The ethylene-propylene-diene monomer/polypropylene (EPDM/PP) thermoplastic elastomer is prepared by dynamic vulcanization. The effects of different rubber ratios and crosslinking agent contents on the static and dynamic mechanical properties, crystallization and rheological behaviors are investigated and discussed. EPDM/PP with the rubber ratio from 40 to 50% and crosslinking agent content of 1.2 wt% has the highest tensile strength and elongation at break. The fracture morphologies indicate that EPDM/PP with high rubber ratios and crosslinker contents is over vulcanized to harden, which results in that some large particles cannot be fragmented by shear force. The crystallinity obtained from differential scanning calorimetry (DSC) shows a decrease with increasing rubber ratio and a very slight variation with increasing the crosslinking content. The dynamic mechanical analysis (DMA) results display a decrease trend in storage modulus and tan δ with increasing crosslinking density. The rheological behaviors show that the complex viscosity also increases with increasing crosslinking density, indicating that the elastic deformation becomes superior to viscous flow in EPDM/PP.

1 Introduction

Compared with traditional rubber materials, a thermoplastic elastomers (TPE) combining the high elasticity of rubber and toughness of the plastic show many distinct advantages in processing including low energy dissipation, high efficiency, high effective reclaiming. In addition, TPE are used in a wide range of applications due to easy processing by conventional methods like extrusion and injection molding (Drobný, 2014). The advantages in mechanical properties and processing made TPE becoming widely used in automobile, construction, insulator and electric appliances (Müller and Rieger, 2002; Huang et al., 2013; Holden, 2017; Hu et al., 2017; Lu et al., 2018). Among many kinds of TPE, the dynamic vulcanized ethylene–propylene–diene monomer/polypropylene (EPDM/PP) thermoplastic elastomers have attracted broad attention due to their unique properties. In the components, EPDM is copolymerized by ethylene, propylene and unconjugated diene in which the saturated ethylene and propylene constitutional units result in nice weather fastness, heat and ozone resistance (Yetkin et al., 2013; Zhao et al., 2015; Wypych, 2016). One of the double bonds in the non-conjugated diene can be used as an active center for the crosslinking reaction (Parenteaua et al., 2014; Katbab et al., 2015; Khan et al., 2015; Naskar et al., 2016). As for the plastic component, PP has relatively high mechanical properties and a good resistance to heat, insulativity and fatigue resistance is cheap, shows easy processing and is recyclable (Cao et al., 2017).

In the dynamic vulcanization of EPDM/PP, the free radicals generated by the crosslinking agent can react with the unconjugated diene in EPDM to form macromolecular chain free radicals which can be moved by shearing action. The EPDM molecules can crosslink when the chemical reaction of these radicals occurs (Mali et al., 2017). Due to the effects of different processing conditions and components on the microstructure and properties of EPDM/PP elastomers, it is quite important to investigate a good method for the optimization of preparation procedure and formulations. Generally, the main influence factors on the properties of EPDM/PP include the characteristics of PP, rubber (EPDM) ratio, degree of crosslinking and oil charging (Coran and Patel, 1980; Gupta et al., 2000; Winters et al., 2001; Ma et al., 2016). Among these factors, rubber ratio and degree of crosslinking are the most considerable. The compounds of EPDM and PP are part of a binary immiscible system in which the rubber ratio exhibits a great influence both on the crystallinity of PP and the motions of EPDM molecular chains. In addition, the different rubber ratio also results in a different system viscosity which can affect the efficiency of crosslinking and particle dispersion. On the other hand, a proper crosslinking density is helpful to the fragmentation and dispersion of EPDM particles and a too high or low
crosslinking density go against the formation of a stable microstructure. The kind and content of crosslinking agent also exert a great effect on the vulcanization efficiency, which affects the morphology, mechanical properties and processing behavior (Naskar et al., 2004; Martin et al., 2009; Chen, et al., 2013; Uthaipan et al., 2015).

