Rubber Toughened Styrene/Methyl Methacrylate/Butyl Methacrylate Composites by the Concentrated Emulsion Pathway

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SYNOPSIS

Solutions of rubber in mixtures of styrene, methacrylate, and/or butyl methacrylate containing proper amounts of initiator have been polymerized to produce novel polymer composites—MBBS. In these composites, it is expected that tri-component and bi-component copolymers as well as homopolymers coexist. The tensile behavior of composites of various compositions was investigated. At certain weight ratios of monomers, excellent combinations of tensile strength, elongation, and toughness were obtained, which are better than those of most commercial engineering plastics. There is an optimum amount of butyl methacrylate, which is dependent upon the contents of the other monomers, for which the toughness acquires a maximum value. The concentrated emulsion polymerization was employed to prepare the MBBS composite latexes and the products were compared with those prepared via bulk polymerization. While the two polymerization methods provide high, comparable tensile properties and toughness, the concentrated emulsion method generates latexes which can be more easily processed in any desirable shape. © 1994 John Wiley & Sons, Inc.

INTRODUCTION

The family of styrene-based plastics materials constitutes the most important group of thermoplastics. Besides the styrene (St) homopolymer, a series of excellent copolymers was developed to meet the various needs, such as acrylonitrile–butadiene–styrene (ABS),[1] methyl methacrylate–butadiene–styrene (MBS),[2] acrylonitrile–styrene–acrylate (ASA),[3] and rubber-toughened PS,[4-5] etc. In the preparation of the above copolymers, styrene, acrylonitrile, and/or other monomers were added to polybutadiene latexes and the mixtures were further heated for polymerization. The composites usually contain several homopolymers, copolymers, and especially polybutadiene grafted with styrene and other monomers. For some applications, however, the tensile properties of most of these materials are not good enough, the elongation of ABS and ASA being only 20%.[6] Some rubber-toughened polystyrenes have a higher elongation of about 40%, but with tensile strengths below 20MPa.[5]

In this work, a novel styrene-based tough composite—denoted MBBS—was prepared and tested. The name is based on the monomers employed: methyl methacrylate (MMA), butyl methacrylate (BMA), styrene, and a thermoplastic elastomer—styrene/butadiene/styrene tri-block copolymer (SBS). The copolymerization of styrene, MMA, and BMA generated a strong, tough, and easily processible material, which is additionally toughened by SBS and by the grafting of monomers onto the polybutadiene segments. A recently developed synthesis pathway—the concentrated emulsion polymerization[7-9]—was employed to prepare the MBBS composites. A concentrated emulsion differs from a traditional emulsion in that the volume fraction of the dispersed phase is larger than 0.74, which represents the most compact arrangement of spheres of equal size. At high volume fractions the dispersed phase is no longer spherical in shape but becomes polyhedral, the droplets being separated by a network of thin films of the continuous phase. The MBBS composites were also prepared via bulk po-

lymerization for comparative purposes. In a previous paper,[10] rubber-toughened styrene composites have been prepared using similar procedures. The toughnesses obtained in the present paper are much larger than those obtained in that earlier work.

EXPERIMENTAL

Materials

Styrene (St, Aldrich), methyl methacrylate (MMA, Aldrich), and butyl methacrylate (BMA, Aldrich) were distilled before use. Azobisisobutyronitrile (AIBN, Alfa) was recrystallized from methanol. Sodium dodecyl sulphate (SDS, Aldrich) and styrene/butadiene/styrene tri-block copolymer (SBS, Aldrich) were used as received. Water was distilled and deionized.

