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Monodisperse latex with variable glass transition temperature and particle size for use as matrix starting material for conductive polymer composites

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Abstract

A series of surfactant-free monodisperse latices were prepared with varying glass transition temperatures (T_g) and particle sizes using methyl methacrylate (MMA) and butyl acrylate (BA) monomers. Latices with T_gs between −11 and 105°C were synthesized by varying the MMA to BA ratio during batch polymerization. The particle size of latices with a T_g of 19°C was varied by independently changing temperature, initiator concentration and ionic strength of the aqueous reaction medium. These latices provide a model matrix starting material for carbon black-filled electrically conductive polymer composites. When latex with a number average particle diameter (D_n) of 930 nm is substituted for a solution-based polymer the percolation threshold of the final conductive composite drops from 14.5 to 1.45 vol% carbon black. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Substituted polyacetylenes; Ethynylated aromatic Schiff bases polymerization; Transition metal catalysts

1. Introduction

Polymers filled with electrically conductive particles, such as carbon black, have been under investigation for several decades now. When a given polymer is filled with a critical concentration of carbon black, known as the percolation threshold, the composite makes a transition from insulator to electrical conductor [1]. For many filled polymer composites, the critical concentration of conductive filler is around 15% by volume [2–4]. It has been shown recently that the percolation threshold for carbon black-filled polymer composites can be reduced by almost an order of magnitude when latex is used as the composite matrix starting material [5]. Furthermore, several reports have indicated that increasing the ratio of polymer particle size to conductive filler particle size, will further lower the critical concentration needed to induce conductivity [6–8]. These studies of particle size effects on the percolation threshold concentrate on dry polymer powders, such as polyethylene and polypropylene, that is hot-pressed after mixing. Creating composites with latices that have glass transition temperatures at or below room temperature allows for the formation of low percolation threshold materials without the use of heat or pressure. A monodisperse latex system (with variable T_g and particle size) used as the composite matrix starting material would be ideal for a quantitative exploration of the effects of latex particle size and T_g on the percolation threshold of carbon black-filled composites.

Methyl methacrylate (MMA) and n-butyl acrylate (BA) can be co-polymerized to create monodisperse latices with varying T_g and particle size. In theory, the glass transition temperature of a random copolymer prepared with MMA and BA could be varied between −54 and 105°C using the Fox equation [9]:

$$\frac{1}{T_{g(\text{copolymer})}} = \frac{w_{\text{MMA}}}{T_{g,\text{MMA}}} + \frac{w_{\text{BA}}}{T_{g,\text{BA}}} = \frac{w_{\text{MMA}}}{378} + \frac{w_{\text{BA}}}{219} \quad (1)$$

where w is the weight fraction of a given monomer and T_g is the glass transition temperature of a given homopolymer or copolymer expressed in Kelvin. The particle size of monodisperse poly(methyl methacrylate-co-butyl acrylate) latex can be altered with emulsifier type and concentration [10,11], copolymerizable surface-active agent [12], initiator type and concentration [13], reaction temperature [13] and ionic strength [12,13]. Most, if not all, of the literature on P(MMA-co-BA) latex synthesis makes use of a semi-continuous reaction scheme and some type of surface active agent [10–12,14–16].

In the present study, monodisperse P(MMA-co-BA)

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latices with a variety of glass transition temperatures and particle sizes were prepared using a batch reaction scheme. No surface-active agent was used in this synthesis other than the potassium persulfate ($K_2S_2O_8$) initiator, which is known to provide stabilization of latex particles when the SO_4^- ions, at the ends of the polymer chains, migrate to the surface of a polymer particle [17]. Experimentally determined T_gs of prepared latices are compared to the Fox prediction [Eq. (1)] and observed discrepancies are explained. Storage modulus was measured as a function of T_g of dried latex films in an effort to connect mechanical behavior to copolymer composition. The effects of reaction temperature, initiator concentration and ionic strength on latex particle size are quantitatively assessed. Finally, electrically conductive composites were prepared using monodisperse latex (with a room temperature T_g), which demonstrated an order of magnitude percolation threshold reduction relative to a comparable solution-based composite system.

2. Experimental

2.1. Materials

Methyl methacrylate, n-butyl acrylate, potassium persulfate and poly(N-vinylpyrrolidone) (PNVP) powder were purchased from Aldrich. The monomers were inhibited with 10–100 ppm monomethyl ether hydroquinone (MEHQ) and were washed with 1 M NaOH solution followed by deionized water prior to use. Sodium bicarbonate ($NaHCO_3$), from Mallinckrodt, was used as a buffer and sodium chloride (NaCl), from Fisher Scientific, was used to alter the ionic strength of the reaction.

