranes. The NIPS process provides a way to make membranes from polymers which can easily be dissolved at room temperature. However, the NIPS process is not suitable to process UHMWPE. Compared with NIPS, TIPS also can be used for polymers that are hard to dissolve at room temperature. So TIPS can be applied to process UHMWPE. TIPS has several advantages, including easy control, low defects formation and diverse microstructures. It has been explored for making various polymer membranes, such as PE,[12–14] PP,[15] polyvinylidene fluoride,[16,17] nylon,[18] and polyacrylonitrile.[19,20] In the simplest TIPS process of making membrane, a polymer is dissolved in a high-boiling, low-molecular-weight diluent to form a homogeneous solution at a relatively high temperature. Then, the solution is extruded and pressed into membrane shape followed by a

Table I. Recipe for the UHMWPE/SiO_2 Synthetic Paper Preparation

Synthetic paper code	Mineral oil (wt %)	m (SiO_2)/m (UHMWPE) (g/g)
K-0	75	0/100
K-2.5	75	2.5/97.5
K-5	75	5/95
K-10	75	10/90
K-15	75	15/85
K-20	75	20/80
K-30	75	30/70
K-40	75	40/60
K-50	75	50/50

cooling process to induce phase separations: liquid-liquid (L-L) phase separation[21] and solid-liquid (S-L) phase separation.[22] Finally, the diluent is removed by extraction, and the microporous membrane is obtained.

One approach to prepare synthetic paper is the film method, which includes surface coating, surface treatment, and internal paper-manufacturing. Another is the fiber method, including synthetic pulp and spunbond.[23,24] So far, the film method is more commonly used. YUPO synthetic paper developed by Yupo Corporation is made from PP by internal paper-manufacturing method. ALINDA synthetic paper of Dynic Corporation is made from PET by surface coating method. Q-per synthetic paper registered by Japan Synthetic Paper is made by surface treatment. Arjobex's Polyart synthetic paper, made from high density polyethylene (HDPE), has a unique manufacturing process, consisting in biaxially stretching combined with paper-like coating. However, the common methods for preparing synthetic paper just focus on the surface porosity, which directly related to printing performance. As for the overall porosity and light weight, that influence the general application performance of synthetic paper are not yet be considered. Moreover, post-processing is usually necessary for these common methods after obtaining primary film.[23] As a proposed method to make various porous films, TIPS has a great potential to manufacture synthetic paper conveniently. However, there is no literature about synthetic paper prepared by the TIPS method.[25–28]

In our research, a ternary mixed system, containing UHMWPE, mineral oil and SiO_2 was applied to prepare UHMWPE/SiO_2 microporous membrane by using the TIPS method. To solve the processing problem caused by UHMWPE's poor liquidity, mineral oil was adopted as diluent, which can dissolve UHMWPE and form a homogeneous polymer solution at a relatively high temperature. Micron scale SiO_2 was added as modifying agent, since it can reduce the membrane weight and improve the hardness, the opacity and the whiteness.[28] The properties of the UHMWPE/SiO_2 microporous membrane, namely synthetic paper, were characterized by FTIR-ATR, thermogravimetric analysis (TGA), SEM, tensile testing machine, chemical reaction, color measurement spectrophotometer, and inkjet printer.

EXPERIMENTAL

Materials

UHMWPE (number-average molecular mass 2.0×10^6) was purchased from Shanghai Lianle Chemical Industry Science and Technology (Shanghai, China). Mineral oil (alkane mixtures of C15 to C40, kinematic viscosity $65 \times 10^{-6}-71 \times 10^{-6}$ m^2/s) was obtained from China Petro-chemicals Group, Hangzhou Refinery (Zhejiang, China). SiO_2 (surface modified; product code: OK500; mean grain size: 6 μm) was kindly supplied by Shanghai Aile Imaging Materials (Shanghai, China). UHMWPE, mineral oil, and SiO_2 were all industrial grade. Absolute ethyl alcohol used as an extraction agent was AR grade and obtained from Sinopharm Chemical Reagent (Shanghai, China). Cellulose paper (A4 size, 80Gsm) was bought from Onhing Paper (Guangdong, China). Teslin synthetic paper (synthetic printing) was bought from PPG Industries (Pittsburgh). YUPO synthetic paper (FPG95, 100 Gsm) was obtained from Shenzhen Faxin Zhongxin Stickiness (Guangdong, China). Polyart synthetic paper (90 Gsm) was obtained from Arjobex Ltd. (Essex, UK).

