CHAPTER - 3

INTRODUCTION TO POLYPROPYLENE BLENDS

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3.1 WHAT ARE POLYMER BLENDS ?

Owing to their potential technical importance, polymer blends currently command considerable scientific interest. Polymer blends which form a class of multiphase polymer systems can be broadly defined as the mixture of two or more polymers or copolymers as shown in Fig. 3.1 [1].

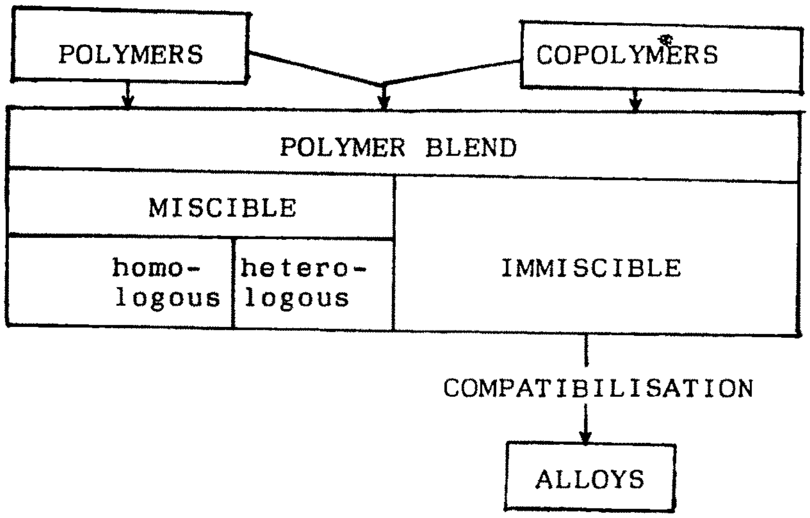

Fig. 3.1

Polymer blend can be either miscible or immiscible. The miscible blends are divided into homologous blends (blends of the same polymer, such as a mixture of polystyrene fractions) and heterologous blends (e.g. polyphenylene ether with polystyrene). Within the immiscible blends there is a subgroup of compatible polymers, e.g. the well-formulated and finely dispersed mixtures of polyolefins, which due to small interfacial tension are morphologically stable. Polymer alloy is considered as a subclass of immiscible polymer blends. Polymer alloy is a class of polymer blends heterogeneous in nature, with controlled morphology and properties, achieved by compatibilisation.

The most interesting features of polymer blends are that the major component retains most of the properties while the dispersed phase imparts certain specific properties. In principle, blending two polymers together is to achieve a balance of properties not obtainable with a single one. Thus, it is an effective technique for scientists and engineers for achieving tailor made material with balanced combination of processing conditions; characteristic properties and cost. Due to these properties, polymer blends have gained a very important position in the panorama of the multicomponent polymer systems. Polymer blends have applications in every major areas, from electronics and telecommunications to building construction appliances, packaging, transport, space and aronoutics engineering, medical technology and automobile industries. Thus, from the stand point of commercial applications and developments, polymer blending represents one of the fastest growing segment of polymer technology.

3.2 FACTORS AFFECTING THE POLYMER BLEND PROPERTIES

The important factors which affect the final properties of polymer blends are as follows.

3.2.1 Compatibility

The polymer compatibility refers to the total miscibility of two polymers on molecular scale. The properties of polymer blends are highly dependent on the compatibility of two polymers. The main reason for compatibilisation is generation and stabilization of optimum morphology to maximize the product performance.

According to thermodymamics, the change in the free energy taking place during mixing of polymers can be expressed as follows,

$$\Delta G_{mix} = \Delta H_{mix} - T \Delta S_{mix} \qquad (1)$$

Where,

ΔG_{mix} = free energy of mixing,

ΔH_{mix} = enthalpy of mixing,

ΔS_{mix} = entropy of mixing and .

T = temperature.

In order to have compatible mixture, it is necessary that the free energy of mixing $\Delta G_{mix} < 0$.

Since two different polymeric molecules have little attraction for each other, ΔH_{mix} is positive. When two large polymeric molecules are mixed, the mixing is less random due to restricted movement of atoms resulting into lower ΔS_{mix} values. Thus, $-T\Delta S_{mix}$ will be insufficient to overcome the positive enthalpy of mixing resulting into a positive ΔG_{mix}. As a result the two polymers become incompatible with each other. Based on Scott's extension [2] of the Flory-Huggins lattice theory for polymer solution (F.H.S.) [3], several theories have been proposed to estimate ΔG_{mix}, ΔH_{mix} and ΔS_{mix} for polymeric mixtures [2,4,5]. However, there is no sufficient experimental data to verify which of these theories are adequate [6-8]. Therefore only important features of these theories are reviewed here.

