ABSTRACT

Structural composite latex particles were prepared via a two-stage emulsion polymerization. In the first stage, partially cross-linked poly(n-butyl acrylate) (PBA) cores were prepared, and in the second stage, a poly(vinyl acetate-co-methyl methacrylate) abbreviated as P(VAc-co-MMA), shell was grafted onto the rubber cores. In this case, a starved feed of shell monomer(s) was applied to avoid further formation of secondary particles in the aqueous phase. The effects of shell chemical composition and MMA/VAc ratio, on the characteristics and morphology of the resulting emulsion particles have been investigated. The resultant particles were characterized by dynamic laser light scattering (DLLS), transmission electron microscopy (TEM) and differential scanning calorimetry (DSC). TEM Micrographs showed that, the increase of methyl methacrylate (MMA) content level in the shell structure of above 50% (by weight) led to composite latex particles with more separated core and shell regions. In addition, the structural rubber particles with various shell structures were used to toughen the cured styrene/unsaturated polyester alkyd (ST/UPA: 75/25) resin. The results showed that the incorporation of rubber core-shell structured particles with VAc/MMA (50/50 wt/wt) copolymer shell improved the impact fracture energy of the ST/UPA resin (UP) considerably. Scanning electron microscopy (SEM) and TEM micrographs revealed dispersed particles as singlet inside the above blend sample, which showed the highest impact fracture energy. Further increase of MMA units of above 50% (by weight) in the shell composition resulted in significant increase in rubber particles agglomeration as big clusters within the UP matrix. However, the particle shell composition and subsequently the particle/resin interfacial adhesion seem to have a crucial role on the dispersion state and toughening efficiency of the rubbery particles inside the UP matrix.

INTRODUCTION

Core-shell structured latex particles as polymer additives have attracted scientists and industrial interests during the past several decades [1-3]. These structural latex particles consist of a partially cross-linked rubber core and a rigid polymer shell grafted onto the core surface. The core-shell latexes are mainly prepared in a two-stage emulsion polymerization process [5-7]. These structural latex particles have been used in a wide variety of industrial applications, such as adhesives [8], coatings [9], papers and rubber modification of brittle thermoplastics [10-12] and resins [13,14]. The grafted shell...
layer provides the compatibility between rubber particles and polymer matrix and prevents the agglomeration of the rubber particles inside the polymeric matrix. The morphology and performance of core-shell latex particles can be influenced by several key parameters, such as the type and amount of surfactant and initiator [15,16], core and shell chemical compositions [17,18], monomer addition mode [19], core/shell ratio [20,21], shell grafting degree and density, and core cross-link density [11]. Nevertheless, in many cases, the morphology of prepared particles deviates from the concentric core-shell morphology with completely separated core and shell phases [22].

Unsaturated polyester resins (UPs) are widely used to manufacture new reinforced composite materials. Nevertheless, the intrinsic brittleness of unsaturated polyester resin limits its application for some material requirements. Poly(vinyl acetate) (PVAc) is one of the low-profile additives that have been mainly used to toughen the cured styrene/unsaturated polyester alkyd (ST/UPA) resins [23,24]. Nevertheless, the poor water resistance, low creep resistance and heat resistance of this thermoplastic limit its application to improve the ST/UPA (UP) mechanical properties. Recently, the preformed rubber composite particles with core-shell structure have been used to toughen the resin and overcome the above problems arising from the use of PVAc additive.

Guhanathan et al. [25] have prepared core-shell rubber particles for toughening of unsaturated polyester resin. They prepared multilayered core-shell particles with different levels of methyl methacrylate/fly ash in the core latexes, a poly(butyl acrylate-co-styrene) second layer, and a poly(methyl methacrylate-co-ethylacrylate) copolymer shell. Subramaniyan et al. [26] used core-shell rubber (CSR) particles along with nanoclay material for toughening vinyl ester resin. The best improvement in fracture toughness was obtained for the blend sample containing the only CSR particles. Huang et al. [14] investigated the effects of core-shell rubber particles on the fracture properties of the UP. They synthesized the rubber particles via two-stage soapless emulsion polymerizations. The prepared particles which consisted of a rubbery poly(butyl acrylate) core and a hard partially cross-linked and functionalized PMMA shell, that is, poly(methyl methacrylate-co-ethylenglycol dimethacrylate-co-glycidyl methacrylate).