Preparation of UHMWPE/SiO_2 Synthetic Paper

UHMWPE, mineral oil and SiO_2 were premixed well using a digital dual-range mixer (RW20, IKA, Germany) at room temperature with 45 rpm for 1 h. The mass fraction of mineral oil in all mixtures was fixed at 75 wt %, while the mass ratio of SiO_2/UHMWPE was variable. Detailed information of the recipe is listed in Table I.

After premixing, the mixture was poured into a conical twin-screw extruder (SJSZ20/40, Whweal, Hubei) with screw speed at 10.0 rpm. The extrusion temperature was independently controlled on five zones along the extruder barrel and a strand die to achieve a temperature profile ranging from 160 to 270°C. The extruded blend was air cooled and then cut into the master batch by using a plastic granulator (LQ25, Tzkfxs, Jiangsu). The master batch was fed into a flat vulcanizing machine (XLB-400 $\times$ 400 $\times$ 2, Qicai, Shanghai), and pressed into membranes with thickness close to 0.5 mm at 240°C and 10 MPa. The membranes were air cooled and then immersed in ethanol for 72 h to remove mineral oil. Subsequently, the resulting membranes were washed with distilled water and freeze-dried by a lyophilizer (TFD 5503, ilShin, South Korea) for 48 h. After that, the synthetic paper was obtained. The corresponding manufacturing route of UHMWPE/SiO_2 synthetic paper is shown in Figure 1.

FTIR-ATR Analysis

To determine the residue of diluent, the mineral oil, SiO_2, master batch and synthetic paper were measured by FTIR-ATR (AVATAR 380, Thermo Electron, America) at wave numbers from 400 to 4000 cm^{-1}.

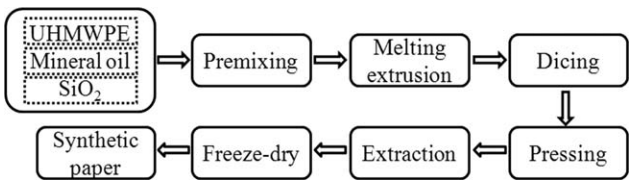

Figure 1. Process flowchart of manufacturing UHMWPE/SiO_2 synthetic paper.

Thermogravimetric Analysis

To obtain the thermal stability of synthetic paper, TGA was conducted on a thermal analyzer (TG209F1, NETZSCH, Germany) under nitrogen atmosphere at flow rate of 20 mL/min. Usually, about 5 mg samples were heated from room temperature to 900°C at a heating rate of 10°C/min.

Overall Porosity Measurement

The overall porosity of UHMWPE/SiO_2 synthetic paper was determined indirectly by measuring the true density and the bulk density.[29] The overall porosity (ε) can be calculated according to eq.

$$\varepsilon(\%)=(1-\rho_b/\rho_t)\times 100 \quad (1)$$

where ρ_b is the bulk density of the synthetic paper, and ρ_t is its true density.

Morphology Observation

The surface morphology of the synthetic paper was observed by using SEM (TM-1000, Hitachi, Japan).The samples were coated with gold in a rarefied argon atmosphere (20 Pa) using an Emitech K550 Sputter Coater, with a current of 12 mA for 50 s.

The distribution of SiO_2 in UHMWPE polymer was assessed by a Transmission Electron Microscopy (JEM-2100F, JEOL, Japan) at 200 kV. Ultrathin section of the sample was prepared by a cryo-ultra microtome (EM FC7 UC7, Leica, Germany) at a thickness about 50 nm.

Tensile Test

The tensile property of the synthetic paper was tested with a digital tensile testing machine (CZ-8010, Zhongzhi, China) at room temperature with a humidity of about 50% at a tensile speed of 5 mm/min. The initial gauge length and width were 50 and 10 mm respectively.

Acid and Alkali Resistance

Different acid and alkali solutions, including hydrochloric acid, nitric acid, sulfuric acid, sodium hydroxide, and ammonia, were adopted to test the acid and alkali resistance property. UHMWPE/SiO_2 synthetic paper and cellulose paper were soaked in above mentioned solutions for 48 h at room temperature. The pH value of chemical baths was adjusted to be neutral with ammonia and acetic acid after soaking. The remainder of paper was then collected from the chemical baths through sand core funnel. The collection was dried in vacuum oven at 50°C for 24 h, and then placed in drying vessel for content weight.

Mass loss ratio (γ) was used as a parameter to determine the performance of acid and alkali resistance. The value of γ after soaking was calculated by eq. (2).

$$\gamma(\%)=(1-m/M)\times 100 \quad (2)$$

where M is the mass of synthetic paper before soaking, and m is its mass after soaking.