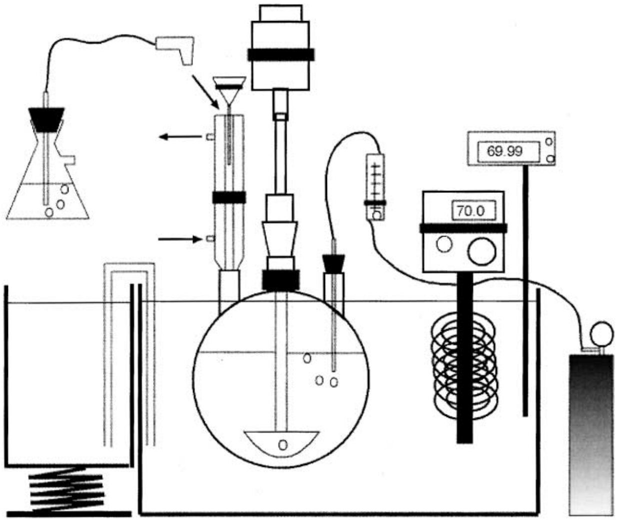

Fig. 1. Schematic diagram of reaction scheme used to synthesize monodisperse latex.

Table 1
Composition of latices with variable T_g

Component	Weight (g)
Monomers (MMA:BA)	248.00
Initiator ($K_2S_2O_8$)	2.82
Buffer ($NaHCO_3$)	2.50
Deionized water	960.00

2.2. Latex synthesis

Poly(methyl methacrylate-co-butyl acrylate) latex initiated by $K_2S_2O_8$ was synthesized using a batch technique similar to that outlined by Goodwin et al. [17]. Synthesis was carried out in a three neck round bottom flask (2-l) equipped with a mechanical stirrer with a Teflon stirring paddle, reflux condenser and nitrogen inlet tube. A schematic diagram of the reaction apparatus is shown in Fig. 1. To begin with, potassium persulfate and sodium bicarbonate were dissolved in 30 ml of water in separate graduated cylinders that were heated to 55°C. Once dissolved, 900 ml of deionized water, 2.5 g of $NaHCO_3$ and all of the monomer (approximately 248 g for each reaction) was added to the reaction flask and the mixture was stirred at 300 rpm for 30 min at the desired temperature. Next, the initiator solution was added through the top of the reflux condenser and the reaction was allowed to proceed for 6 h. An ethylene glycol bath equipped with a heating coil kept a constant temperature during the course of the reaction. At the end of the reaction, the contents of the round bottom flask were filtered through a fine steel mesh to remove the grit formed during the reaction. The compositions of latices prepared with varying T_g are listed in Table 1, and compositions of latices prepared with varying particle size are listed in Table 3. Films for glass transition temperature and mechanical property evaluation were prepared by drying aqueous latices at 130°C for3 h.

2.3. Latex particle size analysis

Latex particle size analysis was performed using a Coulter LS Particle Size Analyzer 3.00.40, which uses light scattering to determine volume (D_v) and number (D_n) average polymer particle sizes. Latex suspensions are diluted down to approximately 1 wt% prior to measurement.

2.4. Latex imaging

Cryogenic transmission electron microscopy (cryo-TEM) was used to visualize latex particle size in uncoalesced samples, which are film forming at room temperature. Freshly synthesized latices were first diluted with 20 parts of deionized water, and 1 μl of the diluted suspension of each sample was withdrawn and deposited on one side of a carbon-coated, perforated polymer film. The perforated polymer film was attached to a 300-mesh TEM specimen-supporting grid (Ted Pella, Inc.). Excess liquid was blotted away from the backside of the grid by a piece of filter paper so that no thick liquid film, i.e. above 200 nm thick, remained in the holes of the supporting film. Once prepared, the sample assemblage was immediately plunged into liquid ethane (−182.8°C). The frozen, or vitrified, sample was then mounted on a Gatan 626 cryo-holder and transferred into a JOEL 1210 TEM with an acceleration voltage of 120 KeV. The specimen temperature was maintained at −180°C throughout the observation.

2.5. Glass transition temperature

Latex glass transition temperatures were evaluated using a Pyris 1 differential scanning calorimeter (DSC) (Perkin-Elmer, Inc.). T_gs were characterized using the midpoint method which takes the intersection of the DSC trace with the bisector of the extrapolated linear signals above and below the transition.

2.6. Minimum film formation temperature

A Rhopoint™ Temperature Gradient Bar (Rhopoint Instrumentation Ltd.), model MFFT-60, was used to obtain minimum film formation temperatures of latices with variable T_g. This instrument was designed to conform to the ASTM D 2354 standard.

2.7. Storage modulus and yield strength

Storage modulus (E') and yield strength (σ_{ys}) of free-standing latex films were evaluated using a Perkin-Elmer DMA 7e dynamic mechanical analyzer. These properties were tested using a tensile fixture with variable applied force to accommodate films with variable modulus due to variable T_g.

