

Compatibility Studies and Characterisation of a PVC/NR Blend System Using NR/PU Block Copolymer

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Summary

Polyvinyl chloride (PVC) has been blended with masticated natural rubber (NR₅) in the presence of a compatibiliser. A block copolymer of NR and polyurethane (PU) based on propylene glycol (PG) and toluene diisocyanate (TDI) was used as the compatibiliser. Compatibilising effect of this block copolymer on PVC/NR₅ (90/10) blend system was investigated by solution viscometry and optical microscopy. Testing and analysis of the blends showed that the mechanical and morphological properties are functions of compatibiliser concentration. Incorporation of 10 parts of NR₅ into PVC caused deterioration of tensile properties of the latter, which were recovered on the addition of 1.5 weight per cent of the compatibiliser. Besides, the tensile impact strength of PVC gets improved greatly. This was attributed to the enhanced interfacial adhesion between PVC and NR caused by the compatibiliser. The modification at the interface leads to finer and uniform distribution of NR domains in the PVC matrix.

Keywords

Polyvinyl chloride, natural rubber, block copolymer, compatibiliser, impact modification

Introduction

Although blending looks very attractive, lack of compatibility between the blend components would lead to underperformance of these materials. Incompatibility is caused by the high interfacial tension due to poor phase adhesion between the components in these blends. The usual method to improve the interfacial characteristics of incompatible blends is the addition of a third polymer (polymer C), which has an affinity for both the initial polymers (polymers A and B). Polymer C can be a homopolymer [1-3] or a copolymer [4-7]. In such a ternary mixture, polymer C can migrate to the interphase of a phase separated polymer blend and can serve to reinforce the biphasic interphase by acting as physical thread that binds the two phases together. The addition of polymer C will also reduce the number of unfavorable

contacts between polymers A and B, which, in turn, will enhance the degree of compatibility of the polymer blend, *i.e.*, compatibilise the blend components.

It is well known that the addition of a block copolymer makes the miscible polymer pairs more compatible. According to Paul and Newman [9-12] the addition of a copolymer reduces the interfacial tension and permits a finer improved interfacial adhesion. There are numerous studies [4, 13-21], related to the compatibilisation of thermoplastic elastomer (TPE) blends by the addition of copolymers (both block and graft). It is known that when suitably chosen graft copolymers are added in small quantities to immiscible polymer systems, the graft copolymer behaves as classical surfactants similar to soap molecules at oil water interface [4]. The segments of the graft copolymers should be chemically identical or compatible with those in the immiscible blends. Lundstedt and Bevilacqua [13] showed that if the graft copolymer of styrene to rubber was made and blended with PS, significant increase in impact strength was observed. Wang and Chen [14] studied compatibility problems in incompatible NBR/PVC blends. Polyvinylidene chloride-co-vinyl chloride was reported to act as an efficient interfacial agent for these blends. Prud'home and Ameduri [15] have reported a ternary system consisting of immiscible PVC/CPVC to which polycaprolactone (PCL) was added to compatibilise it. Oommen and Thomas [16-18] studied the interfacial activity of natural rubber-g- polymethyl methacrylate in incompatible polymethyl methacrylate /natural rubber blends. Mechanical properties of the blends with and without the compatibiliser were correlated to the concentration of the graft copolymer. Asaletha et al [19-20] studied the compatibility of natural rubber (NR) /Polystyrene (PS) blend by the addition of a graft copolymer of NR and PS (NR-g-PS). Compatibility and various other properties like morphology, crystalline behaviour, structure and mechanical properties of natural rubber/polyethylene were investigated by Quin et al [21]. Polyethylene-b-polyisoprene acts as a successful compatibiliser for this system.

The objective of the present work was to study the effect of a compatibiliser viz., NR/PU block copolymer on the PVC/NR blend systems. These blends are very significant in formulating impact modified PVC and also thermoplastic elastomers. It is the former aspect that has been followed in this study. Effect of the block copolymer concentration on morphology and mechanical properties of the blends was studied and reported here.