Whiteness

The CIE Whiteness of UHMWPE/SiO_2 synthetic paper, cellulose paper and Teslin synthetic paper were evaluated by color measurement spectrophotometer (Datacolor650, Datacolor, America) according to the ISO 11475: 2004 standard. Each sample was measured six times in different positions to give an average value.

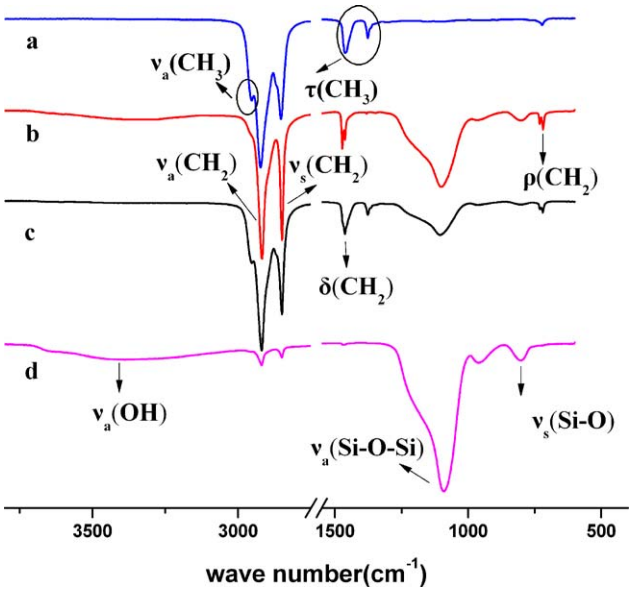

Figure 2. FTIR-ATR spectra of raw materials, master batch and synthetic paper (a) mineral oil. (b) K-50 synthetic paper. (c) K-50 master batch. (d) SiO_2. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Inkjet Printing Test

The print performance of UHMWPE/SiO_2 synthetic paper and the Teslin synthetic paper were evaluated by regular ink jet printer (L801, Epson, Japan). The ink used was original ink.

RESULTS AND DISCUSSION

FTIR-ATR Spectra of Raw Materials, Master Batch, and Synthetic Paper

Figure 2 is the FTIR-ATR spectra of raw materials, master batch, and UHMWPE/SiO_2 synthetic paper. It is shown in curve b of the synthetic paper, the strong peaks at 2918 and 2850 cm^{-1} result from the stretching vibration of —CH_2—. Peak at 1463 cm^{-1} comes from scissoring vibration of —CH_2—. So it proved the existence of —CH_2—.[29] All the characteristic peaks of —CH_2— can also be found in mineral oil (curve a) and K-50 master batch (curve c). In curve a, peaks at 1463 and 1377 cm^{-1} are ascribed to the bending vibration characteristic peaks of CH_3—. And the peak at 2953 cm^{-1} is caused by asymmetrical stretching vibration of CH_3—. The peaks at 2953 and 1377 cm^{-1} exist in curve c but disappear in curve b. This result confirmed that mineral oil can be fully extracted by ethanol.

As shown in curve d, peaks at 1093 and 803 cm^{-1} are assigned to the asymmetrical stretching vibration characteristic peak of Si—O—Si and symmetrical stretching vibration characteristic peak of Si—O respectively. Comparing curve b with curve d, both characteristic peaks of Si—O—Si arise. This proves that the SiO_2 was successfully added into the synthetic paper.

Thermal Stability

Figure 3(a,b) illustrate the TG and DTG curves of UHMWPE/SiO_2 synthetic paper, cellulose paper, pure UHMWPE and SiO_2,