According to F.H.S. theory for polymer solution, ΔS_{mix} is estimated as,

$$\Delta S_{mix} = -NR\left(\frac{\phi_1}{m_1}\ln\phi_1 + \frac{\phi_2}{m_2}\ln\phi_2\right) \qquad (2)$$

for monodispersed polymeric mixture.

Where,

m_1 = degree of polymerisation for polymer-1

m_2 = degree of polymerisation for polymer-2

ϕ_1 = volume fraction of polymer-1

ϕ_2 = volume fraction of polymer-2

R = gas constant

N = number of the segments in the system.

From the equation(2)it appeares that the contribution of ΔS_{mix} towards ΔG_{mix} decreases with increasing m_1 or m_2 leading to poor compatibility for polymeric mixtures. The ΔH_{mix} can be expressed as,

$$\Delta H_{mix} = \Delta U_{mix} + P\,\Delta V_{mix} = NRTX_{12} \qquad (3)$$

Where,

ΔU_{mix} = the change in internal energy

ΔV_{mix} = change in volume

P = the pressure

X_{12} = interaction parameter

X_{12} is referred as interaction parameter and can be calculated [2] from the solubility parameters of the polymers.

$$X_{12} = \left(\frac{1}{RT} \right) (\delta_1 - \delta_2)^2 \qquad (4)$$

from equation (1), (2) and (3) normalized Gibb's free energy of mixing(g) can be expressed as

$$\frac{\Delta G_{mix}}{NRT} \equiv g \equiv \left(\frac{\phi_1}{m_1} \right) \ln \phi_1 + \left(\frac{\phi_2}{m_2} \right) \ln \phi_2 + X_{12} \phi_1 \phi_2 \qquad \textbf{(5)}$$

For stability of polymer mixture without phase separation 'g' versus 'ϕ' curves must be concave upward or in other words, the second partial derivatives of normalized Gibb's free energy of mixing should be greater than zero.

$$g'' = \left(\frac{\partial^2 g}{\partial \phi^2} \right) = (m_1 \phi_1)^{-1} + (m_2 \phi_2)^{-1} - 2X_{12} > 0 \qquad \textbf{(6)}$$

From the equation (6) it is observed that the lower molecular weight will permit miscibility of polymers differing widely in their solubility parameters. However, the miscibility can also be achieved, if the polymers have high molecular weight and if their solubility parameters do not differ much. Thus, the combined effect of solubility parameters and molecular weight can influence compatibility of polyblends, within certain modest limits at thermodynamic equilibrium.

In some polymer pairs [9-11] where solubility parameters and molecular weights are inadequate to explain compatibility of polyblends, homogeneity appears to result from specific group interactions, such as hydrogen bonding and some times forming clearly identifiable complexes or adducts.

The compatibilisation methods can be divided into three categories:

(i) mechanical (ii) chemical and (iii) physical.

(i) The aim of the mechanical compatibilisation is to develop a nonequilibrium morphology which is relatively stable and reproducible and leads to improvement in properties.

(ii) In chemical compatibilisation, chemical reaction is essential for

 (a) the formation of interpenetrating polymer network (IPN) [12,13].
 (b) permenent crosslinking vulcanization [14].
 (c) exchange reaction creating "insitu" compatibilised copolymer and
 (d) reactive processing [15,16].

(iii) Physical compatibilisation involves

 (a) modification of polymeric structure for improvement in miscibility (e.g., by introducing ionic or hydrogen bonding groups)
 (b) control of crystallisation and
 (c) addition of compatibilisers.

The most frequently used compatibilizers are block copolymers, graft copolymers, cosolvents, and interacting copolymers.