2.8. Composite preparation

Composite films were prepared using a high-speed impeller setup. Carbon black powder was added, over the course of 5 min, to latex while the impeller stirred at a rate of 880 rpm. Conductex 975 Ultra (Columbian Chemicals Company) was the carbon black used as the conductive filler. This carbon black has a 21 nm primary particle size and a N_2 surface area of 242 m^2/g. Prior to carbon black addition the latex was treated with 2 wt% Aerosol OT 75% (Cytec Industries, Inc.), based on polymer, to provide shear stability during composite preparation. Approximately seven drops of DrewPlus® L-483 foam control agent (Ashland, Inc.) was added to the composite mixture to reduce the foam formation during high-speed mixing. Following carbon black incorporation, the impeller speed was increased to 3600 rpm for 15 min. The highest concentration carbon black-filled composite was mixed first, with lower carbon black concentrations created by further diluting the mixtures with more latex, followed by another 15 min of impelling at 3600 rpm. Final composites were prepared by transferring the aqueous mixtures into one-inch square plastic molds and then dried for 24 h under ambient conditions followed by another 24 h in a vacuum dessicator to completely remove residual water. The resulting composites were 150–350 μm thick. Additional composites were prepared using the same technique described above with the exception of 10 vol% PNVP in water being substituted for latex.

2.9. Composite imaging

Dried composite films were imaged with a Hitachi S-800 field emission-gun, scanning electron microscope (FEGSEM). Film cross-sections were obtained by soaking dried films in liquid nitrogen followed by hand fracturing. Films were coated with 50 angstroms of platinum prior to SEM imaging. All samples were imaged with an accelerating voltage of 5 kV.

2.10. Electrical conductivity

Composites were removed from their molds prior to electrical conductivity testing. The conductivity measurements were performed with a Veeco FPP-5000 four-point probe apparatus (Veeco Instruments, Inc.). Electrical conductivity below 10^{-5} S/cm could not be detected with this device.

3. Results and discussion

3.1. Glass transition temperature variation

The latices prepared here with varying glass transition temperature used the same monomer/buffer/initiator ratio, by weight, outlined by Guillaume et al. [18] who worked with polystyrene, poly(butyl acrylate) and their copolymers. All of the latices in this study used the compositions shown in Table 1 and were synthesized at 70°C. Latices prepared with these compositions have a very consistent number

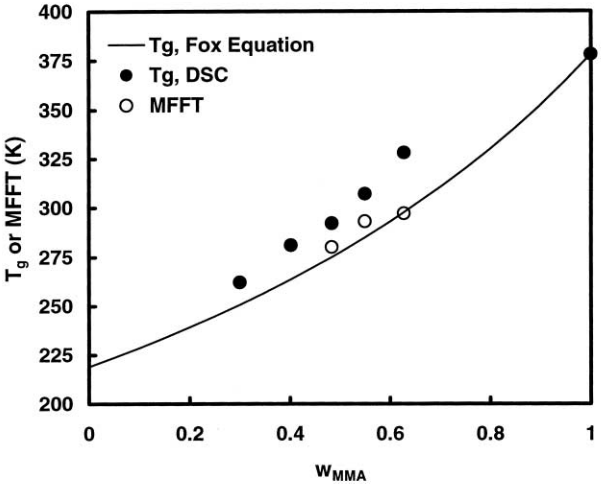

Fig. 2. Glass transition temperature (●) and minimumm film formation temperature (○) as a function of weight fraction methyl methacrylate. Experimental data are compared to prediction of Fox [Eq. (1)] (—).

Table 2
Properties of latices with variable T_g

Latex	MMA/BA (%)	%solids	MFFT (K)	T_g (K)	D_n (μm)	D_v (μm)	D_v/D_n
CoMB378	100:0	18.3		378	0.505	0.533	1.06
CoMB328	62.8:37.2	19.3	297	328	0.511	0.537	1.05
CoMB307	55:45	19.2	293	307	0.542	0.559	1.03
CoMB292	48.4:51.6	19.6	280	292	0.523	0.548	1.05
CoMB281	40.2:59.8	19.3		281	0.526	0.548	1.04
CoMB262	30:70	20.0		262	0.536	0.557	1.04

average particle size (D_n) around 525 nm and a narrow particle size distribution (D_v/D_n) well below 1.1 regardless of monomer ratio.

Fig. 2 shows that experimentally determined T_gs are significantly different than those the Fox equation [Eq. (1)] predicts. This discrepancy between theory and experiment lies in the assumption made by Fox, which suggests the polymerization of MMA and BA occurs in a random fashion [19]. In reality, butyl acrylate monomer is less reactive than methyl methacrylate, which leads to preferential addition of MMA over BA during batch polymerization. This difference in reactivity is expressed by monomer reactivity ratios where $r_{MMA} = 0.920$ and $r_{BA} = 0.130$ [20]. Because r_{MMA} is greater than $r_{BA,}$ MMA prefers to react with itself rather than BA. This preference leads to longer continuous sequences of MMA and shorter continuous sequences of BA within the copolymer [21]. By selectively staining one phase, Zhao et al. [22]showed the microstructure of latex made with styrene and butyl acrylate to be heterogeneous with homopolymer micro-domains. In the case studied here, it is believed the microstructure is like a highly microscopic composite with poly(methyl methacrylate) being the more continuous of the two phases, which would produce a greater T_g than that predicted by Fox.