Experimental

Materials

PVC with K value 65, $\overline{M}_w = 140000$, and density 1.37 (M/s Chemicals and Plastics, Chennai, India) was used for blending. Natural crumb rubber (ISNR-5) with $\overline{M}_w = 8, 20,000$, intrinsic viscosity in benzene at 30°C = 4.45dL/g, (RRII, Kottayam, India) was masticated for 5 min (NR₅) in a two roll mill. Solvents, viz., toluene, methanol, chloroform, and tetrahydrofuran (THF) (E. Merck, India) were dried and distilled before use. Propylene glycol (PG) (E. Merck, India) was distilled and used. Toluene diisocyanate (TDI) was an 80/20 mixture of 2, 4- and 2, 6- isomers (Merck, Germany) and was used as received. Dibutyl tin dilaurate (DBTDL) (Fluka, Switzerland) was used as catalyst without purification. Hydroxyl terminated liquid natural rubber (HTNR) with \overline{M}_w of 6400 and \overline{M}_n of 3750 was prepared in the laboratory by a standard procedure [22].

Procedure

Preparation of HTNR

Natural crumb rubber was masticated for 8 minutes at 40°C. About 100 g of it was dissolved in one litre toluene and the solution was charged into a flat – bottomed borosilicate glass flask of 2L capacity. The flask was fitted with a water condenser and a mechanical stirrer. Hydrogen peroxide solution (100 ml) was added and thoroughly mixed with the solution. The mixture was then homogenised to a certain extent by adding 150 ml of methanol. The whole assembly was placed in sunlight. After about 60 hours of irradiation, the clear supernatant toluene layer was decanted. Toluene was removed by distillation under reduced pressure. The residual viscous liquid rubber containing some toluene was kept tightly corked in the absence of light. The sample for block copolymerisation was purified by reprecipitation from toluene solution with methanol two times and dried in vacuum. Highly viscous liquid rubber was obtained. The sample had an average hydroxyl functionality of 1.94.

Synthesis of block copolymer

The block copolymer was synthesised by a modified procedure of the earlier reported one [23] by reacting together HTNR/TDI/PG in the molar proportion 1 / 16.18 / 14.98 respectively.

Polyurethane oligomers was prepared by dissolving propylene glycol (PG) (0.032 moles) in chloroform taken in a flat- bottomed flask to get a 10% solution. The flask was equipped with a magnetic stirrer, reflux condenser, and a dropping funnel. The catalyst, viz., DBTDL, (about 0.05 % by the total weight of TDI) was added to the solution taken in the reaction vessel. A known amount of TDI (0.0343 moles) in chloroform was added to the reaction mixture in small quantities during a period of 5 min. The reaction was allowed to continue for 1 h at 65°C. Then, 8 g of HTNR was made into a 20% solution in chloroform and added to the reaction mixture and the reaction was continued for 5 h. Finally the excess solvent was distilled off and the viscous polymer solution was poured into trays treated with silicon release agent and kept overnight for casting into sheets. They were subjected to heat treatment at 60°C for 24 h to remove residual solvent. The resulting block copolymer would be having polyurethane content equal to 52.1% as per the quantity of TDI and PG used. Hence the sample is designated as (50/50) which indicates that the block copolymer contains NR and polyurethane formed from PG and toluene diisocyanate in the weight ratio of about 50:50.

Preparation of blends

A 5% (w/v) solution of PVC in THF was prepared with 4 weight % of DBTDL (based on PVC) as a thermal stabilizer. Natural crumb rubber was masticated for 5 minutes. The masticated rubber (NR₅) was dissolved in THF to get a 5% solution (w/v). Blends of PVC and masticated NR were prepared by adding required amount of masticated NR solution to PVC solution at various compositions. It was thoroughly mixed at room temperature using a magnetic stirrer for 5 h and cast on glass plates. The samples were then dried in vacuum at 70°C for two days to remove traces of residual solvent.

Preparation of compatibilised blends

Blends with NR/PG block copolymer as compatibiliser were prepared as follows. A solution of the block polymer in the common solvent THF was added to the 90/10 blend solution of PVC and masticated NR prepared as described above. It was kept overnight followed by stirring for 5 hours with a magnetic stirrer, cast on a glass plate, and dried in vacuum for two days. Blend films with varying weight percentage of compatibiliser (0.5, 1, 1.5 and 2%) were prepared.

Designation of blends

The blends were designated as follows. $C_{(0\%)}$ refers to PVC/NR₅(90/10) blend containing 90 parts by weight of PVC and 10 parts by weight of NR₅ and 0 % of compatibiliser. Similarly $C_{(0.5\%)}$, $C_{(1\%)}$, $C_{(1.5\%)}$, and $C_{(2\%)}$ stands for the same blend system with 0.5, 1, 1.5 and 2 weight % of compatibiliser respectively. P₁₀₀ stands for unmodified PVC.