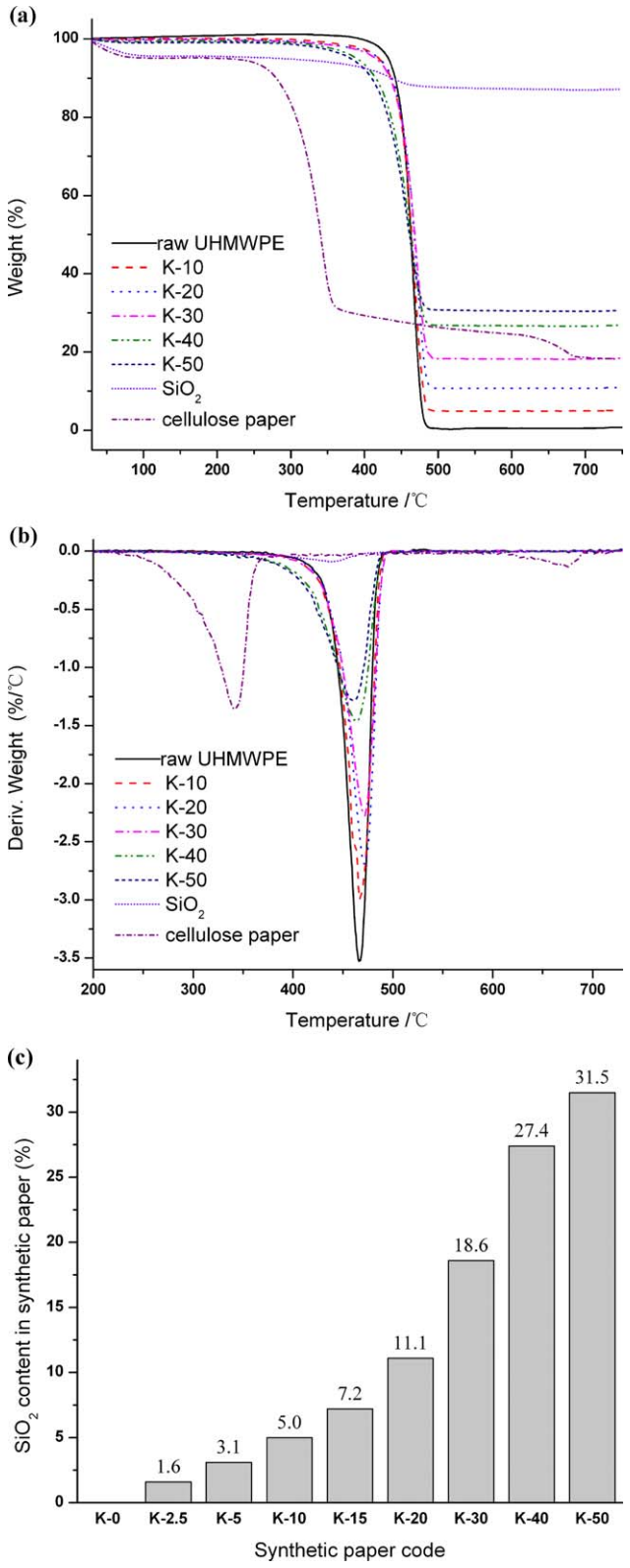

Figure 3. Thermal properties of UHMWPE/SiO_2 synthetic paper, cellulose paper, and pure UHMWPE (a) TG curves. (b) DTG curves. (c) SiO_2 content in synthetic paper. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table II. TGA Data for Pure UHMWPE, SiO_2, and UHMWPE/SiO_2 Synthetic Paper

Analyte	T_{onset} (°C)	T_{max} (°C)	T_{offset} (°C)
pure UHMWPE	448.4	467.6	477.5
SiO_2	381.2	436.2	459.8
K-10	448.8	467.1	479.7
K-20	447.0	471.5	482.6
K-30	445.6	471.9	482.6
K-40	428.1	463.1	478.3
K-50	422.2	459.1	476.0

respectively. According to the result, the TG curves of UHMWPE/SiO_2 synthetic paper are similar to that of pure UHMWPE. The thermal decomposition of synthetic paper almost begin at 360°C. As for SiO_2, the weight loss from 30 to 100°C was perhaps attributed to the bound water. In the case of cellulose paper, the weight loss from 30 to 100°C was also caused by dehydration, and its thermal decomposition began at