3.1.1. Minimum film formation temperature

Minimum film formation temperature (MFFT) was tested for selected copolymer compositions and the results are shown in Fig. 2 and listed in Table 2. All of the MFFTs measured are lower than the corresponding experimentally determined T_g, for the same latex. This result is well established and occurs because MFFT is influenced by particle size, phase separation within individual latex particles, plasticizing effect of water and other additives, as well as T_g [23].

3.1.2. Storage modulus and yield strength

Storage modulus (E') and yield strength (σ_{ys}) were both measured as a function of T_g in an effort to link mechanical behavior of latex films to this quasi-intrinsic parameter. Storage modulus measures the response of a material to a sinusoidally applied stress and has nearly the same value as Young's modulus (E) when measured at room temperature (~20°C) [24]. Yield strength is the level of stress required to cause a material to undergo permanent (or plastic) deformation [25]. Both of these properties (measured at 20°C) increase with increasing T_g, as shown in Fig. 3. The dashed vertical line in Fig. 3 represents room temperature, at which point a transition in the rise of E' and σ_{ys} is observed. The exponential rise in storage modulus, covering three orders of magnitude, is fairly steady over the range of T_gs shown with the exception of a discontinuity at 19°C (~292 K), which is most likely due to the transition between rubbery and glassy behavior. Yield strength, however, shows a much steeper rise for samples with T_gs above room temperature, which may be caused by the dramatic increase in difficulty associated with unraveling polymer entanglements to induce permanent deformation. Both properties tend to saturate beyond a T_g of approximately 340 K.

3.2. Particle size variation

Temperature, initiator concentration and ionic strength of reaction medium were all varied in an effort to determine the effect of each parameter on final latex particle size. Table 3 lists the specific combination of temperature, initiator and salt concentration for each of the latices examined, along with the resulting number average (D_n) and volume average (D_v) particle diameters achieved with each set of variables.

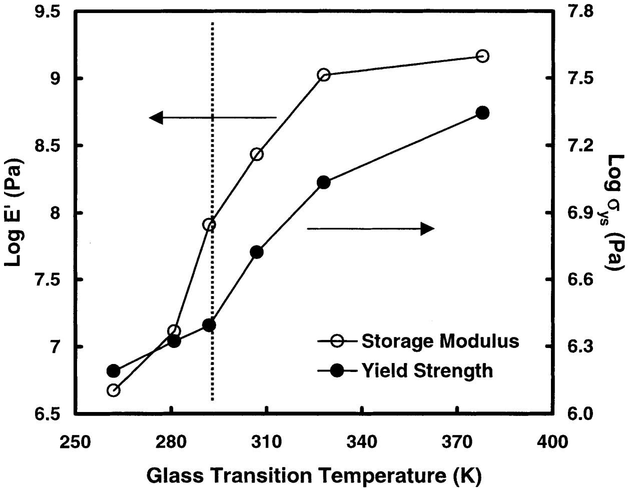

Fig. 3. Storage modulus (●) and log yield strength (○) as a function of glass transition temperature. Dashed vertical line indicates room temperature (~19°C).

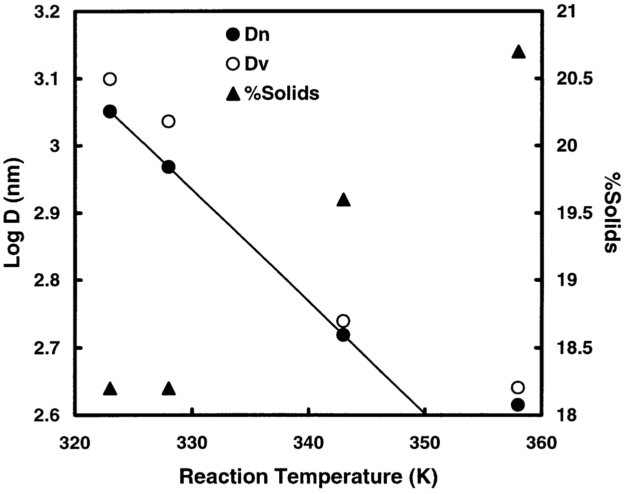

Fig. 4. Number average (●) and volume average (○) latex particle size as a function of reaction temperature along with %solid (▲) on the opposite axis. The straight line fit to the experimental D_n [Eq. (2)] values carries a coefficient of determination (R^2) of 1.

D_n is the more important of these two diameters for percolation threshold prediction, when conductive composites are prepared [5]. All of the latices used to study particle size effects were prepared using a 48.4:51.6 MMA:BA weight ratio, a common ratio for film forming latices [26], which produced latex with a T_g near 19°C and a MFFT of 7°C (see Table 2).