Analysis and measurements

The block copolymer was characterized by IR spectroscopy. IR spectrum of the sample in spectroscopic grade chloroform was recorded using a Shimadzu IR 470 spectrophotometer.

Viscosity measurements

Polymer solutions were prepared by dissolving accurately weighed samples in known volume of the solvent, THF. Polymer mixtures of desired proportion were prepared by mixing measured volumes of individual polymer solutions. The relative viscosities of the polymer solutions were determined by an Ubbelohde viscometer at $30^{\circ}\text{C} \pm 0.01$.

Tensile Measurement

Tensile measurement was carried out in a Zwick UTM (model 1474) at a cross head speed of 50mm/min for dumbbell specimens as per ASTM D 638.

Tensile impact measurement

Tensile impact energies of the samples were measured at 30°C as per DIN 53448 standard, using pendulum impact tester (model IMP-DTS-15) having maximum of 2.7 J energy. The test speed was 2.9 mS^{-1} for all cases.

Morphological studies using optical microscopy

The morphology of the samples was examined under an optical microscope. (Model-Letz Metallux-3, Magnification 100-X). Very thin samples were made on specimen glass and dried in a vacuum oven at 80°C for 48 h. The domain size and domain density were measured using these micrographs.

Results and Discussions

A 90/10 blend of PVC and NR₅ was made and modified by incorporating the NR/PU block copolymer into it. Thus a series of compatibilised blends with varying amounts of the compatibiliser was prepared and subjected to detailed testing and analysis for characterisation.

Synthesis and characterisation of the block copolymer

The synthetic procedure employed previously [23] for the preparation of NR based PU block copolymers gave insoluble products. Hence it was proposed to modify the procedure. Thus the PU segments were prepared in the first stage by the reaction between calculated quantity of TDI and PG in chloroform. Slight excess of TDI was used to ensure the presence of isocyanate end groups on the PU segments. HTNR is added to the PU segments in the second stage for chain extension. The sample was prepared by keeping the soft segment to hard segment weight ratio at around 50: 50 with NCO/OH ratio 1.07. The block copolymer was found to be soluble and the solution was used for compatibilisation. It was characterised by IR spectroscopy. The IR spectrum is shown in Figure 1.

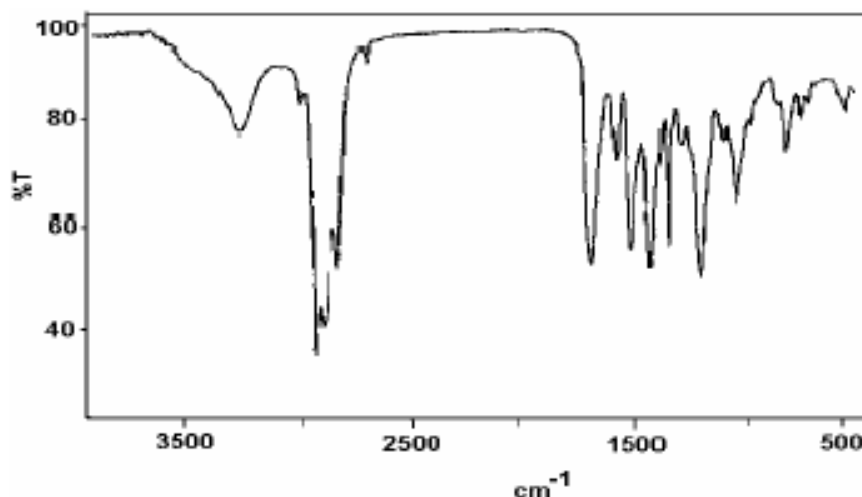


Figure 1. IR spectrum of NR/PG(50/50) block copolymer

Absence of the absorption band at 3400-3600 cm^{-1} , which indicates complete reaction and consumption of the hydroxyl groups of hydroxyl terminated liquid natural rubber during the formation of the block copolymer. The bands at 3300 cm^{-1} (N-H stretching), 1700 cm^{-1} (C-O stretching), 1540 cm^{-1} (C-N-H stretching), and 1220 cm^{-1} (N-C-O stretching) indicate the presence of polyurethane hard segments. The bands at 3000-2900 cm^{-1} (CH_3 stretching), 1600 cm^{-1} (C-C stretching), 1450 cm^{-1} (C-H asym.def CH-), 820 cm^{-1} (double bond in the cis - 1, 4 structures) and 760 cm^{-1} (CH rocking) corresponds to the NR soft segment. Thus the IR spectrum suggests that the hard segment has been coupled with the soft segment during the course of formation of the block copolymer.