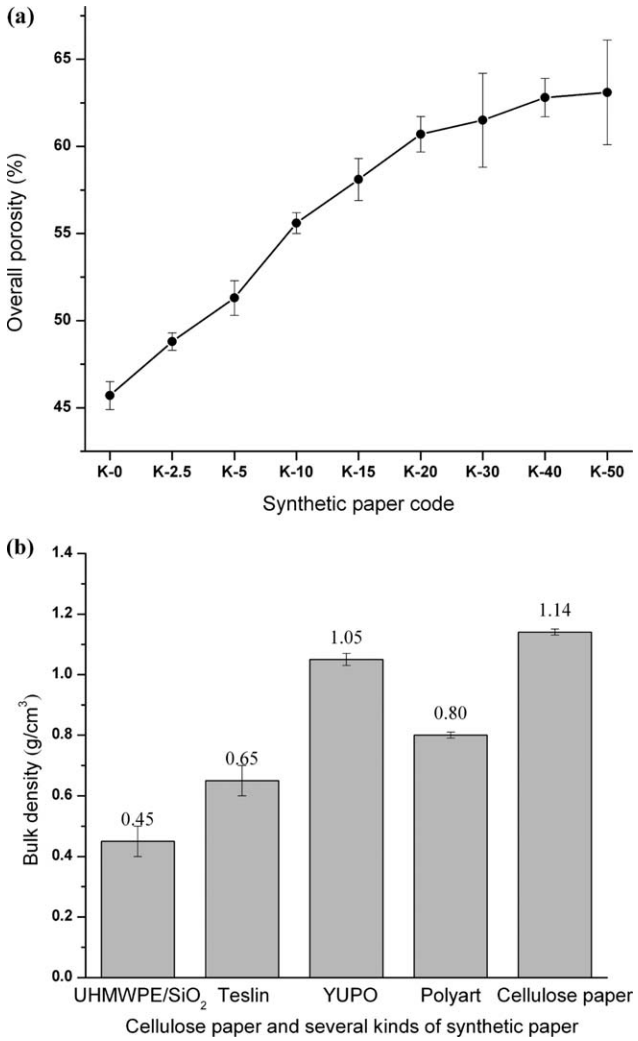

Figure 4. (a) Overall porosity of UHMWPE/SiO_2 synthetic paper. (b) Contrast on bulk density.

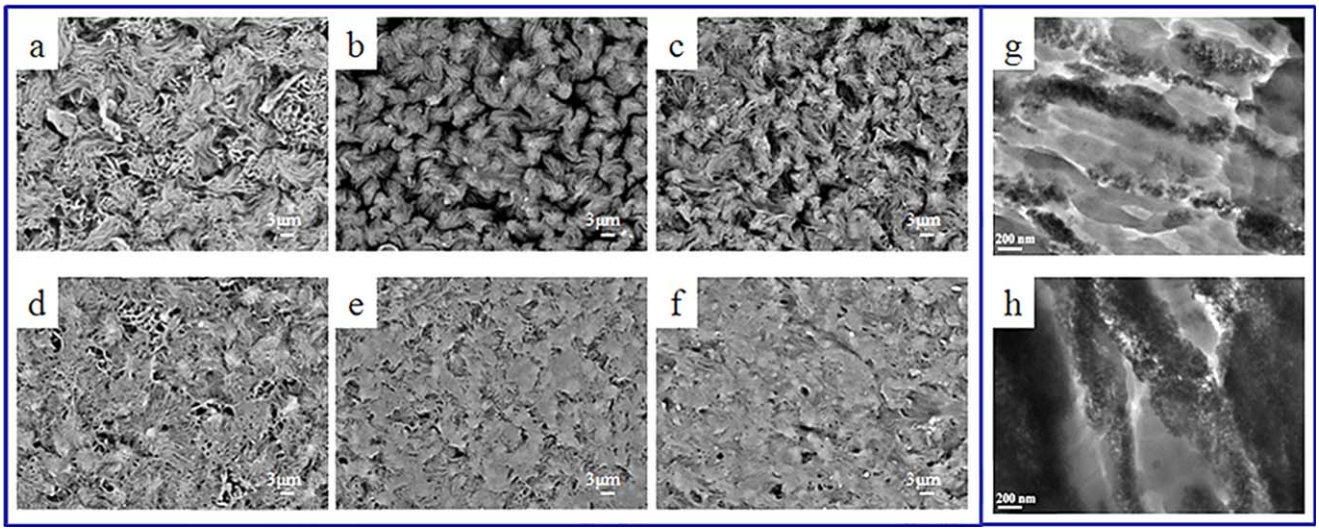

Figure 5. SEM and TEM images of the UHMWPE/SiO_2 synthetic paper surface (a) K-0. (b) K-2.5. (c) K-15. (d) K-20. (e) K-40. (f) K-50. (g) K-15. (f) K-50. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

226°C. Therefore, UHMWPE/SiO_2 synthetic paper shows a better resistance to heat than commercial cellulose paper. As shown in Figure 3(a), K-10 synthetic paper has a maximum weight loss of 95.0%, which indicates the SiO_2 content in K-10 synthetic paper is 5.0%. The content of SiO_2 in synthetic paper can be determined in this way based on the residual quantity. The corresponding data of SiO_2 content in different synthetic paper are shown in Figure 3(c).

Table II shows the onset temperature of thermal decomposition (T_{onset}), the temperature of maximum mass loss rate (T_{max}) and the offset temperature of decomposition (T_{offset}) for pure UHMWPE, SiO_2 and UHMWPE/SiO_2 synthetic paper.