3.2.1. Effect of temperature

D_n and D_v decrease with increasing temperature as shown in Fig. 4. This phenomena has been well documented for both poly(methyl methacrylate) [13]and polystyrene [17] homopolymer latices. The rate of initiator decomposition and monomer solubility increase with the temperature at which the latex is synthesized, which accounts for this decreasing particle size with temperature [13]. This effect saturates at reaction temperatures above 70°C (~343 K) due to the inefficacy of the sulfate ions to stabilize the latex particles when the surface area to volume ratio becomes large. Neglecting the latex produced at 85°C (CoMB292D in Table 3) the decrease in particle size with increasing temperature takes the form:

$$\log D_n = -0.0166T + 8.4236 \qquad (2)$$

where D_n is the number average particle size expressed in nm, the most important parameter for percolation threshold prediction [5], and T is the reaction temperature expressed in K. Eq. (2) is shown as a solid line in Fig. 4. At reaction temperatures greater than 75°C, Eq. (2) breaks down due to the inability of SO_4^- groups provided, by the initiator, to sufficiently stabilize latex particles with such a large surface area-to-volume ratio. Another side effect of increasing reaction temperature is higher solids in the final latex, as shown in Fig. 4. Given the same amount of reaction time (6 h for this study), a higher reaction temperature will lead to faster consumption of monomer and greater overall weight of polymer particles.

3.2.2. Effect of initiator concentration

The dependence of latex particle size on the level of $K_2S_2O_8$ initiator follows the same general trend as reaction temperature. Fig. 5 shows the dependence of latex particle size on initiator concentration. The number average particle size changes according to:

$$\log D_n = -0.1335\log[I] + 2.8794 \qquad (3)$$

where $[I]$ is the initiator concentration expressed in millimolarity (mM or $M \times 10^3$). At low $K_2S_2O_8$ concentration, the particle size polydispersity (D_v/D_n) becomes so large (>1.2) that the system is no longer considered truly monodisperse [27]. The fit of Eq. (3) to the experimental data in Fig. 5 is somewhat muddled due to competing effects, which have opposite effects on latex particle size. When initiator concentration is decreased there are fewer sulfate ions available to stabilize growing latex particles and overall particle size increases in an effort to decrease surface area relative to particle volume [13]. However, the true increase in latex particle size due to initiator reduction is somewhat stunted by the decrease in ionic strength that accompanies a smaller concentration of potassium persulfate, resulting in an unclear trend of particle size as a function of initiator concentration.

Table 3
Properties and compositions of latices with variable particle size (all of the lattices below were prepared with a MMA:BA monomer weight% ratio of 48.4:51.6)

Latex	%solids	D_n (μm)	D_v (μm)	D_v/D_n	T (K)	$K_2S_2O_8$ (g)	NaCl (g)
CoMB292A	19.6	0.523	0.548	1.05	343	2.82	0.00
CoMB292B	18.2	1.125	1.256	1.12	323	2.82	0.00
CoMB292C	18.2	0.929	1.087	1.17	328	2.82	0.00
CoMB292D	20.7	0.412	0.437	1.06	358	2.82	0.00
CoMB292E	18.7	0.764	0.945	1.24	343	0.282	0.00
CoMB292F	19.3	0.473	0.499	1.05	343	11.28	0.00
CoMB292G	20.2	0.523	0.566	1.08	343	2.82	0.40
CoMB292H	19.8	0.621	0.708	1.14	343	2.82	0.80
CoMB292I	20.4	0.833	0.890	1.07	343	2.82	1.60

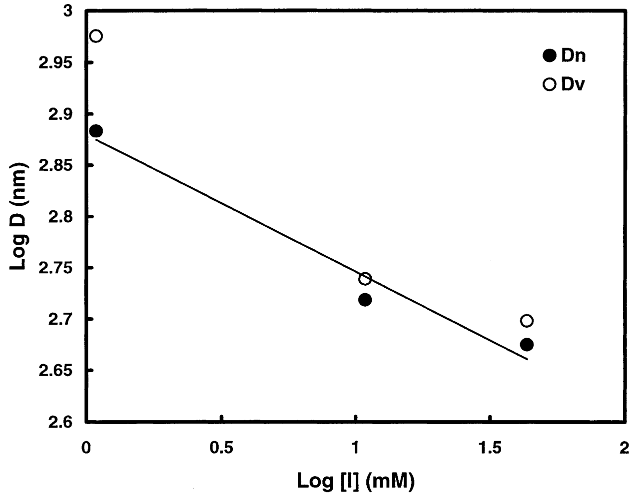

Fig. 5. Number average (●) and volume average (○) latex particle size as a function of initiator concentration (mM0 in the aqueous reaction medium. Solid line indicates best fit to experimental data with equation and quality of fit shown. The straight line fit to the experimental D_n values [Eq. (3)] carries an R^2 value of 0.968.