Characterisation of the blends

Compatibility studies using solution viscometry

All the blends were tested for the compatibility of the components by solution viscometric analysis. The compatibility was characterised by a parameter, Δb , which is defined by equation (1),

$$\Delta b = b_{12} - b_{12}^* \quad (1)$$

where b_{12} is an interaction term calculated from equation (2) as proposed by Krigbaum and Wall [24],

$$\eta_{sp(m)} = [\eta_1]C_1 + [\eta_2]C_2 + b_{11}C_1^2 + b_{22}C_2^2 + 2b_{12}C_1C_2 \quad (2)$$

$\eta_{sp(m)}$ is the specific viscosity of the blend solution, $[\eta_1]$ and $[\eta_2]$ are the intrinsic viscosity of blend components 1 and 2 respectively, C_1 and C_2 are the respective concentrations, b_{11} and b_{22} values are interaction terms of the individual components which are equal to the $k[\eta_1]^2$ and $k[\eta_2]^2$ in the respective Huggin's equation, b_{12}^* is theoretically calculated from the relation

$$\frac{b_{11} + b_{22}}{2} \quad (3)$$

Negative values of Δb are found for solutions of incompatible polymer systems while positive values refer to attractive interactions in compatible systems.

The compatibility was also characterized by a comparison between the calculated intrinsic viscosity of the components as per equation (4) and the experimental viscosity of the blends.

$$\left(\frac{\eta_{sp,m}}{C} \right)_{C \rightarrow 0} = [\eta_1] \left(\frac{C_1}{C} \right)_{C \rightarrow 0} + \eta_2 \left(\frac{C_2}{C} \right)_{C \rightarrow 0} \quad (4)$$

A negative deviation from calculated value is due to repulsive interaction between the component polymers. The repulsive interaction causes a reduction in the hydrodynamic volume of the polymer molecules and hence viscosity of the solution diminishes. Positive deviation on the other hand, indicates compatibility of the component polymers.

The values of Δb have been plotted against total concentration for all the blends which are shown in Figure (2). Curves of $C_{(0\%)}$ and $C_{(0.5\%)}$ lie in the negative region indicating incompatibility. The lowest value for Δb is seen for $C_{(0\%)}$, i.e., the uncompatibilised blend system. As the compatibiliser concentration increases Δb value enters into positive region. This was observed for $C_{(1\%)}$, $C_{(1.5\%)}$, and $C_{(2\%)}$ blends suggesting that these are compatible blends. The compatibility was aided by the presence of sufficient quantity of the compatibiliser. The highest value of Δb is shown by $C_{(1.5\%)}$. The lowest value for $C_{(0\%)}$ is discernable considering the fact that it is an incompatible blend in which the component polymers, viz., PVC and NR possess polar and non polar characteristics respectively. The highest value shown by $C_{(1.5\%)}$ is indicative of the optimum level of compatibilisation achieved with the help of 1.5 % compatibiliser that has been incorporated into the blend.

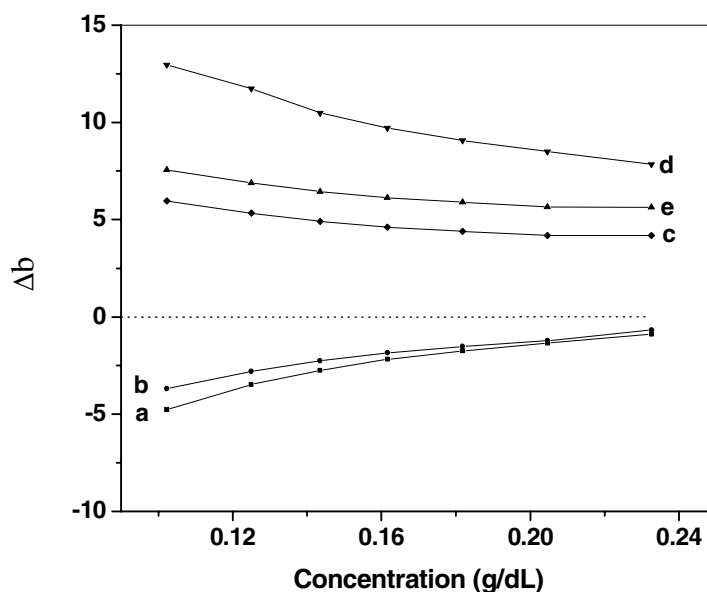


Figure 2. Plot of Δb versus total concentration of PVC/NR₅ blends: (a) C_(0%); (b) C_(0.5%); (c) C_(1%); (d) C_(1.5%); (e) C_(2%)