3.2.2 Morphology of polymer blends [17-20]

The overall properties of the polymer blends and alloys are determined mainly by the morphology of the blends. Whenever a large quantity of a polymer is blended with a small quantity of another polymer and if the resulting polymer blend is not completely compatible, the major polymer will tend to form continuous matrix phase and minor polymer will separate as discrete particles scattered through out the matrix. The scattered phase is known as domain. A wide range of size and shapes can be obtained for the minor phase during processing. Generally, the size ranges from about 0.1 μm to 20 μm and spherical, ellipsoidal, cylindrical and ribbon like morphologies can be obtained. The simplest domain structure is the spherical particles of the dispersed phase scattered individually throughout the continuous matrix of the predominant phase. Control of the morphology of immiscible blends during processing is of critical importance. The size, shape and distribution of the minor phase profoundly influences the mechanical properties of the blends, especially impact strength.

3.2.3 The phase behaviour of polymer blends

Macromolecules mixtures show different phase behaviour compared to mixtures of low molecular weight species. The phase diagram for a two component system, (i.e. a mixture of two monodispersed polymers) will show either an upper critical solution temperature (UCST) or a lower critical solution temperature (LCST) or tendency towards both. The UCST is observed mainly for most low molecular weight solutions and generally not observed for high molecular weight polymer blend systems, but has been observed in certain polymer solvent mixtures e.g., poly styrene-benzene [21] and blends of low molecular weight oligomers e.g., polystyrene and poly(ϵ -Caprolactone) [22]. Lower critical solution temperature (LCST) is observed for polymer blends [23,24].

At temperature above UCST or below LCST, the binary mixtures are completely miscible at all compositions. In addition, two peak co-existance curves have been observed for certain polymer mixtures e.g., poly (styrene)- Poly (butadiene) [25] in the presence of solvent. The data on LCST is very useful in proper selection of compounding techniques. If two polymers are incompatible in molten phase, it is not possible to produce a homogenous blend by melt mixing technique. However, it is possible to produce a solution blend at temperature below LCST. In such cases where the LCST curves lie at a temperature below the melting point, it is important to ensure that the blend is not used in application where the material would be exposed to temerature above LCST curve.

3.3 POLYPROPYLENE BLENDS

Isotactic polypropylene, one of the largest selling polyolefin is highly crystalline polymer with relatively high melting point. These properties make it a desirable polymer for those applications where a high strength/ stiffness is a prerequisite, such as in fiber, films, pipes and injection molded goods. The high melting point results into products having attractive properties over a wide temperature range. However, this commodity plastic has some drawbacks in its end properties such as absence of any reactive group, poor hydrophilicity, difficulty to dye and sensitivity to photo oxidation. Due to excellent price/performance ratio PP is a good base for reactive blends, widely used in automobile industries and also an attractive product for reactive blending. However, it is necessary to introduce polar reactive groups in the main chain, as it is discussed in Chapter 2, which interact with other polymers and lower down the interfacial tension between PP and other polymers and improve interfacial coupling. Such dispersing agents comprise functionalised PP and are called interfacial agent or compatibiliser.

3.3.1 Why use compatibiliser ?

Theoretically the polymeric products with desirable properties can be achieved by combining two or more different polymers. However, in practice it is difficult to achieve such combinations because of the immiscibility of two polymeric phases. The immiscibility imparts interfacial tension and poor adhension between two polymeric phases, leading to the problems in the processing and unsatisfactory end properties. The interfacial tensions contribute to high viscosity and thus to the inherent difficulty in imparting the desired degree of dispersion to random mixtures, resulting in their subsequent lack of stability to gross separation during processing or use. Poor adhesion leads to very weak and brittle mechanical behaviour. This problem can be alleviated to some extent by using certain suitably chosen block or graft copolymers having ability to alter the interfacial situation in the polymeric mixtures. As a consequence such species are often referred as interfacial agents (compatibilisers). These block or graft copolymers are preferably located at the interface of two phases as shown in Fig. 3.2

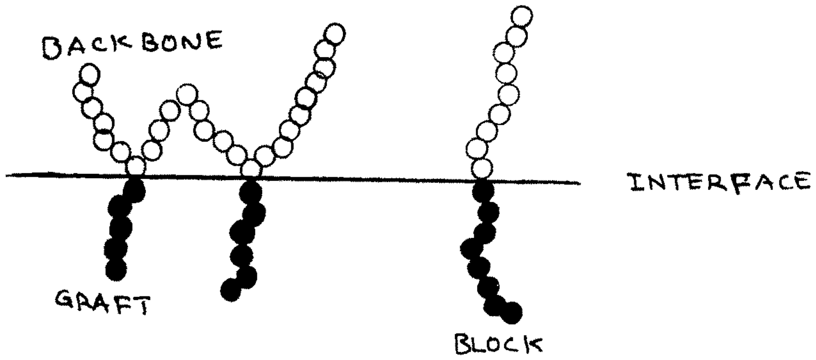

Fig. 3.2

Ideally this component should be block or graft copolymer composed of different segments, which are chemically identical to those in respective polymeric phases. However, effect may still result if one of the arms of the block or graft copolymer is miscible with one of the phases.