3.2.3. *Effect of ionic strength*

The effect of ionic strength on particle size is clearly evaluated when initiator concentration in kept constant while the concentration of an additional component, like sodium chloride (NaCl) in this study, is varied. As ionic strength is increased by the addition of NaCl, the latex particle size also increases, as shown in Fig. 6. Number average particle size increases with ionic strength according to:

$$\log D_n = 0.7214 \log[\text{ionic strength}] + 1.51 \quad (4)$$

where [ionic strength] is the concentration, expressed in mM, of ions in the aqueous phase at the start of the polymerization reaction. As the ionic strength of the reaction medium is increased, the rate of primary latex particle coagulation increases due to a screening effect that diminishes the electrostatic repulsion between particles. Latex particle coagulation results in fewer overall particles with a larger size [28]. Another minor contribution is from the diminished water-solubility of methyl methacrylate that occurs in saline solutions, which may decrease the rate of polymerization in the aqueous phase [13]. Fewer particles will be initiated as a result of increasing salt concentration and the resultant particle size will increase. The D_n associated with a reaction that contains no NaCl is also included in Fig. 6 to draw attention to the fact that the ionic strength contributed by the initiator does not have the same effect on final particle size that NaCl does. Fig. 7 shows cryo-TEM images of three latices (CoMB292G—I in Table 3) produced using the three different concentrations of NaCl. These images provide a visual means of evaluating the increase in particle size with salt concentration in the reaction mixture, which should be 523, 621 and 833 nm for Fig. 7(a)–(c) respectively according to Table 3.

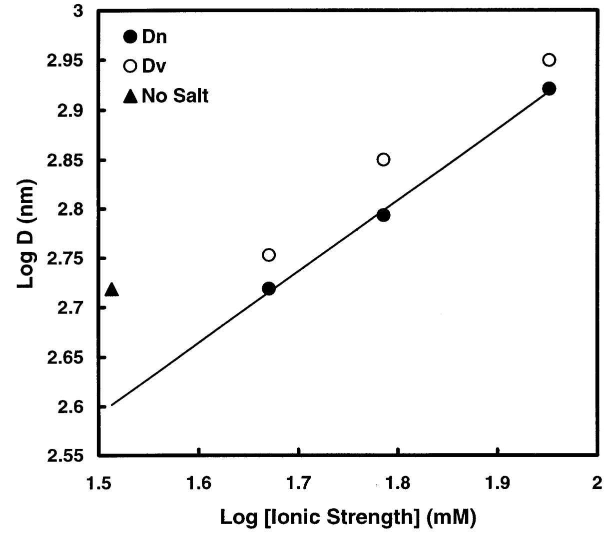

Fig. 6. Number average (●) and volume average (○) lates particle size as a function of ionic strength of aqueous reaction medium. Solid line indicates best fit to experimental data with equation and quality of fit shown. Experiment containing no additional sodium chloride is also shown (▲). The straight line fit to the experimental D_n values [Eq. (4)] carries an R^2 value of 0.998.

3.3. *Carbon black-filled composites*

3.3.1. *Composite electrical conductivity*

The ultimate goal of this synthetic study was to produce film-forming latices that could be used to create electrically conductive polymer composites with low percolation thresholds. Fig. 8 shows the log of electrical conductivity (σ) as a function of carbon black concentration, expressed in terms of volume fraction, for composites prepared using CoMB292C latex (see Table 3). The solid curve in Fig. 8 is a fit to experimental data created using the percolation power law [1]:

$$\sigma = \sigma_0(V - V_c)^s \quad (5)$$

where σ is the composite electrical conductivity (expressed in S/cm), σ_0 is a proportionality constant which often resembles the intrinsic conductivity of the filler, s is the power-law exponent (typically between 1.6 and 2) and V_c is the volume fraction of filler at the percolation threshold (near 0.15 for random filler placement). The percolation threshold for the CoMB292C-based composite was determined to be 1.45 vol% carbon black, using Eq. (5), which is an order of magnitude smaller than the 14.5 vol% obtained for a comparably prepared poly(N-vinylpyrrolidone) solution-based composite previously studied [2,5].

3.3.2. *Composite microstructure*

When carbon black is added to the latex, a segregated filler network is formed during drying due to the excluded