Preparation Procedure

Styrene, MMA, and BMA monomers were mixed in various proportions. SBS (20 g per 100 ml monomers) and AIBN (0.4 g per 100 ml monomers) were introduced into the monomer mixtures and the systems were allowed to stand overnight to generate uniform monomer-rubber solutions. An aqueous solution of SDS (5 g SDS per 100 ml water) was introduced into a single-neck 100 mL flask provided with a magnetic stirring bar, the volume of SDS aqueous solution being one-fourth of the monomer-rubber solution employed. Then the flask was sealed with a rubber septum and half of the monomer-rubber solution was added with a syringe through the rubber septum, dropwise, with vigorous stirring. The whole addition process lasted about 15 minutes and took place at room temperature. The paste-like concentrated emulsion thus formed was stirred for an additional 15 minutes and was finally transferred to a tube of 30 mL capacity. The tube was introduced into a water bath of 60°C for polymerization. Another half of the monomer-rubber solution was transferred to another tube which was introduced into a Cole Parmer ultrasonic mixer, at 60°C, for 6 hours for polymerization. The system was mixed during polymerization with ultrasonic vibrations. After 6 hours the system's viscosity became very high and mixing was no longer possible. Consequently, the tube was transferred to a water bath of 60°C. Both polymerization processes lasted 96 hours. The material obtained by the concentrated emulsion method was transformed into a fine powder in a blender, washed in an extractor with methyl alcohol for 24 hours, and dried in a vacuum oven for another 24 hours. The product obtained by bulk polymerization was directly used in various testings.

Differential Scanning Calorimetry (DSC)

The thermal transitions of the samples were determined with a Perkin–Elmer DSC instrument. Each sample was heated twice from–60° to 210°C, with a heating rate of 10°C/min. After the first heating, the sample was cooled at a rate of 10°C/min to a temperature below–60°C and then heated for the second time.

The Tensile Testing

Certain amounts of powder for the products of the concentrated emulsion polymerization, or bulk material for the products of bulk polymerization, were hot-pressed in a Laboratory Press (Fred S. Carver Inc.) at 180°C for 3–5 min, and then cooled to room temperature. The sheet thus obtained was cut to the size required by the ASTM D.638-58T. The tensile testing was conducted at room temperature with an Instron Universal Testing Instrument (Model 1000). The elongation speed of the instrument was 50 mm/min.

RESULTS AND DISCUSSION

The Glass Transition Temperature

The glass transition temperatures are listed in Table I. Note that each sample has one T_g in the range of 60 to 95°C. These transition temperatures are higher than that of PBMA (27°C) but lower than those of PS (100°C) and PMMA (114°C), and decrease as the content of BMA increases. Obviously, they represent the T_g of the copolymer. Since no T_gs of the homopolymers were detected, it is clear that their contents are small.

The Stress–Strain Curves

Two sets of stress–strain curves of the MBBS composites are presented in Figures 1 and 2, for composites containing MMA weight fractions of 0.09 and 0.27, respectively. The curves are similar in several aspects: (i) Each has a pronounced yield point, the yield strain being about 4%; (ii) A stress minimum appears at an elongation of about 20%; (iii) The ultimate stress, which is taken as the tensile strength, is almost the same as the yield stress. All

Table I The Glass Transition Temperatures (°C) of the Samples Prepared via Concentrated Emulsion Polymerization

wt Ratio* St/MMA/BMA	First Heating	Second Heating
A. wt. fraction of Styrene = 0.45		
5/5/0	97.0	97.0
5/3/2	89.5	82.1
5/2/3	85.1	79.2
5/1/4	63.5	60.8
5/0/5	61.9	55.5
B. wt. fraction of MMA = 0.27		
7/3/0	94.9	92.3
6/3/1	91.2	89.1
5/3/2	89.5	82.1
4/3/3	67.9	72.7
C. wt. fraction of BMA = 0.27		
7/0/3	67.5	64.2
5/2/3	85.1	79.2
4/3/3	67.9	72.7

* The system also contains 20 g SBS per 100 ml monomer mixture.

these common characteristics of the stress-strain curves suggest similarities among these composites. The MBBS composites consist of a rubber phase (the polybutadiene in SBS) and several glassy phases of the polystyrene segments in SBS, the homopolymers and the copolymers. The distinct yield point indicates that the glassy phases constitute the continuous phase which contains rubber particles.[11-12] The glassy phases provide high tensile strength and toughness, and the rubber particles contribute additionally to the toughness. The presence of BMA with its butyl lateral chain in the copolymer increases the free volume, since the polymer chains can no longer organize in a compact manner. This increases the mobility of the chains and results in high elongation and toughness. However, there is a major difference between the two sets of stress-strain curves regarding the stress hardening. The curves of Figure 1 pass through an approximately flat region followed by stress hardening; those in Figure 2 pass directly from stress softening to stress hardening. Since the flat region is a result of the motion and orientation of segments, one can infer that the composites with lower MMA contents allow a higher extent of such motions than do those with a higher MMA content.

