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Development and Characterization of PVC/ABS Polyblends†

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This paper discusses about the development and nature of property relationships generated by blending a low cost homopolymer (PVC) with ABS terpolymer. The blend properties are strongly influenced by the phase behaviour of the constituents which is due to interactions among them. PVC/ABS blends are microheterogeneous: they have a rigid matrix with soft dispersed phase but are mechanically compatible. Because of this partial compatibility, additive responses are observed (as a function of blend ratio) in tensile strength and modulus, flexural strength and modulus and viscosities. The mutual interaction also accounts for positive deviations of experimental specific gravities from empirically calculated ones, using the values for PVC & ABS alone. The pay-off for blending comes from “synergistic” improvements in the impact strength of PVC/ABS blends, which undoubtedly comes from the presence of discrete elastomeric phase. PVC/ABS blends are attractive not only due to their high impact but offer “built-in” flame retardance, moderate cost, good processability, high gloss etc.

INTRODUCTION

The driving force to formulate polyblends comes from the desire to achieve performance characteristics, cost dilution, or an optimum cost-to-benefit ratio. Physical blending appears to be a more rapid

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TABLE I
Commercially available PVC/ABS polyblends

| Sr. no. | Trade name | Grades | Supplier |
|---------|------------|-------------------------|-----------------------|
| 1 | Cycovin | K-20, K-25 K-29, KAF | Borg-Warner |
| 2 | Polyman | 507, 509, 511 | A. Schulman, Inc. |
| 3 | Kralastic | FVM, FVJ | Uniroyal |
| 4 | Abson | — | Abtec |
| 5 | Lustran | 860, 865 | Monsanto |
| 6 | Ronfaloy | RN-03, RN-05 | DSM |
| 7 | 832-1000 | — | Comalloy Intl. Corpn. |

and less expensive route to meet the demands of the market place than the development of new polymers.

PVC/ABS polyblend system was first introduced commercially in 1960. It is available in the market^{1,2} under different trade name, grades (Table I).

Polyblends based on PVC/ABS are used in a wide variety of applications, including sophisticated, high-technology ones and are aimed to replace flame retardant ABS and NORYL in their respective markets. The PVC/ABS blend has found applications in several areas such as electrical & electronics³⁻¹², appliance housings⁵⁻¹⁰ and automobiles.¹³⁻¹⁴

The outstanding commercial success of PVC/ABS polyblend derives partly from the cost reduction, high performance characteristics and adding ABS to PVC. In the polyblends, PVC component contributes to flame retardance, tensile and flexural properties whereas ABS contributes processability¹⁵ and impact and environmental crack resistance,^{16,17} thus giving a balance of properties as well as dilution of cost. The rubber particles in ABS act as shock absorbers against tendencies to fracture in PVC/ABS blends. In blends of PVC with MBS¹⁸ (a terpolymer similar to ABS, but Methyl methacrylate-based), fatigue crack propagation is found to be significantly better than that of a commercial polycarbonate.¹⁹ Lower densities of PVC/ABS blends provide a volume-to-weight advantage over PVC and can contain high amount of fillers. Blending process is less expensive than copolymerization.

Elastomer-toughened PVC blends are expected to have an improved low temperature impact strength, due to low T_g of the elastomer phase. By a proper selection of both elastomeric and plastomeric components and their percentage in the blend, a wide range of properties can be obtained. ABS can additionally act as a PVC photostabilizer¹⁷ restraining photodehydrochlorination and improving weatherability.

EXPERIMENTAL

Proper balancing of the rheological properties of the components in the melt state by selection of appropriate MWD grade is an important means for successfully tailoring morphology and balance of properties to meet product needs.

IPCL'S PVC grade (67ER092) was blended with ABS (Absolac-100 obtained from M/s. ABS Plastics, Baroda, India).

(a) ABS morphology selection

ABS has limited affinity with PVC owing to which the multiphase structure—a necessary condition for the reinforcement of PVC—is maintained. The separated phase is necessary for the impact modifier to become effective in impact reinforcement (5 to 30% rubber content is optimum). The grafting composition in ABS which gives the best results is a (75:25) styrene acrylonitrile copolymer. Toughness obtainable for the modified rigid PVC depends on the type of elastomeric component as well as on the size of elastomeric particles. Use of ABS is advantageous in this respect in comparison to other elastomeric modifiers for PVC. While the non-crosslinked type modifiers (CPE, EVA) may be dispersed to very small domain sizes, the crosslinked modifiers (ABS, MBS) can only be dispersed to the size of the crosslinked elastomeric emulsion particles in the ABS or MBS resin.