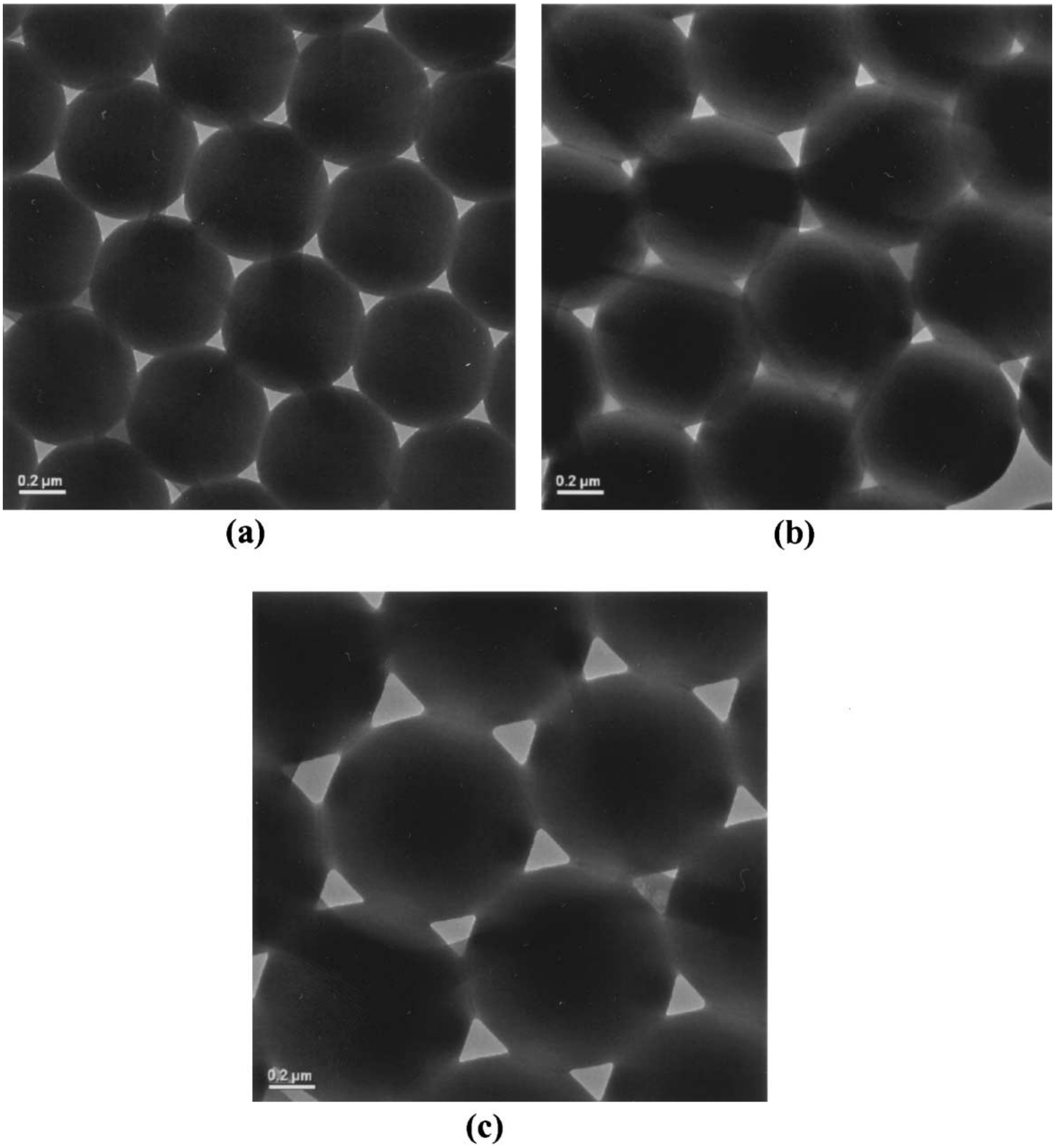

Fig. 7. Cryo-TEM images of monodisperse latices prepared using 0.4 g (a), 0.8 (g) (b) and 1.6 g (c) of NaCl to increase ionic strength of reaction medium.

volume created by the latex particles and the inability of the latex particles to fully wet the surface of the conductive filler. Instead of being able to distribute itself anywhere within the composite volume, as is the case with traditional solution- and melt-based composites, the carbon black is restricted to the surface of the individual latex particles and the interstitial space between them. This preferential placement of conductive filler serves to form a network of electrically conductive pathways that extend macroscopic distances with a relatively small concentration. Percolation thresholds that are approximately one order of magnitude below that of comparable composite systems prepared as a melt [4] or solution [5] are the result of this segregated network.

Fig. 9 shows two SEM images of a CoMB292C-based composite, containing 8 vol% carbon black, taken at different magnifications. The lower magnification image [Fig. 9(a)] highlights the inhomogeneous distribution of carbon black, seen as small white speckles, throughout the thickness of this composite. Both of the images in Fig. 9 show distinct clusters of carbon black separated by equivalent regions where carbon black appears to be absent, which provides the basis for the term segregated network. Individual carbon black clusters are better discerned in the higher magnification image [Fig. 9(b)], where it can be seen that the diameter of an individual latex particle is 10–20× the size of an individual carbon black particle. As a result of this size disparity, the carbon black is forced to occupy the

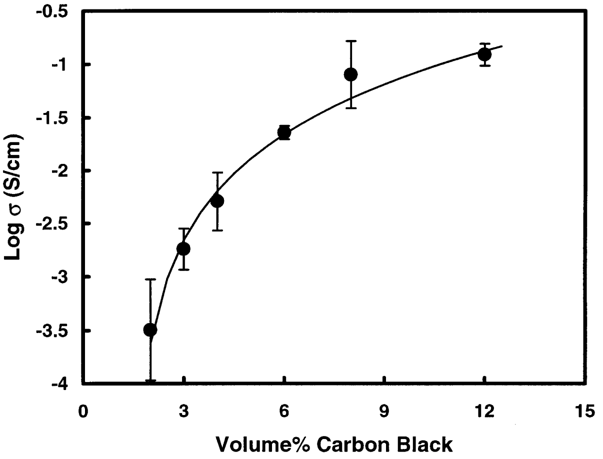

Fig. 8. Electrical conductivity as a function of carbon black concentration for a CoMB292C matrix with percolation power law fit [Eq. (5)] shown as a solid curve.