Tensile Strength and Elongation

Regarding the tensile strength and elongation at the break point, one can notice the excellent combination of properties achieved by the MBBS composites, which are better than those of most styrene-based materials already produced. The latter provide tensile strengths between 30-50 MPa and elongations at the break point of 40-20%, the higher tensile strength being associated with the smaller elongation.[5,6,13,14] As shown below, the MBBS composites provide tensile strengths of 40-60 MPa and elongations greater than 50%.

A. Effect of the MMA/BMA Weight Ratio

The investigation of the effect of the weight ratio MMA/BMA at constant styrene content was carried out in four sets of experiments, and the results are listed in Table II. The general trends are similar in all four sets of data; the larger the MMA/BMA ratio, the higher the tensile strength and the lower the elongation. The tensile strength decreases sharply at the beginning and moderately later, while
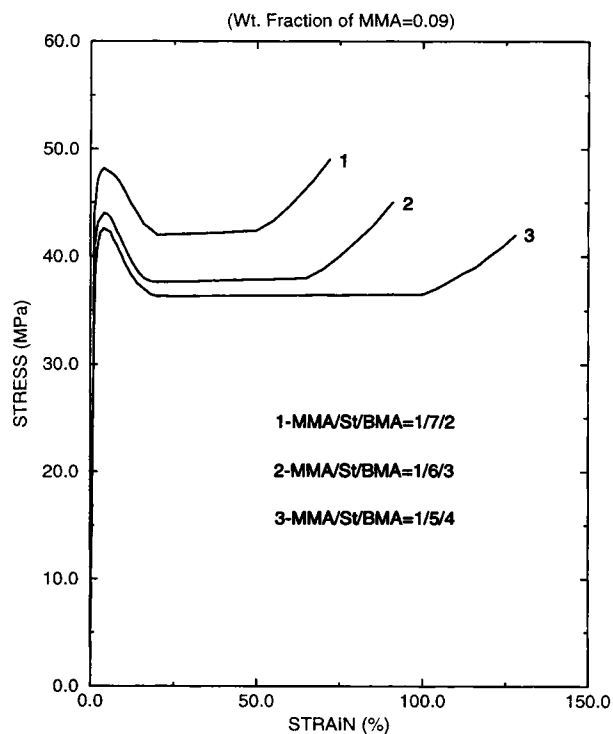

Figure 1 Stress–strain curves of MBBS composites prepared via concentrated emulsion polymerization (wt fraction of MMA = 0.09).
1-MMA/St/BMA = 1/7/2 wt ratios
2-MMA/St/BMA = 1/6/3 wt ratios
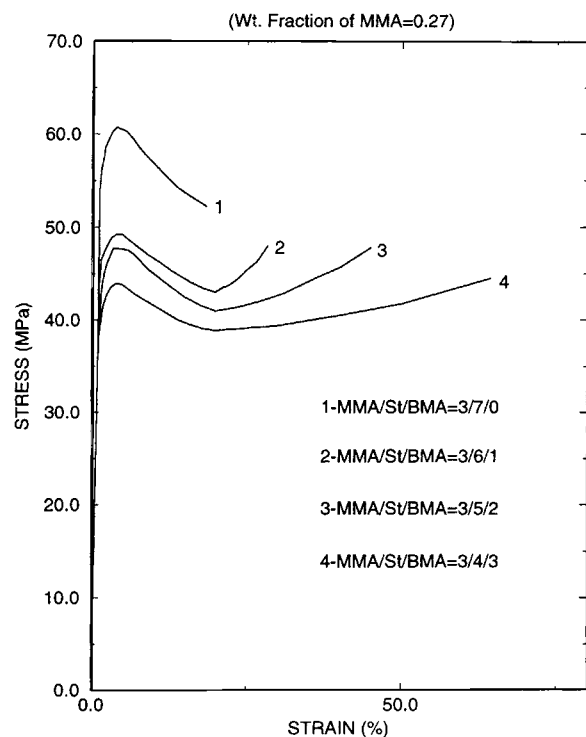3-MMA/St/BMA = 1/5/4 wt ratios