The block and graft copolymers alter the interfacial situation by,

(a) Reducing interfacial energy between the phases,

(b) Permitting finer dispersion during mixing

(c) Providing a measure of stability to gross segregation, and

(d) Resulting in the improved interfacial adhesion

3.4 REVIEW OF THE WORK DONE EARLIER ON POLYPROPYLENE BLENDS

Most of the literature about PP blends and alloys is in patent form. Considering all important aspects; in the proposed work an investigative research work has been carried out in the field of PP blends and alloys. Important published work in the field of PP blends and alloys is reviewed in this chapter.

3.4.1 PP/SEBS (Styrene - ethylene - butadiene - styrene) copolymer blends

Gupta and Purwar [26-29] have studied PP/SEBS blends extensively. They observed that PP/SEBS blends show decreased softening and flow temperatures. Melt viscosity was observed to be decreased to a maximum at about 5% SEBS content where as melt elasticity decreased with increasing SEBS content. Melt fracture of PP was decreased on blending it with SEBS. They also observed ductile fracture for the blends. They observed decrease in crystallinity, increase in spherulite size accompanied by the decreases in tensile strength, tensile modulus, elongation at break and yield stress in the region of low SEBS content (0 - 5%). They suggested that the crystallisation of PP component influences the tensile properties of PP/SEBS blends. They observed the stress whitening characteristic of shear band formation during early stages of tensile deformation and suggested that mixing of the two phases was better in the solution blending than in an extruder.

They [30-32] have also studied the effect of incorporation of third component such as high density polyethylene (HDPE) and poly styrene (PS) to PP/SEBS blends. They observed improved impact strength but decreased tensile strength for PP/SEBS blends on incorporation of HDPE. Addition of PS as a third component to PP/SEBS blends produced reduction in tensile strength, tensile modulus and impact strength. Improvement in processibility of PP on blending with one or two components was seen with the low softening and flow temperatures. Melt viscosities for the PP/SEBS and PP/SEBS/HDPE and PP/SEBS/PS blends were observed to be higher than PP/PS and PP/HDPE blends but melt elasticity of ternary blends were found to be lower than PP/PS and PP/HDPE blends.

3.4.2 PP/EPDM (Ethylene-propylene-diene) terpolymer blends

A considerable amount of work has been reported on the blends of PP and EPDM due to their commercial importance [33-35]. The blends of crosslinked EPDM and PP were prepared in a roll mill or extruded by the "dynamic curing" method. These cured thermoplastic elastomeric blends have been widely used in the plastic industries [36-39]. Crystallisation studies of PP/EPDM blends by Martuscelle et al. [40,41] showed the spherulite growth rate to be not affected by the presence of amorphous EPDM. The melting temperature was also found to be increased. This increase in melting point was also observed by Greco [44] in compression molded samples of EPDM and PP blends. Karger-Kocsis et al. [42] prepared blends of PP with various EPDM rubbers differing mainly in their melt viscosities. They found clear relationship between dispersed phase particle size and the melt viscosity ratios.

Ha et al. [43] found that with increasing DCP concentration in blends of 75% EPDM and 25% PP, melt viscosity increases, but it decreases with increasing DCP concentration in the blends of 75% PP and 25% EPDM. In cure blends melt viscosity was observed to increase with increasing DCP concentration. The melt viscosity was decreased with increasing intensity of shear mixing due to formation of the smaller seggregated microdomains of the crosslinked EPDM gels in both cure blend and blend cure. Ha and Kim [45] studied the morphology and mechanical properties of dynamically cured EPDM and PP/HDPE ternary blends. They observed increased tensile strength and modulus with increased DCP concentration for the blends of EPDM rich compositions but decreased tensile strength and modulus for the blends of PP rich compositions. They observed through the morphological analysis by SEM that the small amount of EPDM acts as a compatibiliser to HDPE and PP. It was also noticed that the dynamic curring reduces the domain size of crosslinked EPDM.