In this work, the two factors above are mainly discussed and the peroxide co-agent vulcanization system is applied. The effects of different rubber ratios and crosslinking agent contents on the static and dynamic mechanical properties, crystallization and rheological behaviors of dynamic vulcanized EPDM/PP are analyzed and discussed. The main purpose of this work is to investigate and evaluate these effects to provide the theoretical and data support for the optimal processing and formulation of dynamic vulcanized EPDM/PP elastomers.

2 Experimental

2.1 Materials

Ethylene-propylene-diene monomer (EPDM, 4770P) was purchased from Dow Chemistry, US. The ethylene content was 70%, the diene content was 5%, the propylene content was 25%, the density was 0.87 g/cm³, and the Mooney viscosity was 70 M. Polypropylene (PP, T30 s) was supplied by Sinopec Co., Ltd., PRC. Melt flow rate is 3.0 g/10 min; the density is 0.90 g/cm³. The crosslinking agent and co-agent used in this work were dicumyl peroxide (DCP) and triallyl isocyanurate (TAIC), respectively. The density of DCP is 1.08 g/cm³, the molecular weight is 338.5. Pure peroxide has an active oxygen content of 9.45%. The purity of TAIC is 99% and the mass is 249.27. They were supplied by Akzo Nobel Chemicals Co., Ltd., The Netherlands.

2.2 Preparation of Samples

PP and EPDM with different ratios were dried in an oven at 70 °C for 8 h before extruding. EPDM/PP was extruded with different contents of crosslinking agent (DCP) and co-agent (TAIC) on a twin-screw extruder (TSE–40A, L/D = 40, D = 40 mm, Coperion Keya Machinery, Co., Ltd., PRC) at 185 to 200 °C. The mixing time in the screws was set at 40 to 60 s to further cross-linking. Then the samples were injection molded on an injection molding machine (CJ80MZ-NCII, Chengde Plastics Machinery Co., Ltd., PRC) at 195 to 210 °C.

2.3 Measurements and Characterization

2.3.1 Mechanical Properties

The tensile strength was measured by the material testing machine type WDW-10C (Shanghai Hualong Test Instrument Co., Ltd., PRC) with the tensile speed of 50 mm/min. The bending strength was measured by the same machine, with the crosshead speed of 2 mm/min. All mechanical tests were performed at the room temperature of 23 ± 2 °C.

2.3.2 Scanning Electronic Microscopy (SEM)

The SEM images of fracture surfaces were obtained by a Quanta FEG230 scanning electron microscope. SEM images of the composites were recorded after gold coating surface treating, with the accelerating voltage of 10 kV.

2.3.3 Dynamic Mechanical Analysis (DMA)

The rectangular composites samples were tested on a dynamic mechanical analyzer (Q800, TA Instruments) using a dual cantilever setup. The dynamic mechanical properties were analyzed at a heating rate of 3 °C/min over a temperature range from –60 to 60 °C. The measurements were performed with imposed frequency of 10 Hz and oscillation amplitude of 15 μm in bending mode. The length of the spline is about 40 mm, the width is about 5 mm, and the thickness is 1 mm.

2.3.4 Differential Scanning Calorimetry (DSC)

The crystallization behavior of samples were measured by DSC (Q-10 s, TA Instruments Co., Ltd., USA). Each sample of about 8 mg was loaded and sealed in an aluminum sample pan. The samples were first heated to 200 °C, and held 5 min to erase the thermal history, then cooled to 30 °C and reheated to 200 °C at the heating/cooling rate of 10 °C/min in high purity nitrogen atmosphere.

The degrees of crystallinity (expressed in %, Xc) of PP were calculated by integration of the area under the DSC endothermic peak and division by the heat of fusion with 100% crystalline PP using the following equation:

\[ X_c = \frac{\Delta H/C\%}{\Delta H_m \times 100 \%} \]

where \( \Delta H \) is the enthalpy of samples, C% the percentage content of PP matrix in the composites (in this work it is 80%), and \( \Delta H_m \) the value of enthalpy of the melting of 100% crystalline PP and taken as 106.9 J/g (Costa et al., 2007).