Although most researchers have prepared the core-shell rubber particles to toughen many thermoplastics and epoxy resins, less attention has been paid for preparation of core-shell impact modifiers that are suitable for the brittle UP. In the present research work, a new typical core-shell latex particles with a partially cross-linked poly(butyl acrylate) (PBA) core and a rather rigid poly(vinyl acetate-co-methyl methacrylate), shell has been prepared via seeded emulsion polymerization. The effect of shell composition, that is, MMA/VAc ratio, on the particle morphology, dispersion state and impact performance of the composite rubber particles inside the UP matrix has been investigated.

EXPERIMENTAL

Materials

All chemical reagents were prepared from Merck Co. (Germany) unless otherwise stated. Butyl acrylate (BA), methyl methacrylate (MMA), styrene (ST) and vinyl acetate (VAc) were distilled under vacuum before use. Both allyl methacrylate (ALMA) as cross-linking agent and 1-dodecamethiol (DDM) as chain transfer were purchased from Sigma-Aldrich (Germany). Sodium dodecyl sulphate (SDS) and potassium persulphate (KPS) were prepared as surfactant and initiator, respectively. Distilled de-ionized water (DDI) was prepared in the author's laboratory. Tetrahydrofuran (THF) and acetone, all analytical grades, were used for characterization experiments. The unsaturated polyester alkyd (Bushepol 751129; Bushehr Chemical Industry, Iran) was based on the maleic anhydride, isophthalic acid, propylene glycol, and diethylene glycol units. The unsaturated polyester alkyd (UPA) had an average of 5.88 vinylene groups per molecule. The average molecular weight of the UPA was 2750 g/mol, and the equivalent molecular weight per carbon-carbon double bond was 468 g/mol. An amount of 1.5% (by weight) methyl ethyl ketone peroxide (MEKP, Peroxir KP50; Iran Peroxide Co.) and 0.2% (by weight) cobalt naphthenate (CoN, 10% in white
spirits, Chekad Co., Iran) were used as the low-temperature catalyst and promoter, respectively. In this work, the unsaturated polyester alkyd is designated by UPA, while the unsaturated polyester resin (UP) is a mixture of UPA and styrene (ST) at a given weight ratio.

**Core Synthesis**
The poly(butyl acrylate) (PBA) core latex was prepared in a batch emulsion polymerization. The core latex was synthesized in a 150-mL three-necked glass reactor equipped with a reflux, inlet nitrogen and a stirrer. The reactor was held in a batch with thermostatic control; 0.125 g SDS was dissolved in 55 g DDI and added to the glass reactor at 60°C with continuous stirring at 400 rpm for 30 min. The reactor temperature was increased to the reaction temperature, and a flow of nitrogen was started to remove any traces of oxygen from the reaction media. When the reactor temperature reached 80°C, 24.9 g butyl acrylate along with 0.1 g allyl methacrylate (ALMA) was added to the reactor. Thereafter, 0.06 g KPS dissolved in 20 g DDI was added to the reactor, and then, the reactor was sealed and left for more than 4 h.

**Core-shell Latex Preparation**
The recipes for the preparation of core-shell rubber particles with various shell chemical compositions are listed in Table 1. The given volume of buffer solution was added to 36-mL core latex in the reactor stirred at 300 rpm. Hereafter, the reactor was heated to the reaction temperature of 80°C. On raising the reaction mixture to the desired temperature, feeds of KPS solution and VAc/MMA monomer mixture with a given amount of DDM were added to the reactor at average rates of 0.15 and 0.1 mL/min, respectively.

**Core and Core-shell Particles Characterization**
The gel content of rubber core particles was measured by solvent extraction method. Dried PBA film, 0.25 g, was added to 25 mL THF and stirred at 300 rpm for 48 h. Then, the sample was centrifuged at 5000 rpm for 1 h at room temperature. The sediment gel phase was separated from the supernatant sol phase and dried in a vacuum oven at 50°C for 24 h. The gel fraction was determined gravimetrically based on the total weight of the sample.