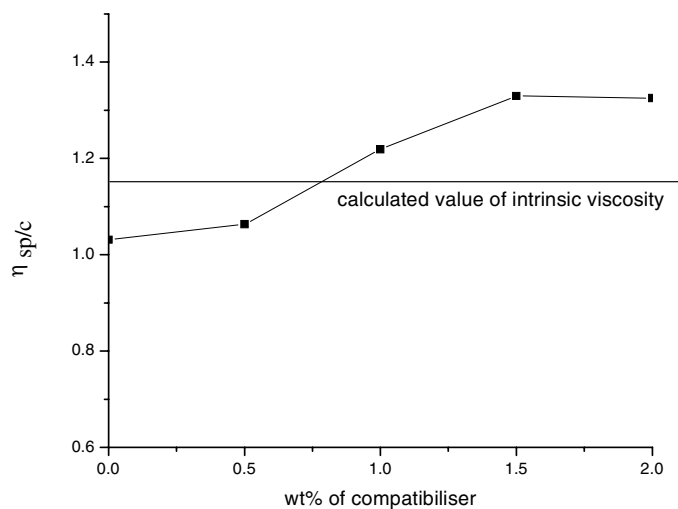


Figure 3. Plot of intrinsic viscosity of blends versus compatibiliser concentration

The intrinsic viscosity values of the blends are plotted against compatibiliser concentration in Figure (3). It is observed that C_(0%), and C_(0.5%) shows negative deviation compared to the calculated value, viz., 1.1543 dL/g. On the other hand C_(1%), C_(1.5%) and C_(2%) show positive deviation. From Figure (3) it is found that the intrinsic viscosity value levels off beyond 1.5% compatibiliser concentration. The positive deviation indicates compatibilisation of the blends and the leveling off shows optimum compatibility at 1.5% compatibiliser concentration.

Stress - Strain Behaviour

Tensile testing was done on the uncompatibilised and compatibilised blend systems. The resulting stress - strain curves are given in Figure (4) and the data calculated in Table (1). For the sake of comparison the tensile curve of unmodified PVC is also presented which shows the characteristic features of a brittle material such as very small deformation under stress. For example failure occurs at 6 % elongation without undergoing any yield phenomenon. Tensile strength and modulus of elasticity of PVC are found to be very high with values of 37.8 N/mm² and 1560 N/mm² respectively. The literature values of a sample PVC are 21.9 % of elongation at break, tensile strength of 30.8 N/mm² and a modulus of elasticity equal to 520 N/mm² [25].

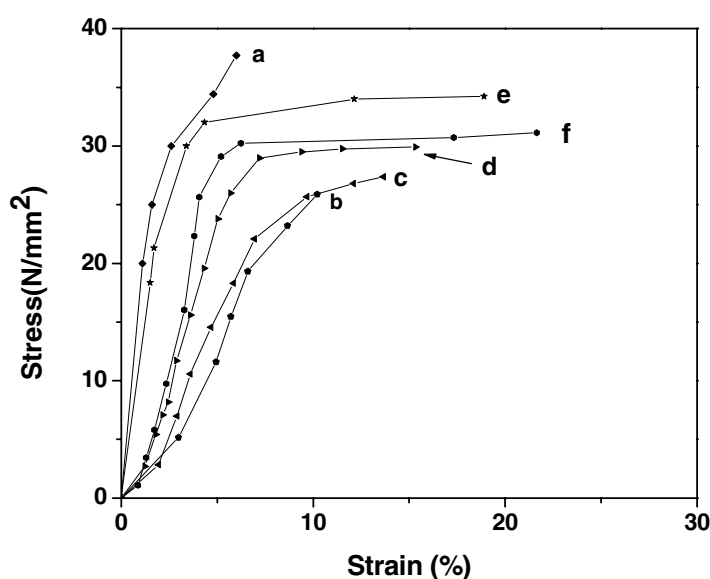


Figure 4. Stress–Strain curves of PVC/NR₅ blends: (a) P₁₀₀ : (b) C_(0%): (c) C_(0.5%): (d) C_(1%): (e) C_(1.5%): (f) C_(2%)

The tensile curve of the C_(0%) blend system shows an overall decrease in rigidity when compared to that of unmodified PVC. It was observed that the addition of 10 parts by weight of rubber to PVC affected the tensile strength, modulus of elasticity and the elongation at break values. The first two values are lower than those of PVC where as elongation at break is higher. Tensile strength decreased from 37.8 to 25.8 N/mm². Young's modulus shows a similar decrease from 1560 to 289 N/mm². Elongation at break increased from 6% to 10%.