Figure 2 Stress–strain curves of MBBS composites prepared via concentrated emulsion polymerization (wt fraction of MMA = 0.27).
1-MMA/St/BMA = 3/7/0 wt ratios
2-MMA/St/BMA = 3/6/1 wt ratios
3-MMA/St/BMA = 3/5/2 wt ratios
4-MMA/St/BMA = 3/4/3 wt ratios

the elongation increases notably with the ratio MMA/BMA. This can be explained as follows. MMA has a polar lateral group — $COOCH_3$. The strong repulsions among these polar groups are responsible for the stiffness of the chains, and the attractive interactions among the segments contribute to the high strength of the material. BMA, however, has a longer non-polar lateral group and, for this reason, its presence in the copolymer generates additional free volume which makes the chain more flexible, thus increasing the elongation.

B. Effect of the St/BMA Weight Ratio

The experimental data of Table III have been carried out at constant content of MMA and various St/BMA ratios. The larger the St/BMA ratio, the lower the elongation and the higher the tensile strength, the elongation again being more sensitive to the St/BMA ratio than the tensile strength. The explanation for the effect of BMA is the same as above; however, the effect of styrene is somewhat different

from that of MMA. Because of the lateral rigid phenyl groups, the styrene units in the polymer chain tend to increase the stiffness and brittleness. However, as can be seen from Table II, the reductions in elongation caused by the increase of St/BMA ratio are smaller than those caused by the increase of MMA/BMA ratio in Table I. This is because: (i) styrene can be more easily grafted onto the rubber chains,[5,15] and the grafted rubber plays a positive role for both tensile strength (since it increases the compatibility between SBS and copolymer) and elongation (since it increases the free volume), and (ii) the compatibility between SBS and copolymer is enhanced by the higher content of styrene. These effects prevail over the negative effect of the phenyl groups.

C. Effect of the St/MMA Weight Ratio

Table IV presents the dependence of the tensile strength and the break-point elongation on the St/MMA ratio at constant BMA content. One may notice that the tensile strength remains almost constant, even though the tensile strengths of MMA and styrene homopolymers are about 75 and 52 MPa,[6] respectively. The composite with a greater content in MMA is, therefore, expected to have a higher tensile strength. This does not happen, however, because the increase in the intermolecular attraction caused by a greater number of MMA units is associated with the decrease in the compatibility of the system. This latter effect can be easily seen from the solubility parameters[16] of the involved homopolymers: PB: 16.2–17.6; PS: 17.4–18.7; PBMA: 17.0–18.0; PMMA: 18.6–19.5 $(MPa)^{1/2}$. In addition, the copolymerization and the grafting also play a role. The copolymerization parameter of MMA/St is about 0.52/0.46, and that of BMA/St is almost the same.[16] As a result, the MMA monomer is more likely to be included into the copolymer chains than styrene. In other words, a smaller fraction of MMA homopolymer is formed than of styrene. Furthermore, as mentioned above, styrene is more active in grafting onto the rubber chains than either of the other two monomers, and grafting leads to higher molecular weights and better compatibility. The copolymerization, which decreases the tensile strength, and grafting, which increases the tensile strength, together with the increase in the intermolecular interaction and the decrease in compatibility, almost compensate one another and, as a result, the tensile strength remains almost constant. The polarity of the MMA monomer, however, increases the stiffness of the molecular chains, and, as a result, the elon-

Table II   The Tensile Properties of the MBBS Composites at Constant Styrene Contents