The shell grafting degree of core-shell particles was determined using the fine powder of the composite latex dried by freeze drying. The powder was dried under vacuum at 40°C for 3 h before use. In this case, 1 g powder sample was dispersed in 20 mL acetone and stirred at 250 rpm for 5 h. The dispersion was centrifuged at 5000 rpm for 2 h at room temperature. The gel phase at the bottom of the cell was separated from the supernatant phase, and both fractions were dried to remove the solvent under vacuum at 40°C for 24 h. The grafting degree, the weight ratio of grafted VAc/MMA copolymer to rubber core particles, G_d, was measured gravimetrically.

The mean particle size, polydispersity index (PDI) and the weight-average to number-average particle size of the structural latexes were measured by dynamic laser light scattering (DLLS) apparatus [11].

| Table 1. Recipes for the preparation of structural latexes. |

<table>
<thead>
<tr>
<th>Ingredients*</th>
<th>CSR1</th>
<th>CSR2</th>
<th>CSR3</th>
<th>CSR4</th>
<th>CSR5</th>
<th>CSR6</th>
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<td>36.000</td>
<td>36.000</td>
<td>36.000</td>
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<td>36.000</td>
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<td>15.000</td>
<td>15.000</td>
<td>15.000</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>-</td>
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<td>4.500</td>
<td>6.300</td>
<td>9.000</td>
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<tr>
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<td>0.070</td>
<td>0.070</td>
<td>0.070</td>
<td>0.070</td>
<td>0.070</td>
</tr>
<tr>
<td>NaHCO₃</td>
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<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
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<tr>
<td>1-Dodecamethiol</td>
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<td>0.090</td>
<td>0.090</td>
<td>0.090</td>
<td>0.090</td>
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</tr>
</tbody>
</table>

(*) All ingredients are in terms of gram; (**) the solid content of the PBA latex with weight-average particle size of 76 nm is close to 25% (by weight).
The measurements were performed using a Sematech SEM-633 stepper-motor-driven goniometer (France) at wavelength of 632.8 nm and with a laser source of light He and Ne gases. Transmission electron microscopy (TEM, Zeiss CEM902A, Germany) was used to observe the morphology of structural latex particles. The latexes were further diluted with DDI and then, diluted droplets were transferred onto 400-mesh copper grids and dried in open air. The samples were then stained by vapour of osmium tetroxide (OsO₄) solution of 1% before microscopy. Differential scanning calorimeter, Mettler Toledo DSC 822 system (Switzerland), was used to measure the glass transition temperature (T_g) values of the composite particles. The temperature scanning ranged from -150 to 150°C at a heating rate of 10°C/min under a nitrogen atmosphere to prevent further oxidation.

**ST/UPA/CSR Blend Preparation**

The prepared core-shell rubber (CSR) powder was dispersed in acetone with continuous stirring at room temperature for 24 h. The dispersion was then added to the UPA, and the mixture was stirred at 75°C in a three-necked glass reactor under vacuum to flash the acetone. After complete removal of acetone, the styrene (ST) monomer was added at a molar ratio of styrene to unsaturated polyester, 3 to 1. The promoter (the cobalt naphthenate, 0.2% by weight) was added into the ST/UPA/CSR ternary mixture with continuous mixing. Thereafter, the low temperature initiator (MEKP, 1.5% by weight) was added to start the curing reaction. The CSR content level in all the blend samples was 5% (by weight) based on the total weight of ST/UPA mixture. The polymerizing sample was poured into the aluminium moulds prepared for the impact test. The samples were cured at room temperature for 24 h and post cured for 3 h at 80°C.

**Impact Test**

Un-notched Izod impact test was performed on the cured ST/UPA and ST/UPA/CSR rectangular samples to determine the impact fracture energy values according to ASTM D-256-81 protocol method A. The energy required to initiate the fracture and continue the fracture until the breaking point is a representative of the Izod impact energy value. Each reported value is determined by an average of six test specimens.

**Fracture Surface and Blend Morphology**

The fracture surface of the cured ST/UPA and ST/UPA/CSR impact test samples were studied by means of scanning electron microscopy (SEM). The fractured surface of each sample was gold-sputtered before microscopy observation. The microscopy was carried out under an accelerating voltage of 20 kV.

The dispersion state of rubber particles inside the ST/UPA (UP) matrix was studied by means of SEM apparatus on the smooth surface of blend sample cut by a diamond knife on a Reichert OMU3 ultramicrotome (USA) at -30°C. The smooth surface was etched by toluene for 3 h and then gold-sputtered before microscopy observation. TEM was also used to study the dispersion state of composite CSR particles inside UP matrix. For this purpose, the ultrathin sections of blend samples were prepared by a diamond knife and then transferred onto 400-mesh cupper grids. The blend sections were stained by vapour of osmium tetroxide (OsO₄) for 24 h.