The stress-strain curves of the PVC /NR₅ blends containing varying compatibiliser concentration of 0.5% to 2% are given in Figure 4 (c) to (f). It is observed that all the curves lie in between those of the unmodified PVC (P₁₀₀) and C_(0%). This shows that tensile properties of the compatibilised blends exhibit some extent of improvement over the C_(0%) sample. As the amount of the compatibiliser is increased from 0.5% to 1.5% the curve seems to be drifting away from that of C_(0%) towards the unmodified PVC (P₁₀₀) curve. This trend breaks at 2% compatibiliser

Table 1 Effect of compatibiliser loading on the mechanical properties of PVC/NR₅ (90/10) blends

Sample	Tensile impact strength (J/m)	Tensile strength (N/mm ²)	Modulus of elasticity	Elongation at break (%)
P ₁₀₀	320	37.8	1560	6
C _(0%)	330	25.8	289	10
C _(0.5%)	340	27	312	14
C _(1%)	358	30.1	458	16
C _(1.5%)	440	34.4	1114	19
C _(2%)	429	31.4	600	22

concentration. This kind of variation in the slope of the curve shows that the rigidity of PVC which was lost by mixing it with 10 parts of NR is gradually regained by the addition of the compatibiliser up to 1.5%. Beyond this level, i.e., at 2%, the value almost levels off.

Young's modulus for PVC is 1560 N/mm². On addition of rubber the values seem to decrease. Among all the blend systems the C_(0%) shows the lowest Young's modulus of 289 N/mm². This value increases to 312, 458 and 1114 N/mm² at 0.5%, 1% and 1.5% compatibiliser concentration respectively. However, as the amount of compatibiliser reaches 2% the Young's modulus decreased to 600 showing a levelling off. It is to be noted that the modulus reaches an optimum value of 1114 N/mm² at 1.5% compatibiliser concentration.

This is the same value as that of P₁₀₀. Similar variation was observed in the case of tensile strength also. The value of 37.8 N/mm² corresponding to P₁₀₀ decreases to 25.8 for C_(0%), the lowest value for all the blends, and then increases with an increase in compatibiliser concentration. It reaches an optimum value of 34.4 N/mm² at 1.5% compatibiliser.

The low elongation at break of (6%) for P₁₀₀ improved to 10% on addition of 10 parts of NR₅ [sample C_(0%)]. With the compatibiliser, the blend shows further improvement in elongation at break. Progressive increase in elongation with the compatibiliser concentration is observed. Marginal increase in elongation of C_(0%) compared to P₁₀₀ is obviously the contribution of the rubber phase in the blend. Higher extent of elongation shown by the compatibilised blends, viz., C_(0.5%) to C_(2%) is attributed to the effect of compatibiliser on the blend system.

The yield behaviour of the samples as seen in Figure (4) is consistent with the above observations. Samples P₁₀₀ and C_(0%) do not undergo yielding indicating their brittleness. This behaviour of C_(0%) shows that the addition of 10 parts of rubber in no way helps to reduce the brittleness of PVC. However, there is a decrease in the ultimate strength of this blend compared to that of P₁₀₀. Addition of the compatibiliser tends to change the yield pattern of the blend. In the presence of 0.5% of compatibiliser the blend system begins to show yielding with a slight extent of necking. The improvement in ductility is obviously due to the interaction of PVC phase with the rubber phase promoted by the presence of compatibiliser at the interphase. Yield stress shows an increase over the uncompatibilised blend which is also an indication of compatibilising effect in the C_(0.5%) sample. This trend shows further enhancement on addition of 1% compatibiliser as the sample exhibits higher ductility along with an increase in yield strength to 30 N/mm². Besides, this value

improves to 34.75 N/mm^2 as the compatibiliser is increased to 1.5%. The sample becomes more ductile as is shown by the corresponding tensile curve (Figure. 4). On addition of 2% compatibiliser, however, the blend system does not show further improvement in this property. This observation again suggests that 1.5% of compatibiliser is optimum to the present blend system.

Tensile impact studies

The low impact strength of PVC has caused long standing problems in the processing and application of unplasticised PVC. This has been overcome with the help of impact modifiers evolved out over a period of time during the development of processing techniques.

