

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

For application demanding high impact resistance and/or high toughness with low moisture absorption, polyamide 12 (PA12, Nylon12) has been in focus due to a longer hydrocarbon chain with 12 carbon atoms and a lower concentration of amide groups (nitrogen-containing organic compounds). As a consequence, Nylon12 shows a higher flexibility and a lower moisture absorption (less than 0.3 %), compared to other types of Nylon, i.e., Nylon6, Nylon66, and Nylon11. In polyamide blend system, the toughness enhancement could be done by incorporating an elastomer into it. Natural rubber (NR) from *Hevea brasiliensis* accounts for more than 99 % of the world's natural source of rubber, in which the major component is *cis*-1,4-polyisoprene. This plant has very high productivity, and the final product usually exhibits excellent properties such as high tensile and tear strength, good crack growth resistance and minimal heat buildup.

In this research work, the non-reactive and reactive compatibilizations of Nylon12 and NR had been studied. For the non-reactive compatibilization, a copolymer of polystyrene and natural rubber (PS/NR) was used as a compatibilizer. Due to a lower interfacial tension between Nylon12 and PS than that between Nylon12 and NR, PS part should face to Nylon12 surface and NR part faced to NR phase. This non-reactive compatibilizer would tie the two phases of Nylon12 and NR together via physical linkages. This phenomenon led to the increasing of interfacial adhesion and the enhancement of mechanical properties. The non-reactive compatibilizer content (5-25 phr) had significantly effect on the blend properties as well as the phase morphology. At the optimum compatibilizer content of 10 phr, the [Nylon12/NR]/[PS/NR] blends showed the highest values of impact energy, tensile modulus and tensile yield stress. These results were also related to the lowering of the dispersed rubber phase size ($\sim 2 \mu\text{m}$). At high compatibilizer content (15-25 phr), the dispersed rubber phases changed from spherical shapes to irregular shapes, causing the reduction of total blend performances.

To enhance compatibility of Nylon12 and NR and to obtain the dispersed phase size less than 1 μm , the reactive compatibilization had been then investigated. A copolymer of polystyrene and maleated natural rubber (PS/MNR) prepared by free radical reaction was used as a reactive compatibilizer. The different mixing procedures (one-step and two-step mixing) and maleic anhydride (MA) contents (3 and 5 wt%) were found to affect to the grafting reaction of MA onto NR. The uses of low MA loading (3 wt%) and two-step mixing that NR was functionalized with MA first provided PS/MNR blend having a lower gel (crosslinked NR) content and a higher MA grafting efficiency. The effect of PS/MNR content (1-10 phr) on rheological properties was studied by using a capillary rheometer. The presence of PS/MNR reactive compatibilizer in Nylon12/NR blend system increased the interfacial interaction and interfacial adhesion at Nylon12/NR interfaces via the formation of amide and succinimide linkages. These specific interactions were produced from the imidization reaction of the MA group in PS/MNR and the amine-end group of Nylon12, hence; PS/MNR would tie Nylon12 phase and NR phase via chemical linkages. At a particular compatibilizer loading of 7 phr, more bulky amide and succinimide linkages made the molecular chains and interfaces became stiff and resisted deformations, leading to the increasing of shear viscosity and flow activation energy. These amide and succinimide linkages also resulted in the decreasing of extrudate swell of the blends due to the reduction of chain elasticity. The correlation of viscosity ratio and phase morphology affecting mechanical properties of the compatibilized blends was then investigated. The results illustrated that the use of reactive compatibilizer gave an effective compatibilization of Nylon12/NR blend (at composition of 80:20 wt%) so that the mechanical properties (both tension and toughening) were significantly improved. The increasing of PS/MNR content results in reducing viscosity ratio in melt state as well as improving mechanical properties in solid state. Especially at the optimum content (7 phr) of the PS/MNR compatibilizer, the blend shows significant improved in toughening with increasing impact energy while retaining the original Nylon12 tensile properties but with twice elongation at break.

Compared with neat Nylon12, the impact energy was found to increase from 115 J/m for Nylon12 to 380 J/m (increased by a factor of 3 approximately) for [Nylon12/NR]/[PS/NR] blends (non-reactive compatibilization) and up to 503 J/m (increased by a factor of 5 approximately) for [Nylon12/NR]/[PS/MNR] blends (reactive compatibilization). It suggested that the toughness enhancement of Nylon12 with natural rubber in the presence of compatibilizer was successfully obtained. However, the reactive compatibilizer (PS/MNR) was used in lower content than the non-reactive compatibilizer (PS/NR) for compatibilizing Nylon12/NR blend system. It was attributed to the formation of amide and succinimide linkages at Nylon12/NR interfaces. These chemical linkages helped increase the interfacial interaction and interfacial adhesion, leading to the stabilization of phase morphology and the enhancement of mechanical properties. For non-reactive compatibilization, the physical linkages are not sufficient to increase the compatibility between Nylon12 phase and NR phase; hence, higher loading of non-reactive compatibilizer is used to improve the blend properties.

9.2 Recommendations

In this research work, the results indicated the increasing of shear viscosity, the stabilization of morphology, and the improvement of mechanical properties. Although the rheological properties could be related to the phase morphology and the mechanical properties, the former parameter was studied in the melt state while the latter parameters were investigated in the solid state. Hence, to relate these properties, the thermal-mechanical properties of [Nylon12/NR]/[PS/MNR] blends should be determined by using dynamic mechanical thermal analysis (DMA).

The presence of gel (crosslink structure of NR) had significantly effect on the filament spinning. The size of gel was higher than the diameter of filament. Hence, the filament spinning would not continue, and the long filament could not be obtained. Furthermore, the materials could not be drawn into the yarn (fiber with very small diameter). As a consequence, the production of woven fiber with high strength could not be obtained, too. For the test of ballistic resistance, due to the limitation of filament spinning, the materials were prepared into the sheet form with

thickness of 3 mm. Although the results showed the penetration of bullet into the materials, the bullet energy and velocity were found to decrease and less damage from the bullet was be delivered. It resulted from more energy absorption and energy dissipation in the materials. Thus, the ballistic resistance could be enhanced by increasing the number of sheets or by increasing the sheet thickness.