3.4.3 PP/EPC or EPR (Ethylene-propylene) copolymer or (Ethylene-Propylene) rubber blend

Blends based on PP and ethylene propylene rubber (EPR) are gaining increasing industrial importance. PP and EPR are generally incompatible and their mixtures are thus heterogeneous [46,47]. Speri & Patric [47] suggested that the EPC acts as a natural toughening agent, for PP, which has enough interfacial adhension. Danesi & Porter [48] observed that both tensile strength and modulus increase with increasing amount of PP in the PP/EPR blends. They found that any type of anneling above melting temperature of the PP brings about a substantial increase in domain sizes of the dispersed phase. Ito et al. [49,50] studied the effect of annealing on PP/EPC blends and observed that the extent of rubber extracted after annealing at 140^{o}C was lower. However, considerable improvement in the impact strength of the annealed blends was also observed. They also studied the thermal and physical properties of annealed PP/EPR blends. They observed that annealing of PP induced an increase in crystallinity and decrease in impact strength, but annealing of PP/EPR improves not only hardness and tensile strength but also impact strength and rigidity at low temperatures. Greco et al. [51] showed that copolymer (EPR) containing PP or PE blocks could act as a nucleating agent for PP spherulities.

They observed a higher compatibility, a lower β-phase and more perfect crystallites for PP/EPR blends along with higher impact strength.

3.4.4 PP/ABS (Acrylonitrile - butadiene - styrene) terpolymer blends

Studies on the blends of PP with acrylonitrile-butadiene-styrene (ABS) terpolymer are mostly confined to patents and rarely to published literature. Markin and williams [52] observed the properties of PP/ABS blends as better the dispersion better the tensile strength and poorer the dispersion better the impact strength. Gupta et al. [53] studied the impact and tensile properties of binary PP/ABS and ternary PP/ABS/LDPE blends. They observed considerable impact toughening of PP on blending with ABS. The maximum impact strength was observed at 10 wt % of ABS in PP/ABS and PP/ABS/LDPE blends. They also observed shear-induced fracture with increased ductility with increasing ABS content in binary and ternary blends.

3.4.5 PP/PE (LDPE and HDPE) blends

Blends of polyethylene (PE) with PP have widely been investigated in many laboratories and used commercially for over last ten years [54,55]. Plochocki and Kou [56] found that DSC thermograms of PP/PE blends reveal peaks related to the two phases being separated. Robertson and Paul [57] investigated the tensile properties of both PP/LDPE and PP/HDPE and found that PP and PE are incompatible. Pakula et al. [58] discussed miscibility and mechanical properties of PP/PE blends by using polarising microscope. Ogawa et al. [59] measured the behaviour of PE/PP blends and found distinguished behaviour for PE-PP copolymer due to separation of two components in the blends. Letz [60] determined the thickness of interface layer from volume changes produced by mutual diffusion of PP/PE mixture and found values of 15 - 28^{o}A which are dependent on time of diffusion. Wenig and Meyer [61] observed that the growth of PP spherulites is not influenced by the presence of PE domains and the spherulite growth rate does not vary with composition. Brewis & Briggs [62] studied the interfacial adhesion property of PP/PE blends and found that PP and PE are not compatible.

Starkweather et al. [63] found that propylene-ethylene copolymer can act as interfacial agent for PP/PE blends whereas Martuscelli [64] investigated the over all morphology of PP/LDPE blends and observed interconnected morphology in case of 50/50 PP/LDPE blends. It was found that when PP crystallises isothermally at a Tc high enough to prevent any LDPE crystallisation, spherulite growth 'G' was almost independent of blend composition. He suggested that the hinderance to spherulite growth due to presence of LDPE occlusion does not cause any slow down in the spherulite growth rate of PP even though drastic changes in the internal structre of the matrix were observed. Ito et al. [50] studied the effect of annealing on PP/PE/Poly (ethylene-co-propylene) blends. They observed that tensile impact strength of annealed blends was remarkably affected by PEP concentration. For PP/PE/PEP blends, annealing temperature above melting point of PE lowers the tensile impact strength and impact strength as observed in PP/LDPE blends. The tensile behaviour of LDPE/PP blends at room temperature was studied by Rizzo and Spadaro [65]. Neck formation and propagation along the whole length of the samples was observed for whole range of composition. The improved adhesion and impact strength for PP/LDPE blends [66] was achieved when croslinking agent or copolymers were added. The impact strength of PP/LDPE/EPR blends was as high as 33.3 kg-cm/cm in comparision to that of binary PP/LDPE blends 16.2 kg-cm/cm. **Rizzo & Spadaro** [67]studied the effect of mixing time on mechanical and rheological properties of LDPE/PP blends. They observed that on increasing the mixing time, mutual dispersion of the two components and consequently mechanical properties improve, whereas the material also undergoes thermal and mechanical degradation. They [68] also studied the effect of mixing temperature and rate on properties of PP/LDPE blends and observed that the tensile behaviour of the homopolymers was unaffected by thermal and mechanical treatments. Brittleness was observed for 50/50 PP/LDPE blends at 0.33 γsec^{-1} mixing rate and 523^{0}K temperature. Park et al. [69] attempted to enhance the compatibility of PP/PE blends and prepared PP-g-MAH/PE-g-MAH blends. They observed a well mixed and interlocked morphology and improved rheological compatibility for grafted blends.