2.3.5 Rheological Analysis

The rheological behaviors were measured on a rheometer (AR 2000) with a nitrogen purge. A 25 mm parallel-plate with a 1000 μm gap was selected for the test. Strain amplitude of 1% was found to be suitable to ensure linear viscoelastic regime and used for both the frequency sweep and temperature ramp sweep modes.

3 Results and Discussion

3.1 Mechanical Properties

The tensile test is usually used to evaluate the mechanical properties of elastic materials (Wong et al., 1997; Lee et al., 2008). The effect of rubber ratio on the tensile strength and elongation

Intern. Polymer Processing XXXIV (2019) 4
at break of vulcanized EPDM/PP thermoplastic elastomer are shown in Fig. 1. EPDM/PP elastomers with the ratios of 40/60 and 50/50 show higher values both in tensile strength and elongation at break. PP acts as rigid component to improve the stiffness and strength in EPDM/PP with the suitable rubber ratio. In dynamic vulcanization, EPDM is fragmented into small particles dispersed in the matrix by the shearing force of the screw, and then the free radicals generated by the crosslinker react with the allyl hydrogen on the pendant group of EPDM to form the net structure. This structure can induce more crazing during the loading procedure to make materials to bear higher stress. With the low rubber ratio (<40%), there is insufficient crosslinking structure to improve the rigidity, while a high rubber ratio (>50%) leads to the decrease of tensile strength and elongation at break, which is attributed to the nonuniform dispersion of EPDM in the low content of PP matrix.

Figure 2 shows effect of DCP content on the tensile strength and elongation at break of vulcanized EPDM/PP (40/60) elastomer. The contents of DCP are set from 0.8 to 1.8 wt% of EPDM while the content of co-agent (TAIC) is set at 1.5% of EPDM for all samples. As the DCP content increased, the tensile strength of EPDM/PP (40/60) increased first and then decreased, and the sample of 1.2 wt% DCP showed the highest tensile strength. When the DCP content is less than 1.4% by weight, the elongation at break remains relatively stable, and when the DCP content is high, the elongation at break rapidly decreases. In the case of low DCP content, only a few EPDMs can be crosslinked, and the crosslinked network structure is unstable, resulting in a decrease in tensile strength. As the DCP content increases, the EPDM crosslink density and viscosity increase, and some free radicals are also produced, and the EPDM molecules crosslink to increase the strength of EPDM/PP. However, when more DCP is added, higher crosslink density will make molecular chain motion difficult and the stress transfer ability of EPDM particles will decrease. Otherwise, excessive free radicals can cause degradation of the PP molecular chain. All of the above factors can cause a drop in tensile properties.

3.2 Morphology Analysis

Figure 3 exhibits the SEM photos of brittle fractures for EPDM/PP elastomers with different rubber ratios. It is observed from Fig. 3 that many EPDM particles disperse in the PP matrix and form a sea-island structure. For low rubber ratio (<50%), the interface zone between EPDM and PP is obviously emerged with many tiny pits that are formed by spalling of rubber particles. With increasing rubber ratio (shown in Fig. 3C and D), less pits are generated and the fractures gradually become smooth.

The SEM photos of brittle fractures for EPDM/PP (40/60) elastomers with different DCP contents are shown in Fig. 4. With low content of DCP (<1.2 wt%), EPDM in the blends has a low crosslinking density. The non-crosslinked part of EPDM will reassemble to large particles and lead to unbalanced dispersion and pits, as shown in Fig. 4A. When the DCP content is between 1.2 and 1.4 wt%, the suitable crosslinking density of EPDM is achieved. Nearly all the large EPDM particles can be fragmented into small particles dispersed in the PP matrix by the shearing force of the screw to obtain better mechanical properties as stated in the previous section. Increasing the DCP content further, EPDM is over vulcanized to harden, which results in that some large particles cannot be fragmented by shear force. These large particles not only decrease the mechanical properties of the materials but also lead to a high melt viscosity to make the extruding process more difficult.

