Study on the effect of processing conditions on the mechanical properties of PP/PC/SEBS ternary blends using Taguchi experimental analysis

O. Moini Jazani, 1 A. Arefazar, 1* M.H. Beheshty 2

1Polymer Engineering Department, Amir Kabir University of Technology, Tehran, Iran; e-mail: arefazar@aut.ac.ir
2Composites Department, Iran Polymer and Petrochemical Institute, Tehran, Iran.

(Received: 14 January, 2010; published: 29 October, 2010)

Abstract: In this study, nine ternary polymer blends based on polypropylene (PP)/polycarbonate (PC)/styrene-ethylene-butylene-styrene triblock copolymer (SEBS) with the same compositions (70%wt PP, 15%wt PC, 7.5%wt SEBS and 7.5%wt maleic-anhydride grafted SEBS (SEBS-g-MAH) as a compatibilizer) are prepared using twin screw extruder at different levels of die temperature (235-245-255 °C), screw speed (70-100-130 rpm) and blending sequence (M1-M2-M3). In M1 procedure, all of the components are dry blended and extruded simultaneously using Brabender twin-screw extruder. In M2 procedure, PC, SEBS, and SEBS-g-MAH minor phases are first pre-blended in twin screw extruder and after granulating are added to PP continuous phase in twin screw extruder. Consequently, in M3 procedure, PP and SEBS-g-MAH are first pre-blended and then are extruded with other components. The influence of these parameters as processing conditions on mechanical properties of PP/PC/SEBS ternary blends is investigated using L9 Taguchi experimental design. The responding variables are impact strength and tensile properties (young modulus and yield stress) which are influenced by the morphology of ternary blend and the results are used to perform the analysis of variance (ANOVA). It is shown that the resulted morphology, tensile and impact strength are influenced by extrusion variables. Additionally the optimum processing conditions of ternary PP/PC/SEBS blends from Taguchi analysis was achieved.

Introduction

Blending two or more immiscible polymers is a well known method to obtain new polymeric materials with synergistic and tailored properties. The final size and shape of the minor phase in polymer blend is a function of several factors as composition, viscosity ratio, interfacial tension, shear rate, elasticity, and processing conditions [1]. In most cases, blending of polymers without compatibilizers does not lead to products with enhanced final properties. In order to alleviate the weak interfacial adhesion of immiscible blends, in situ compatibilization has been extensively used in recent studies. In both PP/PA-6 and PP/PA-6/poly(styrene-b-(ethylene-co-butylene)-b-styrene) (SEBS) ternary systems, employing maleated SEBS (SEBS-g-MAH) as a compatibilizer, strongly influenced the blend morphology and mechanical properties by variation in the degree of interfacial reaction between the succinic anhydride groups of the PA-6 and carbonyl groups of SEBS-g-MAH [2-4]. Cimmino et al. studied
the effect of blending sequence on morphological and mechanical properties of PA6/EPM blends stabilized with EPM-g-MA. They showed that the blends obtained by two-step mixing exhibited a very fine morphology and excellent impact properties compared to the blends obtained by the one step mixing [5]. Willis et al. studied the effect of processing parameters in PA/Polyolefin compatibilized with an ionomer. The migration of modifier to the interface is facilitated when it is initially mixed with the polyolefin component [6]. Torres et al. studied the effect of blending sequence on morphology and mechanical properties of PC/PP blends. The results indicate that the blending sequence significantly affects the morphology and mechanical properties of blends. They showed that for ternary blends (PC/PP/Kraton as compatibilizer), only one-step mixing is sufficient to improve the mechanical properties [7]. Recently the study of ternary blends has been raised the attention of researchers because of wide range of variation in mechanical and morphological properties in these systems [8-20]. It is observed that for the systems containing two minor phases, three distinct types of phase morphology have to be specified. For some ternary systems, one of the minor components forms an encapsulating layer around domains of another minor component, whereas in other systems two minor components form independent phases separately. The third type is the intermediate case, where mixed phases of the two components are formed without any ordered structures [8-14]. In order to predict the tendency for one minor phase to encapsulate the second one, the alternative form of Harkin’s equation is used as follows:

\[ \lambda_{BC} = \gamma_{AC} - \gamma_{AB} - \gamma_{BC} \]  