**RESULTS AND DISCUSSION**

All the composite latex particles were prepared with a core to shell weight ratio close to 50/50 (wt/wt). Using 0.4% (by weight) allyl methacrylate (ALMA) as cross-linking/compatibilizing agent in the first-stage emulsion polymerization resulted in preparing rubber cores with a gel content close to 62%. The CSR1 composite latex particles prepared in the second-stage emulsion polymerization had a soft copolymer shell composed of VAc/BA (75/25 wt/wt) low-glass-temperature units (Table 1). For other structural latexes, the shell consisted of VAc/MMA copolymers in which the MMA content level ranged from 0 to 100% (by weight). In fact, increasing the MMA units in the shell composition seems to vary the rigidity and hydrophilicity of the particle shell. Table 2 shows the characteristics of the structural composite particles with a unique rubbery core and different shell chemical compositions. As shown, the grafting degree of the particles ranged from 42% to 54%. This difference can be attributed to the amount...
of VAc/MMA copolymer chains grafted onto the surface of rubber cores. For the core-shell rubber materials, the DSC results showed two glass-transition temperatures. The lower glass transition temperature and the upper glass transition temperature correspond to the \(T_g\) of the rubbery core and the copolymer shell, respectively (Table 2). As shown, an increase in the shell glass transition temperature was observed on increasing the MMA rigid units in the shell chemical structure. However, the glass transition temperatures of the graft copolymer shells were lower than those theoretically calculated by Fax equation \[27\]. These differences may be attributed to the higher mobility of the copolymer chains grafted on the rubbery cores.

**Particle Composite Morphology**

The morphology of composite latex particles has a crucial role on the performance of rubber particle to achieve the desired properties in its blends with glassy thermoplastics or thermostet resins. The particle morphology of structural latexes was studied by means of transmission electron microscopy (TEM). This morphological characterization method gives more information on the particle-separated phases but contains some difficulties in sample preparation method, such as staining the acrylate composite particles \[7\]. Figure 1a shows the morphology of the CSR1 particles consisting of a rubber PBA core engulfed by a rather soft VAc/BA (75/25 wt/wt) copolymer shell. The dark and gray regions observed in the micrographs reveal the rubber and shell polymer phases, respectively. Although the PBA chains inside the cores are free of any double chemical bonds, the existence of residual or entrapped double bonds of ALMA cross-linker within the rubber cores caused OsO\(_4\) to stain the acrylate core phase preferentially and allow one to distinguish it from the outer shell \[7\]. The presence of higher level of VAc units along with BA ones in the shell of CSR1 rubber particles resulted in the secondary particles formation. More hydrophilic VAc monomer increased the chance of homogeneous nucleation in the aqueous phase of second-stage polymerization. Figure 1b shows CSR2 particle morphology with total amount of VAc in the polymer shell structure. In this case, very small secondary particles are attached to the PVAc shell surface. The latex particles did not exhibit a complete spherical geometry because PVAc domains shift away from particle edges to some extent. The adherence of small unstable secondary particles on the surface of core-shell particles, especially for the CSR1 latex, resulted in structural latex particles with a lower PDI value. Although no extra emulsifier was added in the shell emulsion polymerization (Table 1), the hydrophilic nature of VAc monomer led to the formation of small primary particles attached on the surface of core-shell particles. Incorporating more MMA units in the shell composition of the CSR3 emulsion particles caused no significant new secondary particles to appear (Figure 1c). Therefore, a core-shell structured morphology was resulted, although the shell thickness was not uniform around core particles. For these emulsion particles, the MMA

<table>
<thead>
<tr>
<th>Code</th>
<th>(D_n) (nm)</th>
<th>(D_w) (nm)</th>
<th>PDI</th>
<th>(G_d) (%)</th>
<th>(T_{g,c}) (°C)</th>
<th>(T_{g,s}) (Exp.) (°C)</th>
<th>(T_{g,s}) (Cal.) (°C)</th>
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<td>CSR1</td>
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<tr>
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<tr>
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<td>78.9</td>
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<tr>
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<td>44</td>
<td>-55.1</td>
<td>104.3</td>
<td>105.0</td>
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</table>