Ono [70] used PP/HDPE (30/70) blends in the formation of ropes useful for automatic packing machine. These ropes had good appearance and gave tight knots and 3 mm knot elongation at 10 g tension. Fujiama and Kawasaki [71] studied the rheological and morphological properties of PP/HDPE blends and observed that when HDPE content in blends accounts 70 wt% or above, PP particles form dispersed phase and particle size decreases with decreasing viscosity of PP, whereas if HDPE contents are 30 wt % or below, HDPE particles form the dispersed phase. They [72] also observed that the slope of storage moduli of the blends decreases at interface.

3.4.6 PP/PC blends

Blends of polycarbonate (PC) with polypropylene (PP) have received limited attension in literature. Due to the polar and non polar nature of PC and PP, large interfacial tension results into coarser phase morphology. In a patent [73] modified PC/PP blends are reported. The moldability of the PP/PC blends was improved by using Cu formate or its copper ethanolamine complex as the modifying additive. They have prepared PP/PC blend by first extruding PP with modifying agent and then mixing with PC at 190-270^{0}C. Favis and Chalifux [74] studied the effect of viscosity ratio on the morphology of PP/PC blends. When PC was dispersed in PP both the number average and volume average diameter of dispersed phase were highly dependent on viscosity ratio and when PP was dispersed in PC a minimum particle size was achieved at $P \simeq 0.15$. Below this value at low concentration the particle size remains constant. Favis [75] studied the effect of processing conditions on the morphology of PP/PC blends and concluded that most of the deformation processes occur in the first 2 min of mixing. Extension of the time of mixing from 5 to 20 min has little influence on the minor phase size and its distribution in PP/PC blend over a wide torque ratio range. Favis and Therrien [76] studied the modification of the morphology of PP and PC blends prepared in a co-rotating, intermeshing twin screw extruder. They found composite blend morphology (occlusion formation) at 60 % of PC. PP-g-maleic anhydride (PP-g-MAH) [77] was used as a compatibiliser in PP/PC blends. Here, PC/PP-g-MAH showed improved miscibility over PP/PC blend with regards to melt rheology, morphology and thermal properties. On the other hand, they found that the PP-g-MAH in PP/PC/PP-g-MAH had a little effect on phase morphology and thermal behaviour.

3.4.7 PP/PBR blends

PP/PBR blends were studied by Sheng [78]. He observed that the crystal rate, crystal growth and crystal structure of PP gets affected by the presence of PBR. Gupta and Ratnam [79] studied the crystallisation behaviour and mechanical properties of PP/PBR blends in the composition range of 5 - 35 wt % of PBR. They observed that the rate of crystallisation of PP increases in the presence of PBR. Impact strength of PP improves by a factor of 1.5 for 5 wt % of PBR. Moreover they observed decreased tensile properties with increased PBR content. In the SEM studies, shape and size of PBR changes from spherical to elongated (non spherical) droplets with increasing PBR concentration. The structure and mechanical properties of PP and poly (trans-1,4-butadiene) blends [80] were investigated by Petermann and Xu [80]. An increase in Young's modulus and fracture stress was observed by them.