It is shown in Table II that T_{onset} decreases with the increase of SiO_2 content. UHMWPE/SiO_2 synthetic paper and pure UHMWPE almost share the same T_{max} (465.5 ± 6.4°C) and T_{offset} (479.3 ± 3.3°C). T_{onset}, T_{max} and T_{offset}, however, all decline sharply when the SiO_2 content exceeds 20%. This may be caused by the higher thermal conductivity of SiO_2 ($\lambda_{SiO2} = 1.4$ W m^{-1} k^{-1}) than that of UHMWPE ($\lambda_{UHMWPE} = 0.3$ W m^{-1} k^{-1}). When the SiO_2 content is above 20%, heat will be conducted more easily caused by thermal conductive chains between silica and silica. As a result, excess silica can facilitate the decomposition of UHMWPE and accelerate the formation of amorphous regions.

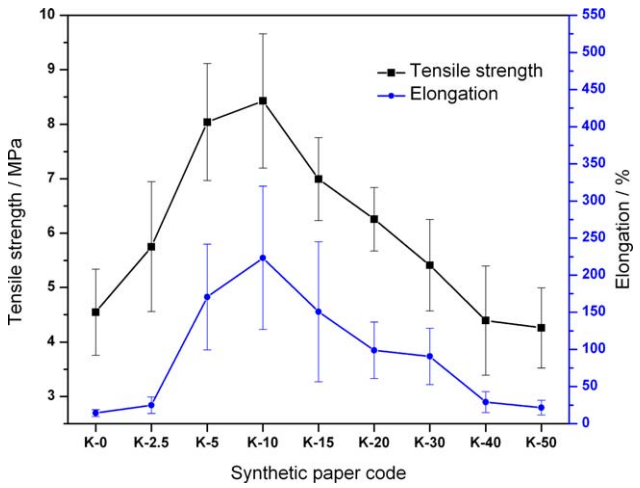

Figure 6. Tensile properties of UHMWPE/SiO_2 synthetic paper. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Overall Porosity Measurement

Figure 4(a) shows the overall porosity of UHMWPE/SiO_2 synthetic paper. As can be seen, the overall porosity of synthetic paper increases from 45.3 to 65.3% with the SiO_2 content increases. Generally, the polymer/diluent mixture undergoes phase separation paths to form membrane. After cooling down to the crystallization temperature, S-L phase separation occurs and the polymer crystals are formed. Compared with UHMWPE, the increase of relative amount on mineral oil brings about more pores after the diluent is removed.

The contrast on bulk density of cellulose paper, UHMWPE/SiO_2 synthetic paper and several typical commercial synthetic paper

Table III. Mass Loss Ratio and Color Change of UHMWPE/SiO_2 Synthetic Paper and Cellulose Paper After Soaking in Acid and Lye Solution

Test solution (wt %)	Synthetic paper γ (%)/ color change	Cellulose paper γ (%)/Color change
38% Hydrochloric acid	3.1/none	32.7/(White → pale yellow)
68% Nitric acid	0.7/none	48.5/(White → grey)
98% Sulfuric acid	0.0/none	100.0/(White → black)
40% Sodium hydroxide	2.1/none	11.1/(White → green yellow)
28% Ammonia	1.5/none	5.6/(White → off-white)

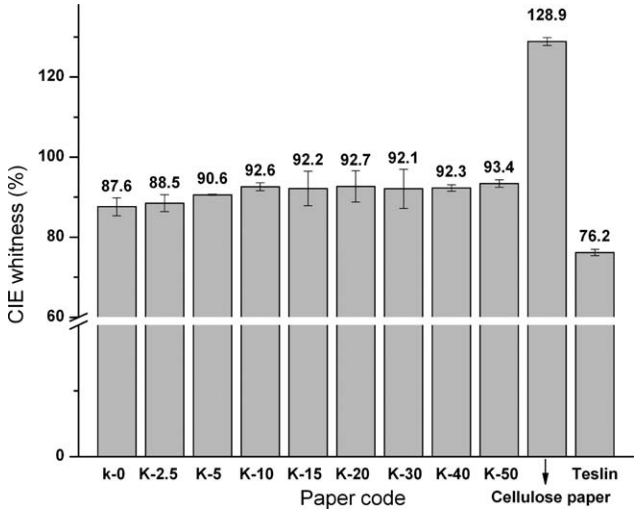

Figure 7. CIE Whiteness of UHMWPE/SiO_2 synthetic paper, cellulose paper and Teslin synthetic paper.

is shown in Figure 4(b). The bulk density of UHMWPE/SiO_2 synthetic paper, namely the average value of K-0, K-2.5, K-5, K-10, K-15, K-20, K-30, K-40, and K-50 is 0.40–0.50 g/cm^3, which is much lower than that of cellulose paper and other commercial synthetic paper. Thus, UHMWPE/SiO_2 synthetic paper made by TIPS method exhibits a light weight feature.