3.3 Crystallization Behavior

Figure 5 shows the crystallization and melting curves of EPDM/PP with different rubber ratios and the detailed data including crystallization temperature (Tc), melting temperature (Tm), heat enthalpy of crystallization and melting (AHc and AHm), and calculated relative crystallinity (XC) are exhibited also in Table 1. With increasing rubber ratio, both crystallization and melting curves shift to lower temperature and the peak values of these curves become lower. The calcul-
lated $X_c$ values show a very slight decrease when the rubber ratio varies from 30 to 50%, while it decreases dramatically when the ratio comes to 60%. The vulcanized EPDM chains present an amorphous structure with random coil and partly cross-linked net structure. The structure leads to a decrease in regularity of molecular chains of PP in the interface area between PP and EPDM, which results in the decrease of crystallinity.

Figure 6 shows the crystallization and melting curves of EPDM/PP (40/60) elastomers with different DCP contents and the detailed data are listed in Table 2. It is found that the crystallinity curves first move slightly to higher temperature (up to 1.2%) then shift to a lower temperature with increasing DCP contents, while the melting curves show the shifting trend to lower temperature all the time. The calculated $X_c$ values of EPDM/PP (40/60) with different DCP contents show a very slight variation trend of less than 2.3%. The contents of free radicals in the melt also increase with increasing content of DCP, and some free radicals can react with PP to induce the crosslinking and degradation of PP. It is inferred that the crosslinked PP molecular chains decrease their motion ability, which makes the crystallization to occur at a higher temperature.

![Fig. 3. SEM photos of brittle fractures for EPDM/PP with different rubber ratios: A) 30/70; B) 40/60; C) 50/50; D) 60/40](image1)

![Fig. 4. SEM photos of brittle fractures for EPDM/PP (40/60) with different DCP contents: A) 0.8 wt%; B) 1.2 wt%; C) 1.4 wt%; D) 1.8 wt%](image2)
When the DCP content is over 1.4 wt%, the degradation of PP gradually predominates the process to slightly improve the motion of PP chains and $T_c$ decreases. The formation of gels could be responsible for the changes seen in the crystallization behavior.

### 3.4 Dynamic Mechanical Properties

Dynamic mechanical analysis can be used to measure the relationship between the mechanical properties and temperature of a bi-material, and to analyze the compatibility between the dispersed phase and the matrix (Antunes et al., 2011; Lima et al., 2015; Prut et al., 2017; Mazidi and Aghjeh, 2015). Storage

![Crystallization and melting curves of EPDM/PP with different rubber ratios](image1)

**Fig. 5.** Crystallization (A) and melting (B) curves of EPDM/PP with different rubber ratios

![Crystallization and melting curves of EPDM/PP (40/60) with different DCP contents](image2)

**Fig. 6.** Crystallization (A) and melting (B) curves of EPDM/PP (40/60) with different DCP contents

| EPDM/PP 30/70 | $T_c$ °C | $T_m$ °C | $\Delta H_c$ J/g | $\Delta H_m$ J/g | X % |
|---------------|----------|----------|-----------------|-----------------|-----|
| EPDM/PP 30/70 | 119.9    | 161.4    | 59.1            | 51.4            | 35.1 |
| EPDM/PP 40/60 | 115.2    | 161.5    | 48.9            | 43.4            | 34.6 |
| EPDM/PP 50/50 | 113.8    | 164.2    | 40.4            | 32.9            | 34.4 |
| EPDM/PP 60/40 | 106.1    | 157.9    | 25.2            | 22.5            | 26.9 |

