Quantitative analysis of unknown compositions in ternary polymer blends: A model study on NR/SBR/BR system

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\section*{Abstract}
In this work, a quantitative analysis of compositions in ternary blends were performed using multi-techniques including Fourier transform infrared (FT-IR) spectroscopy, thermogravimetric analysis (TGA), differential scanning calorimetry (DSC) and pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) with a model ternary blend system of natural rubber (NR), styrene-butadiene rubber (SBR) and butadiene rubber (BR). In FT-IR analysis of pyrolyzate of rubbers, each characteristic peak was affected by the presence of another component polymer in the binary or ternary blends. The TGA shows that the quantitative analysis of SBR/BR blends is impossible because of their very close thermal decomposition behaviors. In DSC analysis, it is possible to determine only the blend composition of SBR/BR. Therefore, it was difficult to characterize a composition of the ternary blend system of NR/SBR/BR. However, the quantitative analysis of compositions using Py-GC/MS is the most precise among other instruments because each characteristic peak on the Py-GC/MS pyrograms is unique.

\section*{1. Introduction}
Recently, the commercial importance of polymer blends is increasing since the performance of polymers can be improved by simple blending of commercially available polymers in order to fulfill industry's need for high performance materials [1,2]. The physical and mechanical properties of these blends are sensitive to small variations in the amounts of the individual polymers used. Therefore, there is a need for developing a variety of analytical tools to monitor blend composition.

Fourier transform infrared (FT-IR) spectroscopy is often used to characterize the composition of polymer blends [2–5]. Ghebremeskel and Shield [6,7] used FT-IR to determine a polymer composition of binary and ternary blends of styrene-butadiene rubber (SBR), nitrile-butadiene rubber (NBR) and poly(vinyl chloride) (PVC).

Thermogravimetric analysis (TGA) [8] can be used as a way to measure the thermal stability of a polymer [9,10] and the thermal degradation of polymer blends [11,12,13] due to the simplicity of the weight loss method. The potential of thermogravimetry (TG)-derivative thermogravimetry (DTG) procedure for quantitative analysis of vulcanizates based on binary elastomer blends was studied by Maurer [14] for NR/ethylene-propylene-diene terpolymer (EPDM) blends, by Brazier and Nickel [15] for blends of NR/polysisoprene rubber (IR), NR/BR and NR/SBR, and by Sircar and Lamond [16] for blends of NR/SBR, NR/BR and SBR/BR. The thermal degradation behavior of a blend has been used to identify SBR/BR blends from SBR based compounds by Amraee et al. [17] using the ratio of the peak height of a DTG peak. Shield and Ghebremeskel [18] utilized the temperature that corresponds to 70\% weight loss of original sample weight (\(T_{70\%}\)) to correlate with the styrene content in SBR. Using same methods, Shield and Ghebremeskel [19] investigated the SBR content in SBR/BR blends.

Differential scanning calorimetry (DSC) is also often used to characterize the thermal degradation of elastomers [20]. Marsh

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et al. [21] have used this technique to characterize a number of blends of commercial importance. It was found that the DSC patterns for a given elastomer are retained in the blend, thus providing a basis for identifying the polymers in the blend, in many cases.

Solid state carbon 13-nuclear magnetic resonance (\(^{13}\)C-NMR) allows identification of functional groups in polymers and provides information of their global chemical structure [22–24]. Also, the relaxation time can provide detailed information about the dynamics of polymer backbone and side-chain motions. However, solid state \(^{13}\)C-NMR cannot be considered as a quantitative method, since it is well documented that aliphatic carbons are overestimated, comparing to aromatic ones [25,26].

Pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) has been used extensively for qualitative and quantitative identification of polymer blends [27–40]. Ghebremeskel and Hendrix [41] used Py-GC/MS to characterize blends of NR/SBR and NR/BR. Ghebremeskel et al. [42] used Py-GC/MS to determine the styrene content of a SBR copolymer.

In ternary systems, it has always been difficult to determine the real composition of polymers [43,44]. The NR/SBR/BR ternary blend system may be quite unique in that there are three different possible binary pairs (NR/SBR, NR/BR and SBR/BR) and SBR contains BR as a constituent.

In this study, therefore, compositions in the ternary NR/SBR/BR blends were quantitatively analyzed by TGA, DSC and Py-GC/MS, in addition to the FT-IR spectroscopy of rubber pyrolyzates.