(b) Compatibilization

Grossly incompatible polymers can be made more compatible to form functionally useful polyblends. Compatibilizer is an additive

which improves the interface adhesion without rendering the polyblend miscible. Examples of compatibilizers suitable for PVC/ABS blends are: petroleum resin, thermoplastic polyurethanes,²⁰ α -methylstyrene-co-acrylonitrile polymer, nitrile rubber, etc.

(c) Processing of PVC and ABS

It should be possible to obtain a stable polyblend by dispersing and stabilizing the system by means of an appropriate compatibilizer. Alloying of PVC and ABS with additives was done using a Buss-ko-Kneader (temperature profile 80–155–160–170°C) at different blend ratios.

All processing and molding temperatures should be lowered and the fortified material should not be run at the usual maximum ABS temperatures. Blended PVC/ABS materials were evaluated for mouldability on a Windsor SP-300 Injection Moulding machine. Operating parameters are as follows:

| | |
|----------------|------------------------|
| Injection time | 8–12 sec |
| Pressure | 140 kg/cm ² |
| Screw RPM | 25 |
| Cooling time | 20 sec |
| Moulding temp. | 190–210–210–210–200°C. |

Moulded products were much superior in surface gloss to moulded PVC articles. Moulding temperature could be varied between 170°C to 210°C, without having any adverse effect on the degradation of the alloy.

(d) Test procedures for PVC/ABS specimens

Tensile properties were measured on an Instron Universal Tensile Testing machine, Model 1195, according to the ASTM D-638.

Flexural properties were also measured on the Instron 1195 Model, as per the ASTM D-790 method I, Procedure B.

Izod Impact, notched was determined as described in ASTM D-256 on a TMI system.

Heat deflection temperature as prescribed by ASTM D-648 was measured on a Wallace equipment under a load of 264 psi.

Rockwell hardness was determined according to the standard ASTM D-785 procedure in the 'R' scale and procedure 'B' on an ACCO Wilson instrument.

Glass transition temperature was measured on Du Pont DSC 990 model at a heating rate of 10°C/min and in an atmosphere of Nitrogen (flow rate 110 ml/min). Samples of about 2–3 mgm size representing the cross-section, were cut from the moulded specimens for the scan.

Viscosities of 1% solution of PVC/ABS mixtures in methyl ethyl ketone (MEK) were experimentally determined on a LAUDA Viscometer at 30°C.

RESULTS AND DISCUSSIONS

Impact strength versus blend composition

It is expected that the addition of ABS to PVC would result in impact improvements. The present data, while fulfilling and even exceeding our expectations in this regard, show synergistic improvement in impact strength (for blends containing 30% to 50% ABS). It is reasonable to assume that the first small additions of rubbery particles would not be sufficient to show any effect, and that increasing rubber concentration would show increasing improvement in impact strength (up to 50% ABS, Figure 1). The impact strength of the blends does not level off beyond ABS content of 50%, but drops sharply again towards high ABS contents. The maximum impact strength obtained at the best polyblend ratio is considerably higher than that of the high impact ABS constituent itself. Since the particle size of the dispersed polybutadiene phase is unlikely to change with blend composition, it may be concluded from above results that there is a critical volume fraction of elastomer phase (having spherical particles of a precise, optimum diameter) necessary for maximum improvement in impact strength. When this critical content of elastomer (or ABS content) is exceeded, impact strength drops.

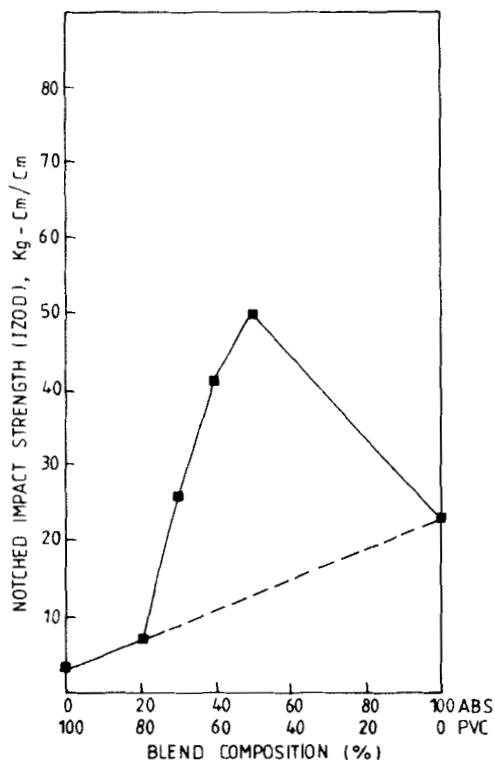


FIGURE 1 Notched impact strength vs. blend composition curve for PVC/ABS polyblends.