**Table 1.** Crystallization data of EPDM/PP with different rubber ratios
modulus (G'), loss modulus (G'') and tan δ curves of EPDM/PP elastomers with different rubber ratios are shown in Fig. 7. The EPDM and PP molecular chains are in the glassy state and show rigidity with high G' values when the temperature is lower than –40°C. With increasing temperature and rubber ratio, the G' values decrease significantly. In the temperature range from –60 to 60°C, all the curves of G' show two different peaks at –30 and 10°C, except for the PP content of 40%, which is attributed to the vitrification of EPDM and PP, respectively. A partial miscible compound system consists of polymers having two glass transition temperatures (Tg) (Jung and Jhon, 2010). With increasing rubber ratio, the α peak value becomes higher while the β peak decreases significantly, which is attributed to the fact that the irregularity of EPDM weakens the ordered arrangement of PP molecules. In addition, the free radical decomposed by the crosslinking agent in the vulcanization process can also react with the tertiary hydrocarbon hydrogen atom in the PP molecular chain, causing degradation and fracture of the PP, lowering the molecular weight, and reducing the mechanical loss.

Figure 8 shows the curves of G', G'' and tan δ of EPDM/PP (40/60) with different DCP contents in the temperature range from –60 to 60°C. With higher DCP content, The G' value increases. The higher crosslinking density makes the motions of molecular chains difficult, which improves the stiffness of materials. The two peaks also appear in the G'' curves as mentioned above. With increasing DCP content, the peak increases first and then decreases. This indicates that moderated crosslinking improves the rigidity of materials with low DCP content. However, high DCP content and high crosslinking density increases the internal friction of molecular chains in glass transition to promote the mechanical loss. The G' curves also show that the values of β peaks increase with increasing DCP content, which indicates that DCP also can lead to the crosslinking of PP and the drag increment of segmental motion occurs in glass transition. In addition, tan δ curves show that α peaks of 0.8 wt% DCP samples shift to lower temperature dramatically compared with the other samples. The insufficient free radicals generated by the low content of DCP result in the low efficiency of vulcanization.

| DCP content (wt%) | Tc (°C) | Tm (°C) | ΔHc (J/g) | ΔHm (J/g) |
|-------------------|---------|---------|-----------|-----------|
| 0.8               | 111.17  | 161.21  | 50.79     | 45.80     |
| 1.0               | 109.94  | 161.58  | 48.88     | 43.42     |
| 1.2               | 111.20  | 161.50  | 48.90     | 43.40     |
| 1.4               | 111.76  | 160.05  | 49.81     | 44.29     |
| 1.6               | 113.01  | 158.37  | 50.62     | 45.30     |
| 1.8               | 112.54  | 158.46  | 50.35     | 44.86     |

Table 2. Crystallization data of EPDM/PP with different DCP contents

The specific focus on rheological behavior are the G', G'' and complex viscosity (η*) of EPDM/PP with different rubber ratios with different frequency (ω) at certain temperature – Fig. 9. All the η* values decrease with increasing shear ω, which shows the shear-thinning of pseudoplastic fluids. The samples with higher rubber ratios also have higher η* values and η* - ω curves gradually become linear in the logarithmic plot, indicating that the shearing flow of EPDM/PP melt obeys the power law. In Fig. 9B and C, both the G' and G'' values increase with increasing ω. When ω is low, the variation of shear force is relatively slow so that the movements of molecular chains are able to keep pace with the variation of stresses. In this condition, the value of G’ is slightly higher than that of G'' and the materials show a viscosity, but the value of G'' increases more easily and becomes higher than that of G’ at higher frequency. The movement of molecular chains is gradually not able to respond to the stress variations, which means that the material shows elasticity instead of viscosity. With increasing ω further (>10 rad/s), the increase rate of G’ becomes much lower, and the value of G'' remains stable. In addition, the rate of G'/G'' also increases, and the material becomes more elastic. With low rubber ratio (<50%), the G'' value is higher than that of G' at high frequency. The crosslinking densities also increase with higher rubber ratio and generate more entanglement of molecular chains to form a crosslinking net structure, which weakens the motions of molecular chains to make relaxation more difficult.