(1)

where \( \gamma_{AC}, \gamma_{AB} \) and \( \gamma_{BC} \) are the interfacial tensions for each component pair, and \( \lambda_{BC} \) is defined as the spreading coefficient for the shell forming component B on the core of component C. The index A corresponds to the matrix continuous phase. If the \( \lambda_{BC} \) is positive the B-phase will encapsulate the C-phase. Similarly,

\[ \lambda_{CB} = \gamma_{AB} - \gamma_{AC} - \gamma_{BC} \]  

(2)

When \( \lambda_{CB} \) is positive, the component C will also encapsulate component B. However, if both \( \lambda_{CB} \) and \( \lambda_{BC} \) are negative, component C and B will tend to form two separate dispersed phases within the matrix component A. In the intermediate region, where \( \lambda_{BC} \approx 0 \), stack morphology may result, in which component B only partially eliminates the interface between component C and the matrix [3]. Guo et al. have applied their model to different ternary blends and have compared the predicted morphologies with experimental results [8]. Guo Relative Interfacial Energy (RIE) equations are as below:  

\[ (RIE)_{B/C} = \left( \sum A \gamma_{ij} \right)_{B/C} / K = (1+x)^{1/2} \gamma_{AB} + \gamma_{BC} \]  

(3)

\[ (RIE)_{C/B} = \left( \sum A \gamma_{ij} \right)_{C/B} / K = [x^{1/2} \gamma_{BC} + (1+x)^{1/2} \gamma_{AC}] \]  

(4)

\[ (RIE)_{B/C} = \left( \sum A \gamma_{ij} \right)_{B/C} / K = x^{1/2} \gamma_{AB} + \gamma_{AC} \]  

(5)

where \( x \) is equal to \( x = V_a / V_c \), \( \gamma_{ij} \) is the interfacial tension between two phases and \( K \) is a constant. In addition they have successfully converted the phase structures of ternary blends from one type to other using interfacial active block copolymers. Luzinov et al. have shown that the morphology of the ternary PS/SBR/PE blend is
influenced by the weight ratio of the minor component (SBR and PE) and stress transfer from the matrix through the shell to the core which occurs when the ratio of the core size to thickness of the SBR layer is high enough [9-11]. By increasing the viscosity of polyolefins, the size of the cores and SBR domains including them increases. In the case of dispersed phase morphology the hard core in the core-shell phases has no major effect on the mechanical properties whatever the matrix is (PE or PS). The effect of melt viscosity ratio on morphology of ternary blends is very complicated. Kim et al. described that for polyolefin ternary polymer blends with core-shell morphology when two minor phases have the same composition, the minor phase with lower viscosity encapsulates the other phase [12]. Ha et al. reported for PP/PE/HDPE, fibrils were observed when the dispersed phase viscosity (PE/HDPE) was less than that of PP [13]. Nemirovski et al. suggested that for some ternary blends (thermoplastic/thermotropic) core-shell morphology (A will encapsulate B in matrix C) was observed when both thermodynamic (a positive spreading coefficient) and kinetic effects (a dispersed phase viscosity ratio smaller than one) act simultaneously [14]. Moreover, some processing conditions such as feeding sequence, extrusion rate, and temperature profile along the screw can significantly affect the mechanical and morphological properties [18, 21]. In another research, the morphology of HDPE/PS/PMMA ternary blends prepared by twin screw extrusion is investigated as a function of composition, minor phase viscosity ratios, sequence of addition and compounding production rate by Favis et al. [18]. The results have been shown that within explored processing conditions, the final morphology in the studied system is primarily governed by interfacial free energy considerations. It is found that the yield stress and young’s modulus of the PET/PC/E-GMA-MA ternary blends decreased with increasing copolymer content at room temperature, but no significant blending sequence effect was observed [21]. The results are analyzed based on toughening mechanisms during the fracture of toughened ternary blend using combined cavitations and matrix shear yielding mechanisms. As a marked result, the number and size of core structures can influence the mechanical properties, and morphology of ternary blends [19, 20]. In PP/HDPE/EPDM/EP quaternary blends containing more than 30%wt of EPDM, the impact strengths was extensively improved [22]. The higher the PP content in this system, the larger the EPDM/HDPE ratio needed to achieve good impact toughness at low temperature. According to the mentioned literature reviews, the investigation of effective parameters in ternary blend is completely different from one system to another. In this study the effect of processing conditions including screw speed, temperature profile and mixing sequence, are investigated for PP/PC/SEBS ternary blend using twin screw extruder. In order to evaluate the effects of processing conditions on mechanical properties and morphology evolution, the experiments are designed using Taguchi method of experimental design. The blend is compatibilized with SEBS-g-MAH to attain good adhesion between three phases based on previous studies [2-4]. Attentions will be focused on the phase morphology and its effect on the mechanical properties via manipulation of processing conditions.