Wt ratio* St/MMA/BMA	Concentrated Emulsion				Bulk Polymerization			
	Tensile Strength (MPa)		Elongation (%)		Tensile Strength (MPa)		Elongation (%)	
	Ave. Value	Std. Error	Ave. Value	Std. Error	Ave. Value	Std. Error	Ave. Value	Std. Error
A. wt. fraction of Styrene = 0.64								
7/3/0	63.9	2.5	17.1	0.9	61.8	4.0	18.5	1.1
7/2/1	51.4	3.0	25.2	2.8	49.5	5.1	32.5	1.2
7/1.5/1.5	51.5	3.5	32.2	2.2	48.2	4.4	36.3	3.1
7/1/2	48.8	0.5	66.5	3.7	48.2	0.6	72.1	5.5
7/0/3	48.7	5.6	101.8	4.1	45.9	1.2	107.2	2.7
B. wt. fraction of Styrene = 0.55								
6/4/0	61.1	2.9	17.2	1.2	59.1	3.1	19.2	1.3
6/3/1	50.7	1.5	24.8	2.7	49.3	2.8	28.4	2.6
6/2/2	49.0	2.7	34.7	1.4	46.4	1.8	38.9	1.5
6/1.5/2.5	47.0	1.4	71.1	1.2	44.3	0.8	76.2	0.8
6/1/3	47.6	3.0	85.4	4.2	44.1	2.2	90.4	3.8
6/0/4	41.5	1.6	120.1	9.8	39.1	3.1	134.1	10.4
C. wt. fraction of Styrene = 0.45								
5/5/0	57.4	0.9	16.3	1.1	56.5	1.3	18.5	0.8
5/3/2	47.3	2.6	37.3	0.5	47.8	2.5	45.0	1.7
5/2.5/2.5	45.3	3.5	59.7	1.9	43.8	3.0	66.9	2.7
5/2/3	45.0	4.3	100.4	12.3	43.0	1.3	106.4	12.0
5/1/4	43.6	1.3	120.7	7.0	42.6	1.7	128.8	8.7
5/0/5	38.0	1.4	131.8	3.7	36.5	1.3	155.4	7.4
D. wt. fraction of Sytrene = 0.27								
3/7/0	56.5	1.5	18.5	0.9	51.0	1.1	20.4	1.8
3/5/2	50.1	1.6	31.9	1.9	46.1	1.3	33.0	2.1
3/2/5	45.7	1.9	109.0	7.9	42.4	1.9	120.3	8.8

* The system also contains 20 g SBS per 100 ml monomer mixture.

gation is negatively influenced by an increase in the MMA content (Table IV).

The Toughness of the Composites

The energy needed to break the sample of unit cross-area and unit length is considered here as a measure of toughness. It can easily be obtained by the graphical integration of the stress-strain curve. Tables V–VII show that the toughness increases with increased content of BMA and decreases as the contents of MMA and styrene become larger. For a polymer to have high toughness, it should simultaneously have strong interactions between the chains and high mobility of the segments.[17] In such cases, the exter-

nal energy is consumed in the motion of the segments without fracturing the material. The design of the MBBS composites prepared in this work was based on the above simple concept. The MMA units provide strong stiffness to the chain because the repulsive interactions among the side groups decrease the mobility; however, the attractive interactions among the segments have a positive contribution to the tensile strength. The styrene units provide some stiffness because of the bulky, rigid side groups; and the nonpolar lateral groups of the BMA units generate an additional free volume among segments, which increases the toughness of the material. However, an excess of free volume is not favorable for toughness, since the interactions among the

Table III The Tensile Properties of the MBBS Composites at Constant MMA Contents

Wt Ratio* MMA/St/BMA	Concentrated Emulsion				Bulk Polymerization			
	Tensile Strength (MPa)		Elongation (%)		Tensile Strength (MPa)		Elonagation (%)	
	Ave. Value	Std. Error	Ave. Value	Std. Error	Ave. Value	Std. Error	Ave. Value	Std. Error
A. wt. fraction of MMA = 0								
0/8/2	50.6	1.6	97.7	4.1	47.8	2.7	104.5	5.5
0/7/3	48.7	5.6	101.8	4.1	45.9	1.2	107.2	2.7
0/6/4	41.5	1.6	120.1	9.8	39.1	3.1	134.1	10.4
0/5/5	38.0	1.4	131.8	3.7	36.5	1.3	155.4	7.4
B. wt. fraction of MMA = 0.09								
1/7/2	48.8	0.5	66.5	3.7	48.2	0.6	72.1	5.5
1/6/3	47.6	3.0	85.4	4.2	44.1	2.2	90.4	3.8
1/5/4	43.6	1.3	120.7	7.0	42.6	1.7	128.8	8.7
C. wt. fraction of MMA = 0.18								
2/7/1	51.4	3.0	25.2	2.8	49.5	5.1	32.5	1.2
2/6/2	49.0	2.7	34.7	1.4	46.4	1.8	38.9	1.5
2/5/3	45.0	4.3	100.4	12.3	43.0	1.3	106.4	12.0
2/3/5	45.7	1.9	109.0	7.9	42.4	1.9	120.3	8.8
D. wt. fraction of MMA = 0.27								
3/7/0	63.9	2.5	17.1	0.9	61.8	4.0	18.5	1.1
3/6/1	50.7	1.5	24.8	2.7	49.3	2.8	28.4	2.6
3/5/2	47.3	2.6	37.3	0.5	47.8	2.5	45.0	1.7
3/4/3	46.4	1.8	59.9	3.9	44.0	2.0	64.4	5.2