2. Experimental

2.1. Materials

Standard Malaysian rubber (NR, SMR #10) was used as natural rubber. Styrene-butadiene rubber (SBR, KOSYN 1502) and butadiene rubber (BR, KBR 01) were produced by Kumho Petrochemical Co., Ltd. The SBR is a random copolymer with a styrene content of 23.5 wt.%. The BR is high cis BR with their 1,4-cis content of more than 94%. The glass transition temperature is \(-107\) °C. The NR, SBR, and BR grades were chosen because of their wide uses in rubber industries. All other compounding materials such as filler, vulcanizing agent (sulfur) and accelerator were commercially available grades.

2.2. Sample preparation

All the binary rubber blends, NR/SBR, SBR/BR and NR/BR systems, were prepared with the blend ratio in the range from 0 to 100% by 10% increase. Additives were compounded in the same proportions to prepare all the blends (stearic acid: 1.0 phr, ZnO: 5.0 phr, carbon black: 50 phr, accelerator CBS: 1.0 phr, sulfur: 2.0 phr). The rubber compounds were mixed in a brabender internal mixer equipped with a banbury-type mixing blade. A rotor speed of 70 rpm and an oil temperature of 70 °C were used. The volume of the mixing chamber was 60 cm\(^3\), and formulations were calculated to give a fill factor of 0.70. A typical mixing cycle in the brabender mixer was to mix the polymers for 2.5 min, to add carbon black, zinc oxide and stearic acid, and to mix for additional 3 min, then to add sulfur and accelerator and to continue mixing for another 0.5 min. Cured samples were prepared by molding the compounds using abrasion test mold (Φ160 mm × 120 mm) for optimum cure of 20 min at 155 °C under pressure. These compounds are coded based on composition of polymers. The NR, SBR and BR are denoted by N, S and B series, respectively. The blend composition is denoted as NxSyBz (NR \(x\)%), SBR \(y\)%), BR \(z\)%), where \(x\), \(y\), and \(z\) indicate the weight percentage of each rubber.

2.3. Sample pretreatment and experimental procedure

2.3.1. FT-IR

Infrared spectra were recorded using Magna 560 spectrometer (Nicolet) equipped with a DTGS detector, using 16 co-added scans acquired at 4 cm\(^{-1}\) resolution in the range of 4000–400 cm\(^{-1}\). A PC running Omnic E.S.P. software (version 5.1) was used to capture the spectra. A small amount of rubber was pyrolyzed to 450–500 °C. Care was taken to keep the delivery end of the pyrolysis tube warm enough so that pyrolysis products do not condense and block the opening, causing the tube to explode. The condensate can be collected in a small test tube containing anhydrous sodium sulfate to remove moisture. A few drops of the pyrolyzate were placed between a pair of polished potassium bromide plates. When the plates are squeezed gently, a thin liquid film is formed between them. A spectrum determined by this method was referred to a neat spectrum since no solvent was used and hence the pair of plates was inserted into a holder which fit into the spectrometer [45,46]. From the absorbance of infrared spectra of each sample, the appropriate peaks for the characterization of each compound were selected so that there was no overlapping either with each other or with the peaks of the matrix. The peak height absorbance values of each selected band were measured employing an appropriate baseline.

2.3.2. TGA

The thermal degradation studies were performed on a TGA 7 thermogravimetric analyzer (Perkin-Elmer). It was performed using 10.0 ± 0.5 mg samples to eliminate any sample size effects. The samples were heated from 30 to 900 °C using heating rate of 20 °C/min. The purge gas (N\(_2\)) flow rate to the TGA was set at 25 mL/min to 550 °C. At this point the purge gas (O\(_2\)) flow rate to the TGA was set at 25 mL/min to 800 °C. And then the purge atmosphere was changed to N\(_2\) and heating continued until a constant weight was achieved at 900 °C.

2.3.3. DSC

Samples were sealed in aluminum pans, and their thermal properties were measured by using Pyris 1 DSC (Perkin-Elmer). Indium was employed for temperature calibration and helium gas with a flux of ca. 30 mL/min was used to prevent oxidative degradation of samples. Samples were molten at 250 °C for 5 min in order to delete any previous thermal history and rapidly quenched in liquid nitrogen. Thermograms were...
then recorded at a heating rate of 10 °C/min. The inflection point of the slope of the heat capacity plot was taken as the glass transition temperature.