**Results and Discussion**

**Interfacial tension**

The interfacial tension coefficients were obtained using harmonic mean equation as:
\[ \gamma_{12} = \gamma_1 + \gamma_2 - \frac{4\gamma_1\gamma_2}{\gamma_1 + \gamma_2} - \frac{4\gamma_1\gamma_2}{\gamma_1 + \gamma_2} \]  
(6)

where \( \gamma, \gamma_d \) and \( \gamma_p \) are surface tension, dispersive contribution of \( \gamma \) and polar contribution of \( \gamma \) at 255 °C. Table 1 presents \( \gamma, \gamma_d \) and \( \gamma_p \) for PP, PC and SEBS at 255 °C (according to Taguchi results) calculated on the basis of data reported in references 3, 26, 27, 28 and 29. As EB is the major part of SEBS chains, the surface tension of this component was estimated by the surface tension data of EB. Table 2 summarizes the interfacial tension between polymer pairs. The spreading coefficient \( \lambda_{C/B}, \lambda_{B/C} \) and relative interfacial energy model are calculated using equations 1-5 and presented in Tables 3 and 4.

**Tab. 1.** Estimated surface tension of polymers at the optimized mixing temperature (255 °C).

<table>
<thead>
<tr>
<th>Polymer</th>
<th>( \gamma_i = A - BT(\degree C) )</th>
<th>Polarity(a)</th>
<th>( \gamma_i^{(d)} )</th>
<th>( \gamma_i^{(p)} )</th>
<th>( \gamma_i^d )</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>30.5-0.056T</td>
<td>0.021</td>
<td>29.65</td>
<td>6.55</td>
<td>23.097</td>
<td>3, 29, 30</td>
</tr>
<tr>
<td>PC</td>
<td>44.1-0.06T</td>
<td>0.246</td>
<td>21.7</td>
<td>0.54</td>
<td>21.15</td>
<td>31</td>
</tr>
<tr>
<td>SEBS</td>
<td>34.56-0.045T</td>
<td>0.002</td>
<td>22.95</td>
<td>1.60</td>
<td>21.34</td>
<td>3, 29, 30</td>
</tr>
</tbody>
</table>

Polarity is independent of temperature. \( \gamma_i = \gamma_i^{(p)} + \gamma_i^{(d)} \) [32].