\(D_n\): Number-average particle size, \(D_w\): weight-average particle size, PDI: polydispersity index, \(G_d\): grafting degree, \(T_{g,c}\): \(T_g\) of rubber core, \(T_{g,s}\): \(T_g\) of polymer shell; \(T_{g,s}\) (Exp.): \(T_g\) of graft shell copolymer measured by means of DSC apparatus; \(T_{g,s}\) (Cal.): \(T_g\) of the copolymer calculated theoretically by using Fox equation.
was 20% (by weight) based on total weight of shell monomers. In fact, the introduction of MMA considerably lowered the PVAc particle nucleation in the aqueous phase. Figure 1d shows CS4 particles with core-shell structure. The presence of 50% (by weight) MMA units in the shell increased the grafting degree to some extent (Table 2). Despite equal concentrations of VAc and MMA monomers in the

Figure 1. TEM Micrographs of structural composite particles with various shell chemical compositions: (a) CSR1, (b) CSR2, (c) CSR3, (d) CSR4, (e) CSR5 and (f) CSR6 (the composite latex particles were positively stained by OsO₄ vapour).
shell polymerization, the higher PVAc chain mobility and hydrophilicity may cause the VAc segments to be located at the outer layer of copolymer shell as compared with the MMA segments.

More real core-shell morphology seems to be observed for the CSR5 and CSR6 composite particle materials having dominant (70% by weight) or neat MMA units in their shell structures (Figures 1e and 1f). Grafting units that are more rigid on the rubber cores raised a kinetic barrier to prevent forming further shell monomer diffusion into the rubber phase. For instance, a clear-bright shell region completely separated from the rubber core region was observed especially for the CSR6 structured core-shell particles with rigid PMMA homopolymer shell. However, the thermodynamic/kinetic control limitations based on minimum possible Gibbs free energy for the composite latex systems control the final particle morphology [22].

Figure 2 shows the DSC curves of composite particle samples that were synthesized via a two-stage emulsion polymerization. As shown, the glass transition temperature of the core phase in all core-shell particles is close to -54°C, whereas the second glass transition temperature indicates the T_g of copolymer shell. An increase in the T_g of the shell phase from 11.2°C for the CSR1 particles to 104°C for the CSR6 particles was observed. This temperature shift can be attributed to the increase of rigid MMA units in the shell structure.

**Blend Morphology**

Dispersion state of core-shell structured particles with different shell compositions inside the UP matrix was studied by SEM apparatus. Figure 3 reveals the dispersion of CSR particles within the blended samples. A good dispersion state of CSR2 and CSR4 emulsion particles, with their respective PVAc and VAc/MMA (50/50 wt/wt) shell copolymer composition was observed (Figures 3a and 3b). In these samples, the microdomains of CSR particles seem to be very close together and dispersed well in the UP matrix. This uniform dispersion can be related to good compatibilization between the matrix and the shell which prevents the formation of very big particle agglomerates inside the UP matrix. In fact, a lower interfacial tension between PVAc shell and UP matrix resulted in a good dispersion state of CSR2 rubber particles (Figure 3a). Thus, the CSR2 particles were discretely dispersed inside the UP matrix to obtain the minimum Gibbs free energy for the blend system. Nevertheless, a few small particle agglomerates are obvious in the blend sample containing CSR4 particles (Figure 3b).

In overall, the VAc/MMA (50/50 wt/wt) copolymer shell with proper compatibility in the ST/UPA/CSR ternary system provides the blend morphology with rather good dispersion of particles. On the contrary, the CSR6 rubber particles were coagulated as very big clusters or rubber chunks inside the UP matrix (Figure 3c). Low compatibility between the dominant PMMA shell units and UP matrix may lead to more increases in particles agglomeration and to appear as very big clusters. In fact, the interfacial adhesion between CSR shell and UP is one of the crucial process parameters to control the morphology and mechanical properties of the rubber-modified unsaturated polyester resin.

The TEM micrographs (Figure 4) show the blend morphology of the blend samples. The bright and gray regions in the micrographs correspond to the rubbery dispersed phase and continuous UP phase, respectively. It seems that in the blend samples the conventional staining method can stain neither
Figure 3. SEM Micrographs of UP blends with various CSR materials: (a) CSR2, (b) CSR4 and (c) CSR6.