The impact modification of PVC with NR was studied in the presence of the block copolymer compatibiliser. The values are tabulated in Table (1). It was found that $C_{(0\%)}$ sample showed nominal increase in impact strength, viz., 10 J/m. Only a similar increase was observed when 0.5% and 1% of the compatibiliser was added to $C_{(0\%)}$. As the compatibiliser was increased to 1.5 weight per cent, a sharp increase in impact strength was observed and the increment amounts to 82 J/m compared to the previous sample. However, the impact strength stabilises almost at the previous level when the amount of compatibiliser was increased to 2 % in the blend system.

It is to be noted that the incorporation of 10% of NR into PVC matrix causes only a slight increase in impact strength with significant drop in tensile strength. The nominal increase in tensile impact strength is viewed only as an outcome of the discontinuity caused in the PVC matrix by the rubber phase which in turn causes a drop in tensile strength. However, in all other cases where compatibiliser is present (below 2 weight %), both the properties show an increase. It obviously points to some basic modification occurring in the morphology of the blend system caused by the presence of the compatibiliser as described above. Such a modification facilitates efficient stress transfer and crack growth resistance in the sample so necessary for the improvement in impact strength.

Optical microscopy studies

Authentic studies regarding the morphology of the samples are being done with the scanning electron microscopy as part of an extensive study of this blend system. However, in this report we discuss the observations made with the optical microscopy studies.

Morphology of the blends was studied as a function of the block copolymer concentration by optical microscopy. The optical micrographs of pure blend and compatibilised blends are shown in Figure 5 (a) to (d). Rubber component is seen as a dispersed phase in all the micrographs.

In $C_{(0\%)}$ and $C_{(0.5\%)}$ the rubber phase is found to be present as a coarse dispersion. This happens because of the incompatibility of NR with PVC so that NR is less efficiently dispersed and hence present as larger agglomerates. The presence of 0.5% of the compatibiliser does not help in achieving the necessary level of dispersion. Almost similar situation persists in $C_{(1\%)}$ sample indicating that 1% compatibiliser is also insufficient to bring about the required level of compatibilisation. This observation is supported by the measurement of domain size and domain density of the respective samples as tabulated in Table. 2.

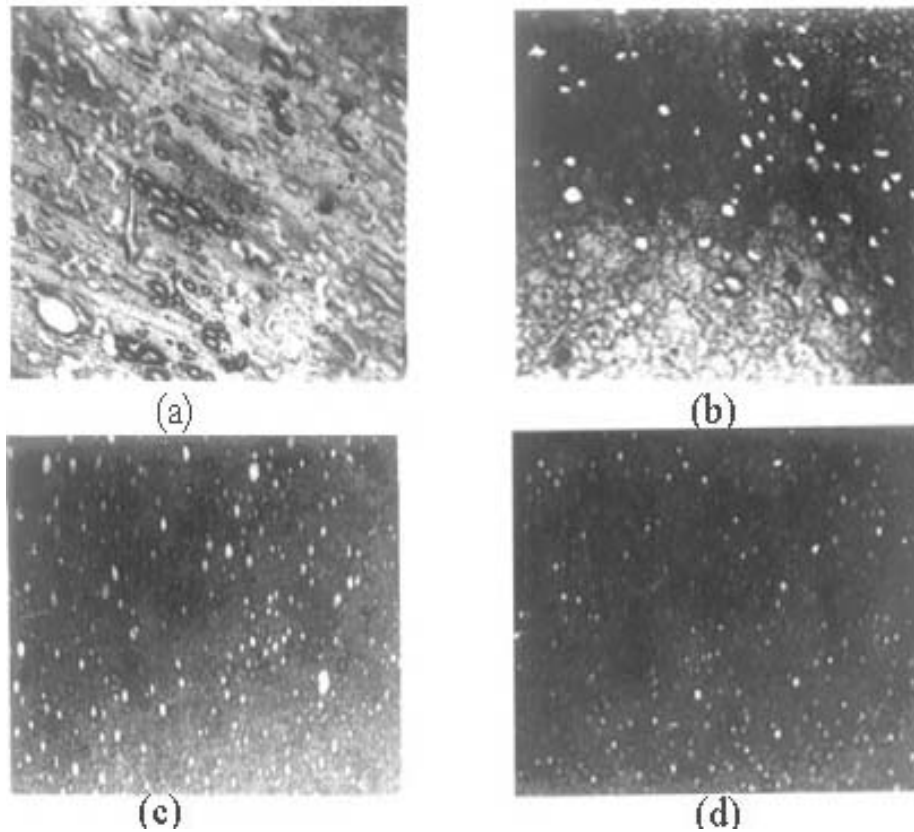


Figure 5. Optical micrographs of PVC/NR₅ blends: (a) C_(0%): (b) C_(0.5%) (c) C_(1%): (d) C_(1.5%): Magnification - 100X