* The system also contains 20 g SBS per 100 ml monomer mixture.

Table IV The Tensile Properties of the MBBS Composites at Constant BMA Contents

Wt Ratio* BMA/St/MMA	Concentrated Emulsion				Bulk Polymerization			
	Tensile Strength (MPa)		Elongation (%)		Tensile Strength (MPa)		Elongation (%)	
	Ave. Value	Std. Error	Ave. Value	Std. Error	Ave. Value	Std. Error	Ave. Value	Std. Error
A. wt. fraction of BMA = 0.18								
2/8/0	50.6	1.6	97.7	4.1	47.8	2.7	104.5	5.5
2/7/1	48.8	0.5	66.5	3.7	48.2	0.6	72.1	5.5
2/6/2	49.0	2.7	34.7	1.4	46.4	1.8	38.9	1.5
2/5/3	47.3	2.6	37.3	0.5	47.8	2.5	45.0	1.7
2/3/5	50.1	1.6	31.9	1.9	46.1	1.3	33.0	2.1
B. wt. fraction of BMA = 0.27								
3/7/0	48.7	5.6	101.8	4.1	45.9	1.2	107.2	2.7
3/6/1	47.6	3.0	85.4	4.2	44.1	2.2	90.4	3.8
3/5/2	45.0	4.3	100.4	12.3	43.0	1.3	106.4	12.0
3/4/3	46.4	1.8	59.9	3.9	44.0	2.0	64.4	5.2

* The system also contains 20 g SBS per 100 ml monomer mixture.

Table V   The Toughness of the MBBS Composites at Constant Styrene Contents

Wt Ratio* St/MMA/BMA	Concentrated Emulsion Toughness (KJ/m³)		Bulk Polymerization Toughness (KJ/m³)	
	Ave. Value	Std. Error	Ave. Value	Std. Error
A. wt. fraction of Styrene = 0.64				
7/3/0	10.6	0.9	11.1	0.7
7/2/1	12.2	1.1	13.6	1.2
7/1.5/1.5	15.5	1.4	16.3	1.4
7/1/2	29.2	2.3	31.3	3.1
7/0/3	44.6	3.9	44.3	2.2
B. wt. fraction of Styrene = 0.55				
6/4/0	9.9	0.7	9.6	0.4
6/3/1	12.2	1.2	13.6	0.8
6/2/2	16.1	0.5	17.1	1.3
6/1.5/2.5	31.7	3.0	32.0	2.5
6/1/3	48.8	2.7	50.4	4.4
6/0/4	44.8	3.3	46.2	3.7
C. wt. fraction of Styrene = 0.45				
5/5/0	8.9	0.2	9.4	0.5
5/3/2	16.8	1.0	20.4	1.1
5/2.5/2.5	25.7	1.7	27.8	2.2
5/2/3	41.9	3.2	42.5	2.7
5/1/4	57.7	3.5	63.8	3.9
5/0/5	47.1	3.7	52.7	4.8
D. wt. fraction of Styrene = 0.27				
3/7/0	10.1	0.7	10.1	0.4
3/5/2	15.2	1.1	14.5	0.7
3/2/5	44.8	3.1	50.1	2.9

* The system also contains 20 g SBS per 100 ml monomer mixture.

chains are too much weakened. Tables V(B) and V(C) show that the toughness presents maxima for certain ratios of MMA/BMA. This happens because, while increasing the free volume (hence the elongation), a too-large content of BMA decreases the interactions (hence the tensile strength) to such an extent that the toughness is decreased.