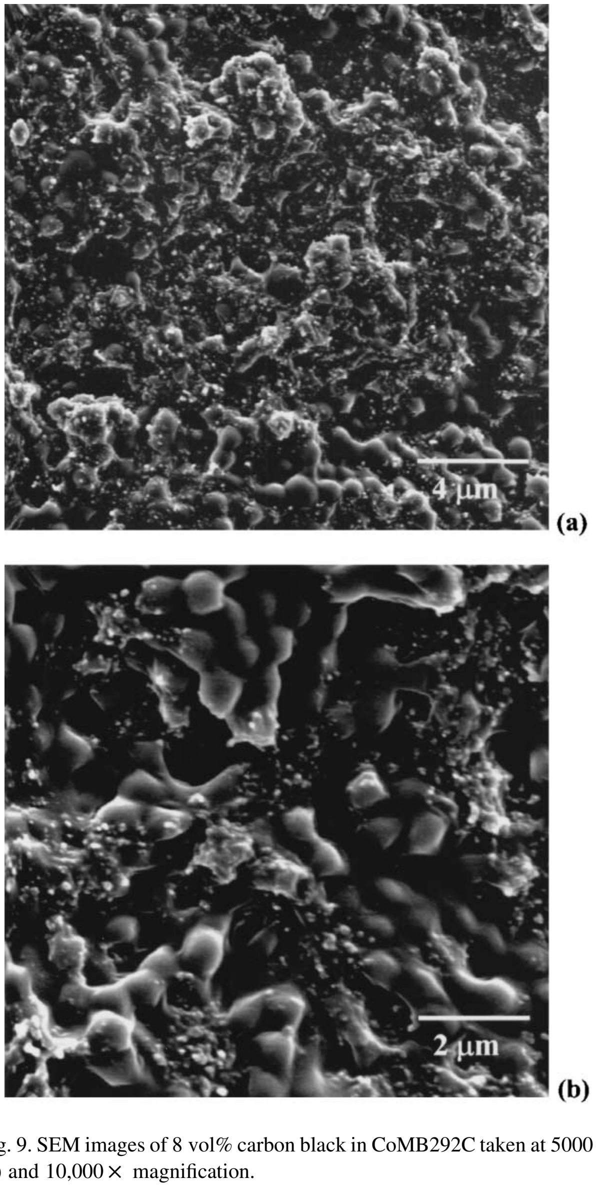

Fig. 9. SEM images of 8 vol% carbon black in CoMB292C taken at 5000× (a) and 10,000× magnification.

interface between latex particles, although not all of the latex particles are coated with carbon black.

It is also apparent from Fig. 9 that the latex is not completely coalesced, as evidenced by the number of relatively large polymer spheres that are discernible. There is evidence to suggest that, as latex coalescence improves, the percolation threshold will be shifted to larger concentrations of conductive filler [29]. This behavior is intuitive due to the latex becoming more like a solution polymer as the T_g decreases and resulting coalescence improves. Better coalescence infers more latex particle deformation and inter-diffusion, which causes the filler material to be more homogeneously incorporated into the film while simultaneously destroying conductive pathways. With this in mind, it is best to have sufficient coalescence to achieve a desired level of mechanical integrity balanced with the need to maintain a well-segregated conductive network. CoMB292C appears to strike the appropriate balance between these two criteria, although the effect of latex T_g on the percolation threshold of these types of composites will be the subject of future work.

4. Conclusions

Monodisperse, surfactant free latices have been synthesized with variable particle size and T_g using butyl acrylate and methyl methacrylate monomers. These latices were prepared in a batch fashion, which yielded T_gs significantly higher than those predicted by Fox [Eq. (1)]. Temperature [Eq. (2)], initiator concentration [Eq. (3)] and ionic strength [Eq. (4)] were all varied in an effort to alter the final latex particle size. Changing ionic strength seems to do the best job of increasing particle size while preserving the monodispersity (D_v/D_n). Electrically conductive polymer composites were prepared with these latices, which have a percolation threshold an order of magnitude lower than conventional melt or solution-based systems. Future studies will examine the effects of latex particle size and T_g on the percolation threshold, maximum achievable electrical conductivity and mechanical behavior of these types of composites.

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