It should be noted for comparison that the notched Izod impact strengths of HIPS, ABS and PVC/ABS (50:50) blend are about 3, 10 and 21 times that of unmodified polystyrene.

The increase in matrix ductility is the dominant factor over the greater part of the composition range (Figure 1). Lower ABS contents increase the ductility of the matrix and reflect the notch sensitivity of unmodified PVC. The peak in impact strength at (50:50) composition marks the optimum balance between an adequate rubber content and the preferred combination of toughening mechanisms (multiple crazing with interacting shear deformation).

It is well-known that polyblends of PVC with different elastomers, e.g. PVC/polyacrylate, PVC/MBS and PVC/CPE, espec-

ially those processed at temperatures greater than 190°C have a network (IPN) morphology.^{21,22} It is shown for PVC/CPE system that once this network structure of elastomer phase is destroyed, the impact strength improvement is also lost.^{21,22} In PVC/ABS system, sudden improvements in various polyblend properties (tensile, flexural strengths and impact strength), all of which occur at blend ratio (50:50), can similarly be attributed to network formation.

Tensile strength and modulus versus blend composition

The curves of tensile strength and modulus (Figure 2) show almost monotonously decreasing properties with increasing ABS content.

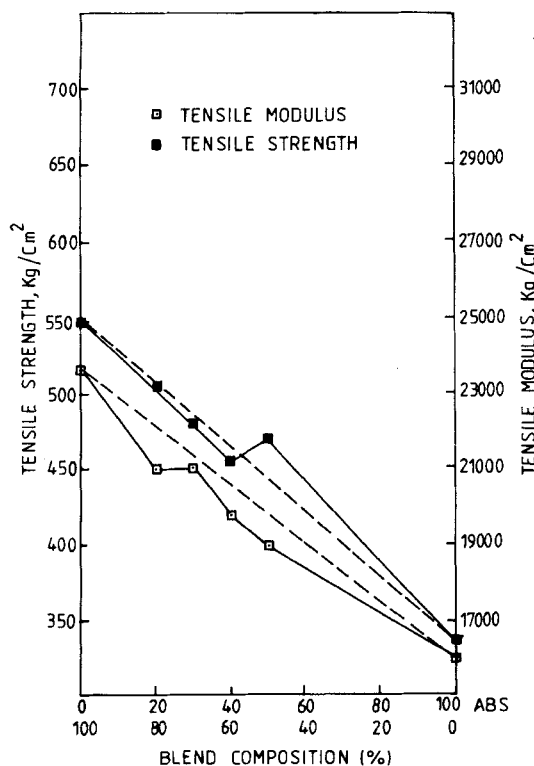


FIGURE 2 Tensile strength and modulus plotted against blend composition for PVC/ABS polyblends.

An increase in tensile strength is observed at 50% ABS content, while the modulus shows slightly negative deviations having minima at 20% and 50% ABS contents respectively. Apart from these local fluctuations (i.e. positive and negative deviations from linearity), both curves show a range of nearly additive response, indicated by dashed lines in Figure 2. Such responses are to be expected^{23,24} for miscible blends with little densification or for immiscible mixtures with good adhesion. PVC/ABS polyblends fit with both the above mentioned categories, depending on their blend ratio.

The reduction in tensile strength upon addition of ABS to PVC arises from polybutadiene domains in ABS which act as heterogeneous centres of stress concentration and initiate premature tensile or flexural failure of the blend.¹⁶

Elongation versus blend composition

Most PVC/ABS polyblends were so strong that they did not show clear breaks. For these, elongations were measured at yield. The initial drop in elongation at low additions of ABS to PVC (Figure 3) indicate miscibility of the two polymers until at about 40% ABS content they begin to phase separate yet reinforce each other as a result of the network formation. In an ABS-rich matrix containing low amounts of PVC also, good compatibility is indicated.