3.4.8 PP/PiB (Polyisobutene) blends

Martuscelli [64] investigated the crystallisation behaviour and crystallisation condition for PP/PiB blends and observed that number of spherulites per unit area (NS), against concentration, shows a maximum for the 90/10 (PP/PiB) blend composition. As the concentration of PiB increases distinct drops of PiB were observed. Further, Bartezak et al. [81] predicted that in the PP/PiB blends, the decreased spherulite growth rate was exhibited due to rejection of dispersed particles. Hsu and Geil [82] studied the structure, property and processing conditions relationships for PP/PiB blends. From the DSC and X-ray studies, it was indicated that the PP and PiB crystallise separately as relatively pure phases. They also observed that PP crystallising at a higher temperature nucleates the PiB resulting in an increase in its crystallisation temperature (TC) over that of the pure PiB.

3.4.9 PP/PS blends

Polypropylene and Polystyrene (PS) are claimed to be incompatible at any composition range [83,84]. Bartezak et al. [85] studied the primary nucleation and spherulite growth rate in isotactic PP-PS blends. They found that PS inclusions are dispersed in PP matrix and their size depend upon the mixing conditions. The spherulite growth rate in the blends does not depend either on concentration of PS in the blend or on the time of mixing. In a Patent [86], styrene-hydrogenated butadiene triblock copolymer was used as a compatibiliser for the PP/PS blends. The blends had good balance of chemical resistance and impact strength. The impact strength was found to be 23 and 63 kg-cm/cm at 23°C and - 30°C respectively.

3.4.10 PP/PET (polyethylene terphthalate) blends

Xanthos et al. [87] prepared PP/PET compatibilised blends using acrylic acid grafted PP as compatibiliser. They found that PP-g-AA promoted a finely dispersed phase morphology which further improves mechanical properties and processibility. In Patent [88], carbonylated PP and EPR were used as interfacial agents for PP/PET blends resulting into improved tensile strength.

Hosoda et al. [89] used poly (propylene-b-methyl methacrylate) copolymer for PP/Polymethylmethacrylate blends. They observed improved tensile strength (165 kg/cm^2) and impact strength (16.9 kg-cm/cm) for the blends.

3.4.11 PP/Nylon-6 blends

Poly propylene/Nylon-6 blends are incompatible at all compositions. Tereda et al. [90] studied the behaviour of

PP/Ny-6 and PP-g-MAH/Ny-6 blends. From the morphological study, it was inferred that the blends in which PP was not modified, the domain size was very large. Whereas in the Ny-6/PP-g-MA blends, fine dispersion of PP was observed. Komasu et al. [91] tried to find out the rheology of same blends by parallel plate rheometer. Blends containing equal portion of PP-g-MA and Ny-6 were found to be nearly homogeneous and a little brittle. Ide et al. [92,93] have studied extensively in the field of PP/Ny-6 blends and alloys. Ide & Sasaki [94] have tried to see the effect of molecular weight of nylon-6 on final mechanical properties of Ny-6/PP blends. The increase in the intrinsic viscosity of nylon-6 from 0.81 to 1.2 was found to increase the impact strength, tensile strength and heat distortion temeprature. But when intrinsic viscosity of nylon-6 was greater than 1.5 the blends were found to have very poor mechanical properties.

PP-g-MAH was used as interfacial agent for PP/Ny-6 blends [95] which gave improved mechanical properties to the blends.

In a Patent [96] the blends prepared from nylon-6 (95%) and PP-g-MA (5%) are reported to be useful as the adhesive film.

Hayashida & Yoshida [97] studied the rheological properties of PP/Ny-6 blends using capillary rheometer. At shear rate of 300 s^{-1} the flow curves of the blends were observed to have minimum viscosity. Marked decrease in the apparent viscosity was observed at 0 - 10 and 90 - 100 weight percentage of nylon-6. When the content of nylon-6 in the blend was between

90 - 100 (w/w) the non newtonien index of the blends was found to approach that of nylon-6; at other compositions it was equal to PP. Koregave & Okuda [98] studied the behaviour of blend containing 6% PP-g-acrylic acid (AA), 35% glass fiber and 59% Ny-6 and observed excellent impact strength.

In a Patent [99], PP-g-MAH was used as compatibiliser for PP/Nylon-6 blends and improved miscibility was observed along with the bonding strength. Bo-Runliang et al. [100] studied the phase distribution morphology and rhelogical properties of PP/Ny-6 blends. They investigated the influence of heating in the reservoir of a rheometer followed by subsequent extrusion through capillary on phase morphology. Phase size growth as a function of time was observed under quiescent and mild deformation rate condition. The decreased discrete phase size with increased extrusion rate was also observed.