2.3.4. Py-GC/MS

The pyrolysis system consisted of a single-shot pyrolyzer (model 1010; Frontier Laboratories). The pyrolyzer was composed of a plunger for the sample, the sample cup, a deactivated needle (into the injector) and a microfurnace. Approximately 100 μg rubber sample was placed in pyrolyzer by sample holder and pyrolyzed at 550 °C. The pyrolyzer was directly connected to the injector of the GC. The transfer line to the GC was maintained at 320 °C. The effluent from pyrolyzer was split 1:200 at the GC injection port.

GC/MS analysis was carried out on Agilent 6890 GC equipped Agilent 5973N MSD. The pyrolysis products were separated on a 30 m long × 0.25 mm inside diameter HP-5MS capillary column (J&W Scientific) with a 0.25 μm thick stationary phase (5% phenyl methyl siloxane). The GC was operated in the pressure control mode using Helium as the carrier gas. The GC oven was programmed to hold at 50 °C for 3 min, then increase to 270 °C at a rate of 15 °C/min, and finally hold at 270 °C for 6.33 min. The total run time was 24 min.

The gas chromatograph was connected to a mass spectrometer operated in scan mode between 35 atomic mass units (amu) and 550 amu. The interface temperature was set to 280 °C. Ionization was effected by electron impact (EI) at 70 eV and mass spectra were collected every second.

In binary blend systems, five measurements were averaged for FT-IR, TGA, and Py-GC/MS analyses. Average values for binary blends were used for the analysis of ternary blends.

3. Results and discussion

The composition of NR, SBR and BR blend was determined using FT-IR, TGA, DSC and Py-GC/MS. In ternary systems, it has always been difficult to determine the real composition of polymers [41,42]. In the ternary blend system of NR/SBR/BR may be quite unique in considering that three binary blend pairs (NR/SBR, NR/BR and SBR/BR) are prepared from three polymer constituents: NR, SBR and BR.

3.1. Binary blend systems

3.1.1. FT-IR

Quantitative methods based on pyrolysis offer the advantages of speed and simplicity. Gheremeskel and Shield [6,7] used FT-IR to determine a polymer composition of binary and ternary blends of SBR, NBR and PVC. In their papers, the elastomer composition of SBR/NBR blends was obtained from a plot of absorbance ratio of a characteristic elastomer peak. Dinsmore and Smith [47] used absorbance ratio for quantitative analysis of natural and synthetic rubber.

The absorbance A of a vibration in infrared spectroscopy is given by the Lambert–Beer law:

\[ A = εlc \]  

where ε is the molar absorptivity, l the sample thickness and c is the concentration. From Eq. (1), in the same spectrum, the ratio of the absorbance does not depend on the film thickness:

\[ \frac{A_1}{A_2} = \frac{ε_1 c_1 l_1}{ε_2 c_2 l_2} = \frac{ε_1 c_1}{ε_2 c_2} \]  

In binary blend system, the ratio of a blend:

\[ x_1 + x_2 = 1 \]  

Therefore, the ratio of the absorbance is,

\[ \frac{A_1}{A_2} = \frac{ε_1 x_1}{ε_2 x_2} = \frac{ε_1}{ε_2} \left( \frac{1}{x_2} - 1 \right) = -k + k \frac{1}{x_2} \]  

where k is the molar absorptivity,

\[ k = \frac{ε_1}{ε_2} \]  

The ratio between the characteristic molar absorptivities of the standard and analyte is constant in a wide range of concentrations and its numeric value is characteristic of the blend system. For this reason this quotient is defined as the characteristic parameter of the blend system. This parameter has to be determined experimentally from reference blends containing known proportions of blend compounds, measuring their respective absorbance values at the chosen wavenumbers, A₁ and A₂.

The absorbance measurement is performed using a previously chosen baseline which eliminates the matrix effect on absorbance signal. When the parameter value has been calculated from the arithmetic media obtained in all reference blends, the quantitative analysis of the analyte in a sample can be carried out by measuring A₁ and A₂ in the modified sample and using Eq. (4) to obtain k. By this analytical methodology it is possible to use the standard as a quantification factor for all the known components in a sample, without the need to know the optical path length.

Characteristic bands of the polymers have to be identified in the IR spectrum of the pyrolyzate (Fig. 1). Characteristic IR transmittance bands for NR, SBR and BR are given in Table 1 [48,49]. The frequencies selected for the characterizations of the blends in this study are 1375, 967 and 699 cm⁻¹.