Table 2 Domain size of dispersed phase in the compatibilised PVC/NR₅ (90/10) blends

Compatibiliser (Weight %)	Average size(μm)	Domain density(m^{-2})
0	3.12	1.33×10^8
0.5	1.73	3.22×10^8
1	1.03	4.59×10^8
1.5	0.86	5.23×10^8
2	0.84	4.77×10^8

For the uncompatibilised blend, i.e., C_(0%), the average domain size is 3.12 μm and the size distribution is from 7 to 1 μm . The domain density was found to be $1.33 \times 10^8 \text{ m}^{-2}$. By the addition of 0.5 weight per cent of the block copolymer to the blend, the domain size was reduced to 1.73 μm , the size ranges from 3 to 0.5 μm with domain density $3.22 \times 10^8 \text{ m}^{-2}$. Reduction in domain size is found to be 44%. On addition of 1 weight % of block copolymer the domain size reduces to 1.03 μm with an increase in domain density to $4.59 \times 10^8 \text{ m}^{-2}$. This indicates a further size reduction of 40%. As the block

copolymer concentration is increased to 1.5% further size reduction is observed only to an extent of 18.95%. The size of the domains and the density finally tend to level off at this concentration of the compatibiliser. A similar situation is also observed in the case of C_(2%). Presence of 0.5% of the compatibiliser does not help in achieving necessary level of dispersion of the NR component. Almost similar situation persists in C_(1%) sample indicating that 1% compatibiliser is also insufficient. Reduction in domain size is maximum for 1.5 weight per cent of the block copolymer. Domain density is also found to be maximum for this compatibiliser concentration.

The morphological observations are in support of tensile and impact properties of the samples presented in the previous sections. The decrease in tensile strength and modulus of elasticity of the sample, viz., C_(0%) may be construed as caused by the disruption of the continuous matrix of PVC by the presence of the incompatible coarse NR phase. The almost unchanged tensile impact strength of this blend also shows its incompatible nature. On addition of the compatibiliser the NR dispersed phase would be surrounded by the copolymer molecules causing compatibilisation with the PVC matrix. As the concentration of the block copolymer increases, a stage will reach at which they form micelle which encompass the NR phase due to favourable interaction with the NR component of the block copolymer. The outer surface of the micelle which is rich in poly urethane becomes solubilised in the PVC matrix leading to high level of compatibility. This process almost nullifies the disruption of the continuous PVC matrix by the NR phase in the C_(0%) blend system. Thus micelle formation is the culmination of compatibilisation and the concentration at which micelle forms is referred to as the critical micelle concentration (CMC). In the present case 1.5 weight % loading of compatibiliser seems to be the CMC as observed from microscopy data given above and also from the optimum tensile properties and the tensile impact strength of C_(1.5%). All the above observations show that uniformity in particle size and narrow size distribution are attained when the block copolymer concentration attains CMC. The finer and even distribution of the rubber phase at the higher compatibiliser concentration leads to improvement in the tensile and impact properties of the blend system. Beyond CMC the excess compatibiliser does not influence the properties [26].

The above results are well in agreement with the compatibility studies carried out by solution viscometry. The optimum compatibility achieved in C_(1.5%) as observed by viscometry is reflected in the characteristic properties of this blend.

Conclusions

The role of an NR/PU block copolymer as an efficient compatibiliser for the PVC/NR (90/10) blend system was established in the present studies. Solution viscometry revealed that optimum compatibilisation of the PVC/NR (90/10) blend occurs at 1.5% of the block copolymer concentration. Optical microscopy studies also supported this finding. The tensile and impact properties of the blend significantly improved in the presence of the compatibiliser and reached optimum values at the compatibiliser concentration of 1.5 weight percent. The addition of NR to PVC causes deterioration in tensile properties of the blend which is regained with the incorporation of 1.5 weight percent of the compatibiliser. Significant increase in impact strength is also observed for the blend. Hence 1.5 weight percent of the NR/PU block copolymer in the blend may be concluded as the critical miscelle concentration at which it compatibilises the NR phase with PVC matrix to an optimum level.

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