In a Patent [101] blends prepared from 46.5% PP, 65% Ny-6 and 3.5% PP-g-AA and spun at 300^{o}C, showed good spinability. Dagli et al. [102] studied the effect of PP-g-AA as a compatibiliser. They found that the PP/Ny-6/PP-g-AA blends showed noticeable difference in flow properties, morphology and tensile strength than PP/Ny-6. Nishio et al. [103] studied the morphology of PP-g-MAH and polyamide-6 blends produced by reactive processing. They observed that the number average diameter of PP particles decreased with increasing PP-g-MAH content. The tensile strength and Izod impact strength increased with decrease in diameter of PP particles. Holsti et al. [104] studied the effect of various compatibilisers on properties of PP/Ny-6 blends, and SEBS-g-MAH was found to be a better compatibiliser among all other compatibilisers studied. Liang and Williams [105] studied the effect of PP-g-AA compatibiliser on dynamic mechanical properties and morphological properties of PP/Ny-11. They observed improved dispersion in blend on addition of PP-g-AA.

TABLE 3.1

Review of the work done on the polypropylene blends :

Sr.No.	Other Component	Remarks	References
Blend without compatibiliser :			
1.	SEBS	Improved impact strength, decreased other mechanical properties and crystallinity.	26 - 29
2.	SEBS, HDPE	Improved impact strength.	30
3.	SEBS, PS	Decreased impact strength with other mechanical properties.	31 - 32
4.	EPDM	Improved impact strength and increased melting temperature.	33 - 39, 40 - 42, 44
5.	Cured EPDM	Increased melt viscosity and higher crystallisation rate.	43
6.	Cured EPDM, HDPE	Decreased tensile strength and modulus.	45
7.	EPR	Improved impact strength but formed heterogeneous mixture.	46 - 47
8.	EPR	Improved impact strength and tensile modulus at low EPC cotnent.	48
9.	EPC	Improved tensile st~~t~~rength and impact strength of annealed blend.	49, 50
10.	EPR	Improved impact strength with improved compatibility.	57
11.	ABS	Improved impact and tensile strength	52
12.	ABS, & LDPE	Improved impact strength	53
13.	PE	Formed incompatible mixtures	56 - 62
14.	LDPE	Observed interconnected morphology in 50/50 blends.	64

15.	LDPE	Improved mechanical properties and observed brittleness at 50/50 composition.	67, 68
16.	PE-g-MAH	Improved rheological and mechanical properties.	69
17.	HDPE	Improved elongation	70 - 72
18.	PC	Improved moldability with modifying agent	73
19.	PC	Improved morphology at 60% PC, observed deformation when subjected to different processing conditions.	74 - 76
20.	PBR	Improved impact strength and modulus.	78, 79, 80
21.	PiB	Increased Tc of PiB and decreased spherulitic growth rate.	64, 81, 82
22.	PS	PS acts as nucleating agent	85
23.	Nylon-6	Change in mechanical properties with change in mol. wt. of Nylon-6.	94
24.	Nylon-6	Improved mechanical properties	93
25.	Nylon-6	Improved morphology when extruded through capillary.	100
26.	Nylon-6	Change in rheological properties with change in composition.	97
Blends with compatibiliser :			
27.	PE, EPC	EPC acts as interfacial agent, improved impact strength.	63
28.	PC,PP-g-MAH	Improved thermal and morphological properteis.	77
29.	PS, (Styrene-b-butadine copolymer	Improved chemical resistance and impact strength.	86
30.	PET, PP-g-AA	Improved processibility and mechanical properties.	87
31.	PET, carboxylated PP and EPR	Improved tensile strength.	88

32.	PMMA, Poly(Propylene-b-methyl methacrylate) copolymer	Improved impact strength and morphology.	89
33.	Nylon-6, PP-g-MAH	Particle size is decreased and improved mechanical properties	90, 95, 99, 103
34.	Nylon-6, PP-g-MAH	Improved homogeneity	91
35.	Nylon-6, PP-g-MAH	Useful in preparation of adhesive film.	96
36.	Nylon-6, PP-g-AA glassfiber	Excellent impact strength.	98
37.	Nylon-6, PP-g-AA	Good spinability, improved morphological and mechanical properties.	101, 102
38.	Nylon-6, SEBS-g-MAH	Improved mechanical properties	104

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