**Tab. 2.** Estimated interfacial tension at 255 °C.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Interfacial Tension at 255 °C (mN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP/SEBS</td>
<td>1.21</td>
</tr>
<tr>
<td>PP/PC</td>
<td>7.03</td>
</tr>
<tr>
<td>PC/SEBS</td>
<td>6</td>
</tr>
</tbody>
</table>

**Tab. 3.** Morphology Predicted by Spreading Coefficient model.

<table>
<thead>
<tr>
<th>Ternary polymer blend</th>
<th>( \lambda_{C/B}^{(a)} )</th>
<th>( \lambda_{B/C}^{(a)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP/PC/SEBS</td>
<td>-0.18</td>
<td>-11.82</td>
</tr>
</tbody>
</table>

(a) C phase is SEBS and B phase is PC.

According to data calculated (Table 3 and Table 4), the spreading coefficient \( \lambda_{B/C} \) and \( \lambda_{C/B} \) are both negative and also the morphology in which the C-phase encapsulates the B-phase has the lowest value of relative interfacial energy (RIE). Based on the concept of the spreading coefficient B and C phases remain separate.
and relative interfacial energy, SEBS is expected to encapsulate PC. Thus, calculations demonstrate a small driving force for the PC encapsulates the SEBS. However, Fig. 2 shows an agreement between the prediction of phase morphology from RIE model and the phase morphology observed via SEM.

**Tab. 4.** Relative Interfacial Energies for (70PP/15PC/15SEBS) Ternary Blends.

<table>
<thead>
<tr>
<th>Ternary polymer blend</th>
<th>$x = V_B/V_C^{(a)}$</th>
<th>$R_{IE_B/C}^{(a)}$</th>
<th>$R_{IE_B/C}^{(a)}$</th>
<th>$R_{IE_C/B}^{(a)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>70PP/15PC/15SEBS</td>
<td>0.76</td>
<td>7.07</td>
<td>16.2</td>
<td>6.75</td>
</tr>
</tbody>
</table>

(a) C phase is SEBS and B phase is PC.

**Taguchi analysis of PP/PC/SEBS ternary blend**

The experimental results for 9 different trial conditions are shown in Table 5. This experimental results have been set up to investigate the influence of processing conditions (die temperature, screw speed and blending sequence) on the mechanical properties of PP/PC/SEBS ternary blend. The mechanical results of pure PP sample were added to Table 1 as 10th specimen to make an evidence to study the order of importance.

**Tab. 5.** Experimental results for PP/PC/SEBS.

<table>
<thead>
<tr>
<th>Run NO</th>
<th>Yield Stress(MPa)</th>
<th>Young's Modulus(MPa)</th>
<th>Impact Strength(J/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>28.25±0.74</td>
<td>1113.23±57.71</td>
<td>88±2</td>
</tr>
<tr>
<td>2.</td>
<td>27.39±0.26</td>
<td>1113.175±39.765</td>
<td>81.5±5.5</td>
</tr>
<tr>
<td>3.</td>
<td>28.3±0.85</td>
<td>1094.05±37.9</td>
<td>114±1</td>
</tr>
<tr>
<td>4.</td>
<td>28.29±0.315</td>
<td>1060.205±55.185</td>
<td>67.75±0.25</td>
</tr>
<tr>
<td>5.</td>
<td>28.45±0.53</td>
<td>1130.45±48.03</td>
<td>115±3</td>
</tr>
<tr>
<td>6.</td>
<td>27.98±0.67</td>
<td>1176.81±163.76</td>
<td>102.3±3.29</td>
</tr>
<tr>
<td>7.</td>
<td>29.33±1.17</td>
<td>1366.92±171.69</td>
<td>95.25±2.75</td>
</tr>
<tr>
<td>8.</td>
<td>28.98±0.53</td>
<td>1299.99±106.62</td>
<td>87. 5±0.5</td>
</tr>
<tr>
<td>9.</td>
<td>29.17±0.31</td>
<td>1307.416±30.29</td>
<td>94±2.94</td>
</tr>
<tr>
<td>Pure PP</td>
<td>32.3±0.39</td>
<td>1167±22.6</td>
<td>25.66±0.471</td>
</tr>
</tbody>
</table>

In order to investigate the role of processing condition on the resulted mechanical properties, the mean effect of each factor must be taken into account. Fig. 1 shows the effect of die temperature on yield stress, modulus and impact strength which are all totally summarized as mechanical properties.