Figure 4. TEM Micrographs of UP blends with various CSR materials: (a) CSR2, (b), (c) CSR4 and (d) CSR6.

Acrylate core nor copolymer shell inside the composite particles, especially for the CSR2 particles with the PVAc homopolymer shell (Figure 4a). This behaviour can be attributed to the inclusion of polystyrene phase inside the composite particles which lowers the staining efficiency considerably. At the same time the very close refraction indices of the UP and CSR particles in the blend systems result in lower
phase contrast. However, a good dispersion of rubber particles was observed in the blend samples containing CSR2 or CSR4 particles (Figures 4a to 4c). In contrast, very big rubber particle agglomerates are observed for the blend sample containing CSR6 particles with an incompatible PMMA shell (Figure 4d).

**Impact Toughness**

The impact test was performed to study the effect of different core-shell rubber particles on the impact toughness of the cured unsaturated polyester resin (UP). The fracture toughness of cured resin without rubber particles was also measured for comparison purposes. Table 3 indicates the impact energy values for the cured resin blended with various types of CSR particles whose shell compositions contain 0, 20, 50, 70 and 100% (by weights) MMA units. As it is shown, varying the shell composition would show different toughening efficiencies of CSR particles under similar impact test conditions. Adding 5% (by weight) CSR4 particles with 50% (by weight) MMA units in their copolymer shell considerably increases the impact toughness of the UP from 35 to 51.4 J/m (Table 3). This mechanical improvement can be ascribed to the proper dispersion state of the rubber particles within the resin matrix (Figures 4b and 4c). Varying the shell chemical composition and consequently interfacial adhesion between the phases alters the particle dispersion state and influences the impact toughness of the matrix. The introduction of

<table>
<thead>
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<th>Code</th>
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</thead>
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<tr>
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<td>CSR2</td>
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<td>BL6</td>
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The core-shell content level in all the blend samples was 5% (by weight) based on the total weight of ST/UPA mixture.

**Figure 5.** The fracture surface of the UP resin containing different types of CSR particles: (a) neat resin, (b) CSR2, (c) CSR4 and (d) CSR6 (mag.: 250×).
CSR materials with higher 50% (by weight) MMA content in the copolymer shell decreased the impact toughness of cured ST/UPA/CSR ternary system as compared to the neat ST/UPA resin without any rubber particles. In fact, the poor resin/particle interfacial adhesion and frequently the agglomeration of rubber particles inside the matrix (Figure 4d) seems to lower the toughening efficiency (Table 3).

Fracture Morphology
The fracture surface of the cured ST/UPA and ST/UPA/CSR blends was studied by scanning electron microscopy. A flake-like microstructure was observed for the cured neat resin with low impact fracture of 35 J/m (Figure 5a). The blend with CSR2 particles showed a rough fracture surface (Figure 5b). Nevertheless, the fracture energy of the blend was close to that of the cured resin without rubber modifier (Table 3). A coarse fracture surface for the CSR4-modified resin corresponded with the highest impact fracture obtained (Figure 5b). The highest impact energy was obtained for the ST/UPA/CSR4 system when compared with the neat resin and other ST/UPA/CSR blend samples. For the blend containing CSR6 particles with PMMA shell, the rough fracture surface consisted of a complete separated ST/UPA continuous phase and a CSR-dispersed phase area (Figure 5d). In this blend sample, the big clusters of rubber particles were dispersed in the matrix (Figure 4d).

CONCLUSION
PBA/P(VAc-co-MMA) structural rubber particles were synthesized via a two-stage emulsion polymerization. The TEM micrographs showed that using higher content of MMA, which was above 50% (by weight), in the shell chemical composition resulted in composite particles with real core-shell structure. The prepared CSR particles were used to toughen the rigid cured ST/UPA (75/25 wt/wt) resin. For the rubber composite particles with MMA shell units up to 50% (by weight), a good dispersion state of rubber particle within the resin was observed. The incorporation of CSR particles with 50% (by weight) MMA copolymer shell resulted in the highest impact strength when compared to the neat and other CSR-modified resins. Further increase of the MMA units in the shell composition led to much more particle agglomeration inside the ST/UPA matrix and lower toughening efficiency.

REFERENCES
10. Kim H, Keskkula H, Paul DR, Effect of acrylonitrile content on the toughness of ABS materials,