The G', G'' and η* curves of EPDM/PP with different DCP contents are displayed in Fig. 10. All the η* values decrease with increasing frequency, which corresponds to the typical behavior of pseudoplastic fluids as analyzed above. It is also observed in Fig. 10A that the value of η* increases with increasing DCP content. So, the crosslinking density increases with increasing DCP content and the higher flow resistance of EPDM melt leads to the increase of η*. The variations of G' in Fig. 10B indicate that each curve shows a plateau zone at low frequency (about <0.1 rad/s) while this zone narrows down with increasing content of DCP. When ω continues to increase (over 1 rad/s), the G' value increases rapidly due to the same issue of responding to the stress variations as stated above. The values of G'' represent the viscous flow of materials, corresponding to the loss of irreversible deformation. The G'' values shown in Fig. 10C also show an increasing trend with increasing DCP content and ω. The higher crosslinking density caused by higher DCP content can limit the motion of molecular chain segments to increase the internal friction and the stiffness is improved to some extent. In addition, the G' values are always higher than the G'' values at the same frequency,
Fig. 7. Storage modulus (A), loss modulus (B) and tan δ (C) curves of EPDM/PP with different rubber ratios

Fig. 8. Storage modulus (A), loss modulus (B) and tan δ (C) curves of EPDM/PP (40/60) with different DCP contents
Fig. 9. Storage modulus (A), loss modulus (B), and complex viscosity (C) of EPDM/PP with different rubber ratios

Fig. 10. Storage modulus (A), loss modulus (B) and complex viscosity (C) of EPDM/PP (40/60) with different DCP contents
which also indicates that the elastic deformation is superior to viscous flowing in EPDM/PP.

4 Conclusions

The data of static mechanical properties show that the highest tensile strength and elongation at break are obtained when the rubber ratio is between 40 and 50% and the DCP content is kept at 1.2 wt%. The SEM photos of fracture surfaces also display a better dispersion and smaller particle size of EPDM with the rubber ratio of 40% and 1.2 wt% DCP content. The DSC results indicate that both crystallization and melting curves shift to lower temperature with increasing rubber ratio and DCP content and crystallinity increase up to the rubber ratio of 40% and 1.2 wt% DCP content. The DSC results show that the peak values become higher while the β peaks decrease significantly with increasing rubber ratio, which can be attributed to the irregularity of EPDM that weakens the ordered arrangement of PP molecules. With higher crosslinking density caused by higher rubber ratio or more DCP addition, the motions of molecular chains become difficult to improve the stiffness of the materials. As for the rheological behavior analysis, the η″ value increases both with higher rubber content up to 50% and DCP contents until 1.8 wt% due to the high crosslinking density and over vulcanization.

References

Antunes, C. F., Duin, M. V. and Machado, A. V., “Morphology and Phase Inversion of EPDM/PP Blends – Effect of Viscosity and Elasticity”, Polym. Test., 30, 907–91 (2011), DOI:10.1016/j.polymertesting.2011.08.013

Cao, L., Zheng, A., Cao, X., Yuan, D., Xu, C. and Chen, Y., “Morphology and Non-isothermal Crystallization of Dynamically Vulcanized PP/EPDM Blends in situ Compatibilized via Magnesium Dimethacrylate”, Polym. Test., 62, 68–78 (2017), DOI:10.1016/j.polymertesting.2017.06.014

Chen, Y., Xu, C., Cao, L. and Cao, X., “Highly Toughened Polypropylene/Ethylene–Propylene-Diene Monomer/Zinc Dimethacrylate Ternary Blends Prepared via Peroxide-Induced Dynamic Vulcanization”, Mater. Chem. Phys., 138, 63–71 (2013), DOI:10.1016/j.matchemphys.2012.10.034