Given that IR provides information attributable to overtone and combination bands, it is more difficult to qualitatively identify blends. However if the blend components are well known, a calibration model can be quickly and easily developed to quantitatively determine the blend composition.

The SBR content of the NR/SBR blends was determined from the ratio of peak heights of the absorbance peaks at 699 and 1375 cm⁻¹, which correspond to SBR and NR, respectively. A plot of the absorbance ratio (699/1375 cm⁻¹) versus the %SBR in Fig. 2(a) yielded an exponential curve with R² = 0.98. The amount of SBR was then determined using the following equation:

\[ \%\text{SBR} = \frac{1}{0.0317} \left( \ln \frac{A_{699}/A_{1375} \text{cm}^{-1}}{0.2179} \right) \]
The BR content of the NR/BR blends was determined from the ratio of peak heights of the absorbance peak at 967 and 1375 cm\(^{-1}\), which correspond to BR and NR, respectively. The absorbance ratio of BR/NR (967/1375 cm\(^{-1}\)) versus the %BR was also plotted in Fig. 2(b) and yielded an exponential curve with \(R^2 = 0.98\). The amount of BR was then determined using the following equation:

\[
%\text{BR} = \frac{1}{0.0197 \ln \left( \frac{A_{967}/A_{1375}}{0.178} \right)}
\]

The SBR content of the SBR/BR blends was determined from the ratio of peak heights of the absorbance peak at 699 and 1375 cm\(^{-1}\), which correspond to SBR and NR, respectively. The absorbance ratio of SBR/BR (699/1375 cm\(^{-1}\)) versus the %SBR was also plotted in Fig. 2(c), which yielded a straight line with \(R^2 = 0.99\). The amount of SBR was then determined using the following equation:

\[
%\text{SBR} = \left( \frac{A_{699}/A_{1375}}{0.4842} - 0.4842 \right) / 0.0405.
\]

### 3.1.2. TGA

These compounds were decomposed in nitrogen between 300 and 550 °C. It converts the weight % at an initial temperature into 100% and the weight % at 550 °C (all polymers are pyrolyzed) into 0%, to exclude the weight effect of carbon black and filler which exists inside the sample [18].

The TGA and DTG curves of vulcanized NR, SBR and BR are given in Fig. 3(a) and (b), respectively. The DTG curves of NR, SBR and BR in nitrogen are characterized by well-defined peaks for each polymer. The degradation peak for NR is 403 °C in comparison to 485 and 501 °C for SBR and BR, respectively. The peak temperature for NR is separated from that of SBR and BR by about 80 and 100 °C, respectively, but the peak temperatures for SBR and BR are less than 20 °C apart. It should, therefore, be possible to characterize NR in the blends of NR/BR and NR/SBR, but it would be difficult to identify the other component. A similar observation was reported in literature by Sircar and Lamond [16] (but the temperature is not exactly coincidence each other). Therefore, the composition of blends was determined by motoring shift in TGA thermograms.

Shield and Ghebremeskel [18,19] showed that the temperature that corresponds to 70% weight loss of the original sample weight (\(T_{70\%}\)) correlated with the styrene content in SBR. In

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**Table 1**

<table>
<thead>
<tr>
<th>Peak no.</th>
<th>Frequency (cm(^{-1}))</th>
<th>Structure</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1375</td>
<td>CH(_3) symmetrical</td>
<td>NR, SBR, BR</td>
</tr>
<tr>
<td>2</td>
<td>967</td>
<td>trans-1,4-Butadiene</td>
<td>SBR, BR</td>
</tr>
<tr>
<td>3</td>
<td>911</td>
<td>1,2-Butadiene or vinyl-butadiene</td>
<td>SBR, BR</td>
</tr>
<tr>
<td>4</td>
<td>699</td>
<td>Styrene</td>
<td>SBR</td>
</tr>
</tbody>
</table>
this study, the temperature that corresponds to $T_{70\%}$ was used in NR/SBR, NR/BR and SBR/BR blends.