Fig. 1 (A) indicates the influence of temperature on the yield stress of the PP/PC/SEBS ternary blend. As it can be seen, the yield stress of ternary blend steadily increases by increasing the temperature. This behavior can be attributed to interfacial adhesion between the phases in ternary blend, whereas the yield stress is known to be highly dependent on the interfacial adhesion among the other mechanical properties. Pukansky et al [27, 28] showed that in complete achievement
of interfacial adhesion the yield stress of a blend must obey the mixture law as follows:

$$\sigma_{yb} = \sigma_{ym} (1 - \varphi_d) + \sigma_{yd} \varphi_d$$  \hspace{1cm} (7)

where $$\sigma_{yb}$$, $$\sigma_{ym}$$, $$\sigma_{yd}$$ and $$\varphi_d$$ are yield stress of the blend, yield stress of the matrix, yield stress of the dispersed phase and volume fraction of the dispersed phase respectively. In another words, the maximum deviation from mixture law (equation 7) is indicating very poor interfacial adhesion and vice versa. In our study, the yield stress of pure PP and PC are 32.3 and 66 MPa respectively. As the composition of the another ingredients are low compared to PP and PC, the yield stress of the blend must be achieved approximately 35.98 MPa. As can be seen, the experimental results in Table 5 show a minor negative deviation from the theoretical yield stress calculated by equation 6 which is remarked in 7, 8, 9 series of this table. This observation is completely confirmed with SEM evaluations. Figure 2 presents the morphology of the 70/15/7.5/7.5 blend of PP/PC/SEBS / SEBS-g-MAH according to L9 designed in Table 8.

![Graphs showing mechanical properties](image)

**Fig. 1.** Mean effect of die temperature on the mechanical properties of PP/PC/SEBS. A) Yield stress, B) Young's Modulus, C) Impact strength.

As it can be seen, SEM micrographs of the etched impact fractured samples reveal the existence of composite droplets of SEBS and PC embedded in PP matrix with SEBS and SEBS-g-MAH shells around the PC and also individual droplets of PC and SEBS. According to the explanation given for the temperature effect, for No 8 compound, the
The dispersion of droplets is finer than that of 2 and 5 compounds and smaller particle size of droplets can be distinguished. Fig. 1B shows the influence of temperature on the young modulus of PP/PC/SEBS ternary blends. As it can be seen, the modulus of ternary blends increases slightly from 235 °C to 245 °C and sharply from 245 °C to 255 °C. This observation may be attributed to the orientation of PC as a reinforcement in ternary blends. Increasing temperature causes a decrease in viscosity and so the probability of PC orientation during the process in twin screw extruder increases and this matter causes modulus to increase in PP/PC/SEBS ternary blend. The effect of temperature on impact strength is shown in Fig.1C. The impact strength fixes nearly with increasing temperature from 235 °C to 245 °C and a slight decrease in impact strength with increasing temperature from 245 °C to 255 °C is observed. This drop in impact strength may be attributed to molecular weight reduction of PP due to the thermo-mechanical degradation at high temperature.

![Fig. 2. SEM micrographs of PP/PC/SEBS / SEBS-g-MAH at different processing conditions according to Table 8.](image)

Fig. 3 shows the effect of screw speed on mechanical properties. As it can be seen in Fig. 3A, the yield stress decreases with increasing the screw speed and then
increases slightly with screw speed. Fig. 3B shows the effect of screw speed on modulus. This behavior is expected due to the fact that the crystallinity of PP decreases with increasing of screw speed via reduction of molecular weight and consequent thermo-mechanical degradation of matrix. This effect is compensated partly by increasing the stiffness of blend due to the orientation of PC and thus modulus increases from 70 to 100 rpm and at 130 rpm the orientation of PC is the major factor and the modulus increases sharply.