Coran, A. Y., Patel, R., “Rubber-Thermoplastic Compositions. Part I. EPDM-Polypropylene Thermoplastic Vulcanizates”, Rubber Chem. Technol., 53, 141–150 (1980), DOI:10.5254/1.3535023

Costa, H. M. D., Ramos, V. D. and Oliveira, M. G. D., “Degradation of Polypropylene (PP) during Multiple Extrusions: Thermal Analysis, Mechanical Properties and Analysis of Variance”, Polym. Test., 26, 676–684 (2007), DOI:10.1016/j.polymertesting.2007.04.003

Drobný, J. G., “Chapter 6 Thermoplastic Elastomers Prepared by Dynamic Vulcanization”, in Handbook of Thermoplastic Elastomers, Elsevier, New York, p. 325–328 (2007), DOI:10.1016/B978-081551549-4.50007-4

Holden, G., “Chapter 5 Applications of Thermoplastic Elastomers”, in Applied Plastics Engineering Handbook, Elsevier, New York, p. 91–107 (2017), PMid:27814946; DOI:10.1016/b978-0750601044.10003-0

George, W., “EPDM. Ethylene–Propylene Diene Terpolymer”, in Handbook of Polymers, ChemTech. Publishing, Florida, p. 122–125 (2016), DOI:10.1016/B978-081551549-4.50007-4

Gupta, N. K., Nagpal, A. K. and Jain, A. K., “Dynamically Vulcanized Blends of Polypropylene (PP) and Ethylene Propylene Diene (EPDM) Rubber-A Toughening Mechanism”, J. Polym. Mater., 17, 393–410 (2000)

D.-H. Xu et al.: Influence of Rubber Ratio and Crosslinking Agent on EPDM/PP

Hu, X., Kang, H., Li, Y., Geng, Y., Wang, R. and Zhang, L., “Preparation, Morphology and Superior Performances of Biobased Thermoplastic Elastomer by in situ, Dynamical Vulcanization for 3D-Printed Materials”, Polymer, 108, 11–20 (2002), DOI:10.1016/j.polymerricer.2016.11.045

Huang, H., Zhou, R. and Yang, C., “Fiber Orientation Propelled by High-Pressure Water Penetration in Water-Assisted Injection Molded Fiber-Reinforced Thermoplastic Parts”, Compos. Mater., 47, 183–190 (2013), DOI:10.1177/0020761412438083

Katab, A. A., Nazockdast, H. and Bazgir, S., “Carbon Black-Reinforced Dynamically Cured EPDM/PP Thermoplastic Elastomers. I.raftology, Rheology and Dynamic Mechanical Properties”, J. Appl. Polym. Sci., 75, 1127–1137 (2015), DOI:10.1002/sic.1096-2609(2002)28(7):5<1127::aid-APP5>3.0.CO;2-2

Jung, H. Y., Jhon, M. S., “Partial Miscibility in Multi-component Polymer System”, J. Polym. Sci., Part A: Polym. Chem., 22, 567–576 (2010), DOI:10.1002/pol.170220305

Khan, M. A., Kumar, S. S., Raghu, T. S., Kotresh, T. M. and Sailaja, R. R., “Dispersion Mechanisms of LDPE/PP/Nylon 6/EPDM Reinforced with MWCNT and Kenaf Fiber with Enhanced Mechanical, Thermal and Flammability Characteristics”, Mater. Today Commun., 4, 50–62 (2015), DOI:10.1016/j.mtcomm.2015.04.008

Lee, C., Wei, X. D., Kysar, J. W. and Hone, J., “Measurement of the Elastic Properties and Intrinsic Strength of Monolayer Graphene”, Science, 321, 385–388 (2008), PMid:18635798; DOI:10.1126/science.1157996

Lima, P., Silva, S. P. M. D., Oliveira, J. and Costa, V., “Rheological Properties of Ground Tyre Rubber Based Thermoplastic Elastomeric Blends”, Polym. Test., 45, 58–67 (2015), DOI:10.1016/j.polymertesting.2015.05.006