Fig. 4 shows the TGA thermograms for NR/SBR blends and the SBR content in the thermogram increases from left to right. Fig. 5 shows temperatures of a specific % of weight loss in TGA thermograms for the NR/SBR blend. The shift of the slope (plot of the pyrolysis temperature versus SBR content) of the blends is more pronounced for $T_{70\%}$ than for $T_{30\%}$. These results correspond with the result of Shield and Ghebremeskel [18,19]. A linear regression fit of the plot of the temperature at $T_{70\%}$ versus %SBR yielded the correlation coefficient of $R^2 = 0.97$ (Fig. 5). The SBR content of the test blends was, therefore, determined using $T_{70\%}$.

The NR/BR and SBR/BR blends calculated in this work are almost the same as described above for the NR/SBR blend. As stated above, since the difference in degradation temperatures between SBR and BR is below 20°C, it was difficult to identify the blend composition.

3.1.3. DSC

Polymer blends are miscible if their components form a single homogeneous phase at the molecular scale, or immiscible if they exhibit several distinct phases [44]. Sircar and Lamond [16] used DSC to distinguish between SBR, BR or blends from NR. Yamada and Funayawa [48] reported miscibility of the blends of IR and vinyl functionalized BR (V-BR) with various vinyl contents by measuring the glass transition temperature ($T_g$).
The DSC curves of vulcanized NR, SBR and BR are given in Fig. 6. The \( T_g \) for BR is \(-107{\degree}C\) in comparison to \(-66\) and \(-51{\degree}C\) for NR and SBR, respectively. The \( T_g \) for BR is separated from that of NR and SBR by about 40 and 55 \( ^\circ \)C, respectively, but the peak temperatures for NR and SBR are less than 15 \( ^\circ \)C apart.

Fig. 7 shows the heat capacity as a function of temperature for NR/SBR blends of various compositions. Each curve exhibits two steps in heat capacity at about the \( T_g \)s of the pure polymers and, therefore, indicates immiscible blend. The composition dependence of \( T_g \) is shown in Fig. 8(a), which emphasizes their very small deviation from the corresponding values for pure NR and SBR. The \( T_g \) of NR is visible in blends containing 20% or more NR. It is remarkable that the \( T_g \) for SBR is observed at concentrations as low as 10% SBR, although the transition is not very sharp. Two \( T_g \)s corresponding to those of unblended NR and SBR were observed as indicated by the two horizontal lines. And, the \( T_g \) difference between NR and SBR is below 15 \( ^\circ \)C, so it was difficult to identify each other.

Similarly, each curve exhibits two steps in heat capacity for NR/BR blend at about the \( T_g \)s of the pure polymers and, therefore, indicates immiscible blend. The same tendency is then observed as with the NR/SBR blend. The composition dependence of \( T_g \) is shown in Fig. 8(b), which emphasizes their very small deviation from the corresponding values for pure NR and BR.

For SBR/BR blends of various compositions, unlike the previous NR/SBR and NR/BR blend systems, a single \( T_g \) between \( T_g \)s of SBR and BR, was observed, regardless of blend compositions. A similar observation was reported by Marsh et al. [21]. The explanation given for the behavior of this blend is that due to covulcanization, a new “phase” is formed that behaves differently from SBR or BR. They also mentioned that for certain homogeneous blends, a single \( T_g \), of one of the components, is observed, depending on the blend composition. It should, therefore, be possible to determine the composition of SBR/BR blends from this calibration curve. Fig. 8(c) shows the results. \( T_g \)s for SBR/BR blends are plotted against the blend ratio. A similar observation was reported in the literature by Sircar and Lamond [16], the change of \( T_g \)s with SBR content in SBR/BR blends may be described by two straight lines intersecting at 40% SBR.
3.1.4. Py-GC/MS

Polymers yield high abundances of the monomers when pyrolyzed, so that the relative GC area of monomers can be correlated with weight percent composition [19,41,50,51]. Fig. 9 shows three pyrograms of NR, SBR and BR compounds. The major pyrolyzates of NR are isoprene and dipentene, while those of SBR are styrene and 4-vinylcyclohexene. And that of BR is 4-vinylcyclohexene. These have been labeled and identified by MS and listed in Table 2. From a quantitative analysis point of view, at least one pyrolyzate has to be identified as composition dependent. There are several pyrolyzates that can potentially be used for qualitative and quantitative analysis because their intensities vary with the composition. Three peaks are potentially useful for quantitative analysis: dipentene (peak 3), 4-vinylcyclohexene (peak 5) and styrene (peak 6) for NR, BR and SBR, respectively. They all have large enough intensities so that they can be used to cover a wide range of composition.