In Fig. 3C the effect of screw speed on impact strength is shown. It is obvious that the impact resistance of the blend steadily increases by increasing the screw speed. This behavior can be attributed to better droplet breakup and dispersion of dispersed phase with increasing the mixing intensity in twin screw extruder. Also this effect is visible in SEM micrographs of 1, 6, 8 compounds in Fig. 2. As it clear in these micrographs the composite droplet break up is easier in high screw speeds. In addition, Fig. 4 shows the mean effect of blending sequence on mechanical properties.

![Fig. 3](chart.png)

**Fig. 3.** Mean effect of screw speed on mechanical properties of PP/PC/SEBS ternary blends. A) Yield stress, B) Young's Modulus, C) Impact strength.

From Fig4 (A), it is clear that the yield stress is slightly higher for M3 blending sequence. This observation can be associated with better dispersion of compatibilizer in matrix and better interfacial adhesion between phases in ternary blend. This may be due to primary dispersion of compatibilizer in matrix and capability of compatibilizer to interfacial bonding with matrix. In Fig. 4B shows that the blending sequence has an optimal effect on young modulus. Fig. 4C demonstrates that the blending sequence has the major effect on impact strength.
The reason of high impact strength in M3 blending criteria is that because of well dispersion of compatibilizer in matrix consequence by addition of masterbatch (PP and SEBS-g-MAH) to the disperse phases (PC and SEBS). In the other words, the probability of locating the compatibilizer at interface of PP and PC is easier with respect to the other blending sequences. This probability is very low in M2 blending sequence since the compatibilizer was mixed with the dispersed phases and the mobility of compatibilizer toward interface is restricted. SEM micrographs revealed that blending sequence has significant effect on the micro structure of blends and consequent mechanical properties (yield and impact strength). SEM micrographs of 1,2,3 compounds in Fig. 2 show that in M1 and M3 blending sequences the particle size of composite droplets is smaller and particle size distribution is finer than that of M2 blending sequence. In M2 blending sequence the trapped compatibilizer in minor phases cannot migrate to interface and interfacial bonding of matrix and dispersed phases is very poor.

**Fig. 4.** Mean effect of blending sequence on mechanical properties of PP/PC/SEBS ternary blends. A) Yield stress, B) Young's Modulus, C) Impact strength.

**Dynamic Mechanical Properties**

As it can be seen in Fig. 5, over the temperature range, storage modulus of RT7 sample is larger than the other blends. It can be attributed to fine dispersion of PC and SEBS domains in the PP matrix providing increased interfacial interaction between matrix phase and dispersed phases (as shown in Fig. 2), which is responsible for more efficient stress transfer from matrix to dispersed phases.
Fig. 5. Storage modulus ($E'$) as a function of temperature.

**Optimization of processing conditions**

The mechanical properties as a result of Taguchi analysis is shown in different cases in Table 6.

**Tab. 6.** Mechanical properties of PP/PC/SEBS ternary blends via Taguchi analysis.

<table>
<thead>
<tr>
<th>Processing Conditions</th>
<th>Impact Strength (J/m)</th>
<th>Young's Modulus (MPa)</th>
<th>Yield Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T=255°C N=130rpm M3 blending sequence</td>
<td>115.926 ± 1.1</td>
<td>1345.32 ± 171.29</td>
<td>29.4156 ± 1.15</td>
</tr>
<tr>
<td>T=255°C N=130rpm M1 blending sequence</td>
<td>100.452 ± 3.17</td>
<td>1344.83 ± 105.82</td>
<td>29.1256 ± 0.58</td>
</tr>
<tr>
<td>T=255°C N=70rpm M1 blending sequence</td>
<td>96.1489 ± 1.8</td>
<td>1332.70 ± 106.05</td>
<td>29.5572 ± 0.56</td>
</tr>
</tbody>
</table>