Lu, C., Yu, J., Wang, C., Wang and Chu, F., “Fabrication of UV-Absorbent Cellulose-Resin Based Thermoplastic Elastomer Via ‘Graft from a TRP’”, Carbohydr. Polym., 188, 128–135 (2018), PMid:29525148; DOI:10.1016/j.carbpol.2018.01.062

Ma, L. F., Bao, R. Y., Dou, R., Zheng, S. D., Liu, Z. Y., Zhang, R. Y., Yang, M. and Yang, W., “Conductive Thermoplastic Vulcanizates (TPVs) Based on Polypropylene (PP)/Ethylene-Propylene-Diene Rubber (EPDM) Blend: From Strain Sensor to Highly Stretchable Conductor”, Compos. Sci. Technol., 128, 176–184 (2016), DOI:10.1016/j.compscitech.2016.01.006

Mali, M., Marathe, A. and Mhaske, S., “Influence of (Methacryloxy-methyl) Methylidimethoxysilane on DCP Cured EPDM/PP Thermoplastic Vulcanizates”, J. Vinyl Add. Tech., 24, 304–313 (2018), DOI:10.1002/vnl.21605

Martin, G., Barres, C., Sonntag, P., Garaio, N. and Cassagnau, P., “Morphology Development in Thermoplastic Vulcanizates (TPV): Dispersion Mechanisms of a Pre-Crosslinked EPDM Phase”, Eur. Polym. J., 45, 3257–3268 (2009), PMid:19607130; DOI:10.1016/j.eurpolymj.2009.07.012

Mazidi, M. M., Aghjeh, M. K. R., “Effects of Blend Composition and Compatibilization on the Melt Rheology and Phase Morphology of Binary and Ternary PP/PA6/EPDM Blends”, Polym. Bull., 72, 1975–2000 (2015), DOI:10.1007/s00289-015-1384-6

Müller, G., Rieger, B., “Polypropylene Based Thermoplastic Elastomers by Early and Late Transition Metal Catalysis”, Prog. Polym. Sci., 27, 815–851 (2002), DOI:10.1016/s0032-3861(01)00030-x

Naskar, K., Gohs, U. and Heinrich, G., “Influence of Molecular Structure of Blend Components on the Performance of Thermoplastic Vulcanizates Prepared by Electron Induced Reactive Processing”, Polymer, 91, 203–210 (2016), DOI:10.1016/j.polymerricer.2016.03.070

Naskar, K., Kokot, D. and Noordermeer, J. W. M., “Influence of Various Stabilizers on Anionic Dicyclopentadienyl Peroxycured Polypropylene/Ethylene-Propylene-Diene Thermoplastic Vulcanizates”, Polym. Degrad. Stab., 85, 831–839 (2004), DOI:10.1016/j.polymdegirstab.stab.2004.03.016

Parenteau, T., Berteva, E. A., Aussias, G., Stoeck, R., Grohens, Y. and Pilvin, P., “Characterisation and Micromechanical Modelling of the Elasto-Viscoelastic Behavior of Thermoplastic Elastomers”, Mech. Mater., 71, 114–125 (2014), DOI:10.1016/j.mechmat.2013.06.010

Intern. Polymer Processing XXXIV (2019) 4

465
Acknowledgements

The authors are grateful for the financial support provided for this study by National Natural Science Foundation of China (51602067), Opening Project of State Key Laboratory of Polymer Materials Engineering (Sichuan University) (2017-4-02), International Science and Technology Cooperation Project of Chengdu (2017-GH02-00051-HZ), Guizhou Science and Technology Plan Project (2019/2026), Special Funds of Guizhou Province Outstanding Young Scientists (2015/26), and Guizhou Province High-level Innovative Talents Training Project (2015/4039, 2016/5667), Baiyun District Technology Project of Guiyang City (2018/3, 2018/10).

Date received: March 18, 2019
Date accepted: April 18, 2019