In the NR/SBR blend, if the area of peak due to NR is $A_n$ and the area of the peak due to SBR is $A_s$, then the ratio $A_s$ is defined

![Fig. 9. Pyrograms of three compounds. (a) NR, (b) SBR, and (c) BR.](image-url)
by [52]:

$$A_x = \frac{A_x}{(A_x + A_n)}$$  \hspace{1cm} (6)

Fig. 10(a) shows the relationship between the original compositions of NR/SBR blends and the ratio $A_x$. The ratio $A_x$ versus %SBR yields an exponential curve with $R^2 = 0.99$.

The NR/BR blend calculated in this work is almost the same as described for the NR/SBR blend (Fig. 10(b)). In the SBR/BR blend, the ratio $A_x$ versus %SBR yielded a straight line with $R^2 = 0.98$ (Fig. 10(c)). The amount of SBR was then determined using the equation %SBR = ($A_x - 0.2415$)/($0.0061$).

### 3.2. Ternary blend systems

In Section 3.1, quantitative analysis of binary blend system has been done using FT-IR, TGA, DSC and Py-GC/MS. Based on those results, we tried to determine the blend ratio of ternary blends.

First, we have chosen three peaks (NR: 1375 cm$^{-1}$, SBR: 699 cm$^{-1}$, BR: 967 cm$^{-1}$) for FT-IR analysis. Actually, the 1375 cm$^{-1}$ peak of NR appears also for both SBR and BR. Furthermore, the 967 cm$^{-1}$ peak of BR is also caused by volatiles from NR and SBR. Consequently, it is unreasonable to expand the FT-IR analytic method for the binary system to the ternary system.

In TGA analysis, quantitative analysis is carried out by specified % weight loss such as 30%, 50% or 70%. But a ternary blend system is not as simple as binary blend system. It attributes to the composition result of thermal decomposition for NR, SBR and BR. Therefore, it shows that the result of TGA is not more precise than the result of FT-IR. In DSC analysis, it is only possible to determine the blend ratio of SBR/BR. Therefore, it fails to characterize a ternary blend system of NR/SBR/BR.

In Py-GC/MS analysis, characteristic peaks (NR: dipentene, SBR: styrene, BR: 4-vinylcyclohexene) can be chosen. The dipentene and styrene peaks are unique, respectively. It means that those peaks are not affected by existence of another blend system. On the other hand, the 4-vinylcyclohexene peak has a great influence on the content of SBR. Fig. 11 shows the relationship between styrene (characteristic peak of SBR) and 4-vinylcyclohexene (characteristic peak of SBR).
BR) in NR/SBR blend. It indicates that SBR is decomposed into styrene and 4-vinylcyclohexene whose amount is approximately 18% of area of styrene. Accordingly, it is possible to calculate the ratio of ternary blend ratio using the ratio of NR/SBR and SBR/BR from ternary blend system. It takes notice not to use the ratio of NR/BR. If it is involved for SBR, it may be affected by the content of SBR.

Several test samples of known NR/SBR/BR blends are analyzed using binary blend systems, as shown in Table 3. Table 4 shows the prediction of ternary blend system using results of Table 3. According to this table, it is concluded that the result of Py-GC/MS is the most precise among other instrumental analyses.

In this work, we tried to identify an appropriate analytical method for the determination of the composition of an unknown rubber blend that consists of a mixture of NR, SBR, and BR. Before conclusion, however, it should be noted that the result discussed here is only valid for the specific mixture of specific rubbers. Although it is known that different linking structures in BR do not have a large influence on the pyrolysis products, while different styrene contents in SBR are crucial for the proposed analysis method. In addition, rubber additives like aliphatic or aromatic oils are frequently used even for rubber blends. Therefore, for a general adoption of the proposed method in this work, the effects of other important parameters including different styrene contents in SBR and rubber additives, etc. as well as other rubber blend systems should be also considered. Further studies on the subject are now underway and will be reported elsewhere.

4. Conclusions

In this study, the composition of ternary NR/SBR/BR blends was analyzed by TGA, DSC and Py-GC/MS measurements in addition to the FT-IR analysis of rubber blend pyrolyzates. Among them, the quantitative analysis using Py-GC/MS is the most precise of other instruments. The calculated blend ratios in the ternary NR/SBR/BR blend was found to be within 5% among the true values, providing an excellent method for characterizing the composition of ternary blend systems.

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