The results of Taguchi analysis show that in this work the optimum processing conditions of PP/PC/SEBS ternary blends in order to achieve higher tensile properties and impact strength simultaneously is at temperature degree of 255 °C, screw speed of 130 rpm and M3 blending sequence.
Conclusions

The present research is employed to highlight the role of processing conditions, namely die temperature, screw speed and blending sequence on the morphological and mechanical properties of PP/PC/SEBS ternary polymer blends. In order to obtain this aim L9 orthogonal array of Taguchi’s method is utilized to analyze the influence of these variables on performance of the PP/PC/SEBS compounds with the same composition. The responding variables are impact energy and tensile properties such as young modulus and yield stress which are influenced by the morphology of ternary blends. It is shown, based on Taguchi analysis, that the morphology and the mechanical properties are greatly dominated by the processing parameters. It was also found that the high temperature and screw speed was favorable for the improvement of mechanical properties of pure PP. The influence of blending sequence on the mechanical properties which is associated with their influence on the morphology, is evaluated in this study. The results indicated that the M3 and M1 blending sequence have significant effect on the mechanical properties. Finally the results based on Taguchi approach confirm that the optimum processing conditions for higher impact strength, young modulus and yield strength are: T=255 °C, N=130rpm, blending sequence= M3.

Experimental

Materials

The following materials were used in this research:
(i) An iso-tactic polypropylene homo-polymer (PP), SEETEC H5300 supplied by LG chemical company(Korea) (MFI: 3.5 g/10min, 230 °C, 2.16 kg), (ii) polycarbonate (PC), Makrolon 2858 purchased from Bayer Co(Germany) (MFI: 10 g/10min, 300 °C, 1.2kg), (iii) poly(styrene-b-(ethyleneco-butylene)-b-styrene) (SEBS) tri-block copolymer, Kraton™ G1652 supplied by Shell Chemicals (29% styrene; molecular weight; styrene block 7000, EB block 37500); (iv) maleic-anhydride grafted SEBS (SEBS-g-MAH) tri-block copolymer, Kraton™ FG1901x supplied by Shell Chemicals (29% styrene, nominal weight of grafted maleic anhydride= 1.8± 0.4%).

Experimental design based on Taguchi method

The application of design of experiments (DOE) requires careful planning prudent layout of the experiments, and expert analysis of results .The Taguchi method replaces factorial design with the more suitable partial factorial method based on orthogonal arrays .Since partial factorial design is a subset of full factorial method, so as to determine the reliability and accuracy of the experimental results, standard statistical method of analysis of variance was exploited. In this method, the variance of data is more interest and directly would give an evaluation of the accuracy results [23]. The most appropriate orthogonal array to meet this requirement is a 9-trial experiment (L9). In this design three independent variables are statistically changed at three different levels on the basis of process knowledge [24]. In recent years, there are some applied researches on polymer-based processes using L9 method [25-26]. The responding variable can be optimized using statistical – mathematical calculations via L9 design of Taguchi method.
Blend preparation

As it was mentioned in order to investigate the effect of independent parameters on responding variable for specified experimental runs, Taguchi analysis is a suitable method for reducing the number of runs and evaluating the variation trends based on statistical mathematical analysis. The three independent processing variables in this study are temperature profile, screw speed and blending sequence which are considered on the basis of literature studies [1,18,21] using L9 Taguchi design. These changing variables were prepared in nine ternary blends with the same compositions (70%wt PP, 15%wt PC, 7.5%wt SEBS, 7.5%wt SEBS-g-MAH) in Brabender co-rotating twin screw extruder (diameter of screw=2 cm, length/diameter ratio= 40 ). The temperature profile of Barrel in five heat zones are altered based on die temperature as follows: A1 profile: 210-215-220-225-230; A2 profile: 220-225-230-235-240-; A3 profile: 230-235-240-245-250. Blending sequence was consisted of three different procedures M1, M2 and M3. In M1 procedure, all of the components are dry blended and extruded simultaneously using Brabender twin-screw extruder.