Morphology of UHMWPE/SiO_2 Synthetic Paper

Figure 5 shows the SEM and TEM images of the UHMWPE/SiO_2 synthetic paper. As can be seen in Figure 5(a), the surface of synthetic paper without SiO_2 shows a typical leafy morphology, which is similar to the image in earlier literatures.[30,31] As for the other five sample images, they are found that with the content of SiO_2 increasing, the surface on the synthetic paper becomes denser and more compact. In addition, the surface pores tend to be fewer and smaller. Generally, the pore diameters of K-0, K-2.5, and K-15 are about 3 to 6 μm, while the pores of K-20, K-40, and K-50 are all below 3 μm.

It is also found that the overall porosity of the paper [Fig. 4(a)] increases with SiO_2 content but surface porosity decreases [Figure 5(a–f)]. The crystallization of polymer tends to be impeded after adding more SiO_2. The number of the gaps, which occupied by diluent between silica and polymer becomes larger. More pores will form after diluent was removed, which leads to the increase of the overall porosity. Micron scale silica particles own high specific surface area and high surface activity. When the ternary mixed system (UHMWPE/SiO_2/mineral oil) with higher SiO_2 content was heated up and extruded, more SiO_2 particles tend to agglomerate at the surface, causing the decrease of the surface porosity. This can be further confirmed by the TEM images [Figure 5(g,h)]. It proved that higher SiO_2 content brings about the more agglomeration.

Tensile Properties

As shown in Figure 6, the tensile strength and elongation of UHMWPE/SiO_2 synthetic paper increase significantly when SiO_2 content goes up from 0 to 7.2 wt %. This may be caused by the denser structure of synthetic paper. However, the tensile strength and elongation decrease when SiO_2 content is >7.2 wt %. The excess SiO_2 tends to agglomerate during the extruding process, which leads to poor homogeneity and stress defects. Therefore, mechanical properties deteriorated when SiO_2 content was higher than 7.2 wt %. Usually, the UHMWPE/SiO_2 synthetic paper containing an appropriate amount of SiO_2 (7.2 wt %) shows a

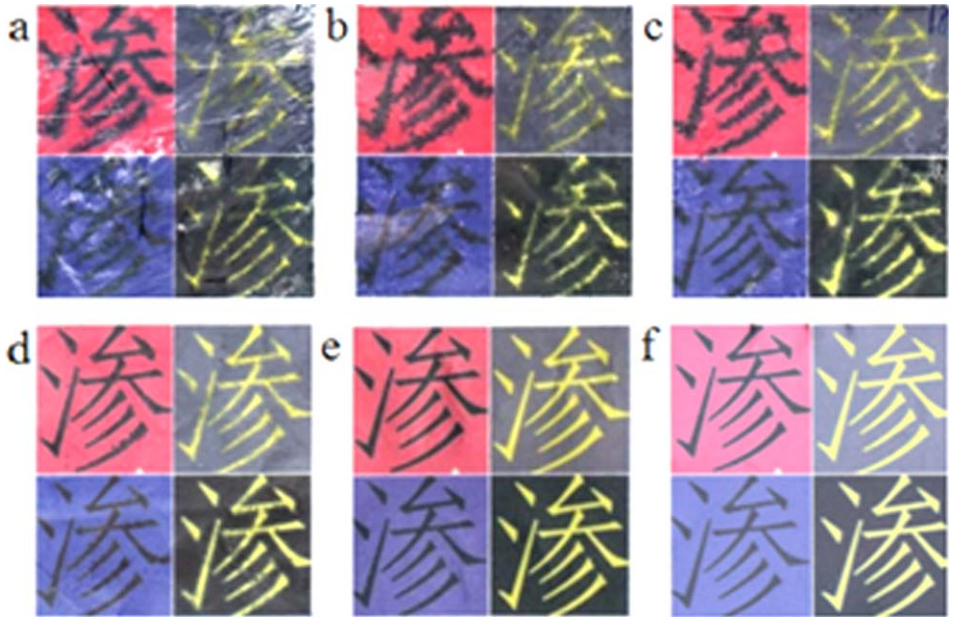

Figure 8. Ink-jet printing on UHMWPE/SiO_2 synthetic paper, cellulose paper, and Teslin synthetic paper (a) K-0. (b) K-30. (c) K-40. (d) K-50. (e) Cellulose paper. (f) Teslin synthetic paper. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

relatively better performance on the tensile test (8.4 Mpa, elongation 223.4%).