Comparison between Concentrated Emulsion and Bulk Polymerizations

From Tables I through VII one can conclude that the mechanical properties obtained via the concen-

trated emulsion polymerization method are comparable to those obtained via bulk polymerization. The tensile strength of the composite based on concentrated emulsions is generally higher than that based on bulk polymerization; the elongation at the break point and the toughness are a little lower. This is a result of the different preparation methodologies. After polymerization, the product of the concentrated emulsion was transformed into a fine powder which was washed with methyl alcohol, whereas that of bulk polymerization was directly used for testing. The oligomers and the unreacted monomers present in the concentrated emulsion product were removed by washing. As a result the molecular weight distribution is probably narrower than in bulk polymerization, and higher tensile strengths and lower elongations and toughness are generated. However, the washing of the concentrated emulsion products

Table VI   The Tensile Properties of the MBBS Composites at Constant MMA Contents

Wt Ratio* MMA/St/BMA	Concentrated Emulsion Toughness (KJ/m³)		Bulk Polymerization Toughness (KJ/m³)	
	Ave. Value	Std. Error	Ave. Value	Std. Error
A. wt. fraction of MMA = 0				
0/8/2	41.4	3.3	42.0	2.9
0/7/3	44.6	3.9	44.3	2.2
0/6/4	44.8	3.3	46.2	3.7
0/5/5	47.1	3.7	52.7	4.8
B. wt. fraction of MMA = 0.09				
1/7/2	29.2	2.3	31.3	3.1
1/6/3	48.8	2.7	50.4	4.4
1/5/4	57.7	3.5	63.8	3.9
C. wt. fraction of MMA = 0.18				
2/7/1	12.2	1.1	13.6	1.2
2/6/2	16.1	0.5	17.1	1.3
2/5/3	41.9	3.2	42.5	2.7
2/3/5	44.8	3.1	50.1	2.9
D. wt. fraction of MMA = 0.27				
3/7/0	10.6	0.9	11.1	0.7
3/6/1	12.2	1.2	13.6	0.8
3/5/2	16.8	1.0	20.4	1.1
3/4/3	25.0	2.2	25.5	1.8

* The system also contains 20 g SBS per 100 ml monomer mixture.

Table VII The Toughness of the MBBS Composites at Constant BMA Contents

Wt Ratio* BMA/St/MMA	Concentrated Emulsion Toughness (KJ/m³)		Bulk Polymerization Toughness (KJ/m³)	
	Ave. Value	Std. Error	Ave. Value	Std. Error
A. wt. fraction of BMA = 0.18				
2/8/0	41.4	3.3	42.0	2.9
2/7/1	29.2	2.3	31.3	3.1
2/6/2	16.1	0.5	17.1	1.3
2/5/3	16.8	1.0	20.4	1.1
2/3/5	15.2	1.1	14.5	0.7
B. wt. fraction of BMA = 0.27				
3/7/0	44.6	3.9	44.3	2.2
3/6/1	48.8	2.7	50.4	4.4
3/5/2	41.9	3.2	42.5	2.7
3/4/3	25.0	2.2	25.5	1.8

* The system also contains 20 g SBS per 100 ml monomer mixture.

is necessary, since otherwise a large amount of surfactant will remain in the system, which is harmful to the mechanical properties. On the other hand, the concentrated emulsion method has the main advantage that it generates a fine powder which can be used in many applications. In contrast, bulk polymerization produces only a bulk material.

CONCLUSION

1. The newly developed MBBS composites possess excellent combinations of tensile strength, elongation at break point, and toughness, which are better than those of most styrene-based polymers previously produced.

2. The concentrated emulsion method can be employed to prepare MBBS composites. The mechanical properties of the composites are comparable to those obtained via bulk polymerization. However, in contrast to the bulk polymerization method, which provides a bulk material, the concentrated emulsion method provides latexes.

3. In the MBBS composites, an increase in the BMA content provides higher elongation and toughness but lower tensile strength.

4. As the BMA content increases, the toughness passes through a maximum. Hence a proper amount of MMA is needed to achieve an optimum toughness.

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