Tab. 7. Variation fashion of three independent parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Unit</th>
<th>Nominal levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of Die</td>
<td>A</td>
<td>(°C)</td>
<td>235-245-255</td>
</tr>
<tr>
<td>Screw speed</td>
<td>B</td>
<td>(rpm)</td>
<td>70-100-130</td>
</tr>
<tr>
<td>Blending sequence</td>
<td>C</td>
<td>(--)</td>
<td>M1-M2-M3</td>
</tr>
</tbody>
</table>

The results of Taguchi L9 design for mentioned parameters are listed in Table 8.

Tab. 8. Processing conditions for preparation of PP/PC/SEBS ternary blends based on Taguchi L9 method.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>A (°C)</th>
<th>B (rpm)</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>235</td>
<td>70</td>
<td>M1</td>
</tr>
<tr>
<td>2</td>
<td>235</td>
<td>100</td>
<td>M2</td>
</tr>
<tr>
<td>3</td>
<td>235</td>
<td>130</td>
<td>M3</td>
</tr>
<tr>
<td>4</td>
<td>245</td>
<td>70</td>
<td>M2</td>
</tr>
<tr>
<td>5</td>
<td>245</td>
<td>100</td>
<td>M3</td>
</tr>
<tr>
<td>6</td>
<td>245</td>
<td>130</td>
<td>M1</td>
</tr>
<tr>
<td>7</td>
<td>255</td>
<td>70</td>
<td>M3</td>
</tr>
<tr>
<td>8</td>
<td>255</td>
<td>100</td>
<td>M1</td>
</tr>
<tr>
<td>9</td>
<td>255</td>
<td>130</td>
<td>M2</td>
</tr>
</tbody>
</table>

In M2 procedure, PC, SEBS, and SEBS-g-MAH minor phases are first pre-blended in twin screw extruder and after granulating are added to PP continuous phase in twin screw extruder. Consequently, in M3 procedure, PP and SEBS-g-MAH are first pre-
blended and then are extruded with the other components. Table 7 represents the nominal independent parameters. The responding variables were impact energy and tensile properties (young modulus and yield stress) which are influenced by the morphology of ternary blends. After analyzing Taguchi method, the optimized conditions will be achieved.

**Mechanical properties**

After melt blending of designed compounds in twin-screw extruder, the blends were quenched in cooling water bath and pelletized in a granulator. Dried blends were molded to from tensile and impact specimens using an ENGEL injection molding machine. The Barrel temperature profile was 180 °C (hopper) to 240 °C (nozzle) and the mold temperature was maintained at 40 °C. Tensile stress-strain data were obtained using Galdabini testing machine in the rate of 50 mm/min according to the ASTM D-638. Morever Izod impact strength was done for notched specimens according to ASTM D-256 using Zwick pendulum-type tester.

**Morphological studies**

In order to evaluate the effect of particle size and the type of resulted morphology on the mechanical properties of PP/PC/SEBS ternary blends, scanning electron microscopy (SEM) micrographs were obtained using AIS-2100 scanning electron microscopy supplied by SERON Company through fracture surface of impact specimens. Before doing scanning electron microscopy, the samples were fractured in liquid nitrogen and consequently were etched by cyclohexane for 24 h to remove SEBS and SEBS-g-MAH minor phases. Then, the etched samples were gold sputtered to make the samples conductive.

**Dynamic Mechanical Analysis**

Dynamic mechanical thermal analysis (DMTA) was carried out using a Tritec 2000 DMA model. The testing was performed in 3-bending mode. The experiments were done at a frequency of 1 HZ, and heating rate of 5 °C/min. The temperature range was -100 to 150 °C.

**References**