According to literature,[32] PP/ethylene propylene rubber synthetic paper owns a highest tensile strength of 3.0 Mpa. While carbon fiber/cellulose composite paper has its maximum tensile strength only about 7.5 Mpa.[33] It is indicated that the resulting UHMWPE/SiO_2 synthetic paper can meet the general application requirements.

Acid and Alkali Resistance of UHMWPE/SiO_2 Synthetic Paper

Table III shows the response of UHMWPE/SiO_2 synthetic paper after soaking in different chemical solutions. K-50 was used as a typical synthetic paper to represent the UHMWPE/SiO_2 synthetic paper. For comparison, the response of cellulose paper was also tested.

The data of Table III proved that synthetic paper has good resistance to acid and alkali. The mass loss ratios of all synthetic paper samples are much $<5.0\%$, while that of cellulose paper are $>5.0\%$. No matter being soaked in what chemical solutions, the synthetic paper always shows primary color. Cellulose paper, however, emerges different color change. UHMWPE has excellent chemical stability, that is, it exhibits good resistance to hydrochloric acid, nitric acid, sulfuric acid, hydrofluoric acid, phosphoric acid, hydrogen peroxide, ammonia, sodium hydroxide, and other chemicals without strong oxidizing property at room temperature. SiO_2 is an inorganic compound that shows good acid and alkali resistance. The mass loss of synthetic paper after soaking may be caused by dissolution of the modifier on SiO_2 and the loss of tiny particles.

Whiteness of UHMWPE/SiO_2 Synthetic Paper

The whiteness of paper is defined as a measurement of light reflectance. Whiteness of paper impacts the effect of printed images, especially the vibrancy of the colors. To some extent, images on brighter white paper exhibit more vibrant colors.

Figure 7 shows the CIE Whiteness of UHMWPE/SiO_2 synthetic paper. The UHMWPE/SiO_2 synthetic paper, with whiteness from 87.6 to 93.4%, is suitable for photo and color printing. For comparison, the whiteness of cellulose paper and Teslin synthetic paper was also tested. Cellulose paper shows the highest CIE whiteness (128.9%) with the help of fluorescent whitening agents (FWAs), while Teslin synthetic paper has a whiteness of 76.2%. Unlike cellulose paper, UHMWPE/SiO_2 synthetic paper displays a sufficient average whiteness of 91.3% and a wider application performance due to no heavy metals, poisonous chemicals or FWAs. Therefore, UHMWPE/SiO_2 synthetic paper can even be used for food packaging and food labels.

Inkjet Printing Performance of UHMWPE/SiO_2 Synthetic Paper

The inkjet printing tests for each sample are illustrated in Figure 8. The synthetic paper (K-0) without SiO_2 displays very poor printing performance [Fig. 8(a)]. The ink on the printed images of K-0 had a gel-like appearance around 30 min after printing. Since the ink can be wiped away by fingers, the synthetic paper without SiO_2 [Fig. 8(a)] was not suitable for inkjet printing.

With SiO_2 content increasing [Fig. 8(b–d)], the printed image became clearer and more vivid. The ink can be absorbed more easily with more SiO_2. That is, ink infiltrates the surface layer of paper more quickly due to the larger surface area provided by increased SiO_2. Meanwhile, tenser surface also helps to prevent ink from lateral diffusion based on its lower surface porosity.

As can be seen in Figure 8(d,f), the UHMWPE/SiO_2 synthetic paper (K-50) shows more vibrant image than the Teslin synthetic paper. In addition, it shows almost the same resolution and the same bright print effect as cellulose paper [Fig. 8(d,e)]. Therefore, the UHMWPE/SiO_2 synthetic paper with good printability and sufficient whiteness itself has a great potential use in color printing.

CONCLUSIONS

The UHMWPE/SiO_2 synthetic paper was successfully prepared using the TIPS method with mineral oil as diluent and micron scale SiO_2 as filler. Light weight, sufficient whiteness, excellent resistance to acid and alkali, and good thermal stability can be achieved. The UHMWPE/SiO_2 synthetic paper shows good print performance when SiO_2 content is up to 31.5 wt %. The results suggested a potential use of the synthetic paper for color printing in severe weather and rugged surroundings, where resistance to heat, acid, or alkali is necessary.

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