Flexural strength and modulus versus blend composition

Flexural strength and modulus generally vary¹⁶ from the high rigidity of the hard component (PVC) to the lower rigidity of the "soft" component (ABS). Results obtained in the present work (Figure 4) show that both flexural strength and modulus decrease with increasing ABS content with a minima at 40% ABS content. Of the two parameters, flexural strength shows a more linear dependence on blend composition and shows a lesser negative deviation from the additive response (dashed line). This linear response of the flexural strength over a range of ABS contents (with exception of those where negative deviations occur) can be attributed to the formation of a single phase¹⁶ due to miscibility of PVC and SAN, which are fairly compatible.²⁵

Disadvantage of adding an elastomeric phase to a thermoplastic is

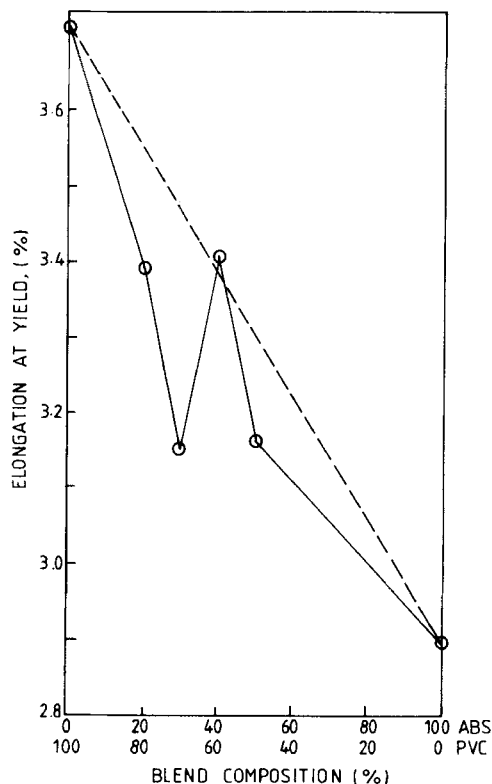


FIGURE 3 Elongation at yield vs. blend composition for PVC/ABS polyblends.

that it usually decreases tensile and flexural strengths and invariably reduces various elastic moduli.

Heat distortion temperature (HDT) versus blend composition

HDT might be expected to follow a straight line for a miscible blend²⁶ to a gradual or S-shaped curve for an immiscible blend. The ABS used in the present work has a high HDT and a plot of HDT versus blend composition dips through a slight minimum at 30% ABS content and then rises again to high HDT values. The HDT curve appears to be a mild mirror image of the impact strength curves discussed above (Figure 5), shifted slightly along the

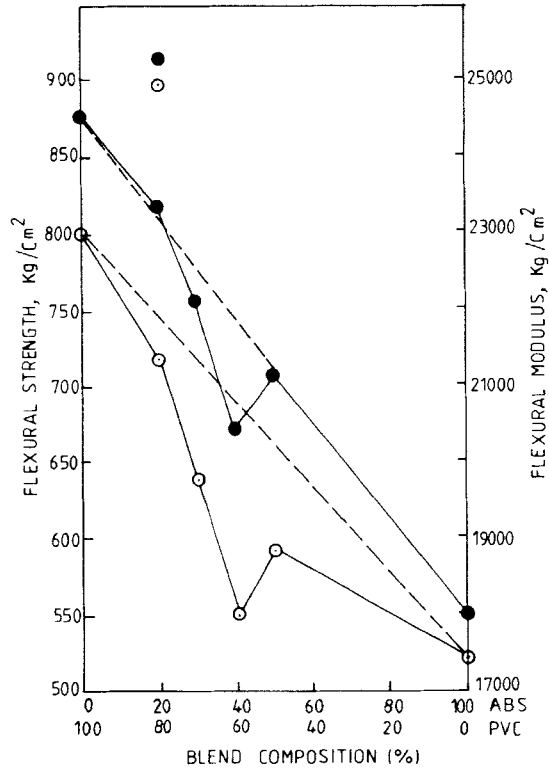


FIGURE 4 Flexural strength and modulus plotted against blend composition for PVC/ABS polyblends.

composition axis. These results are not suggestive of any phase inversion occurring at 30% ABS content, but may involve a theoretical explanation which is rather complex.

Specific gravity—composition curve

Figure 6 shows a comparison of experimentally observed specific gravity data and calculated specific gravities as a function of blend composition. It is seen that the experimental values for the PVC/ABS polyblends are higher than those calculated assuming volume additivity for the constituents (dashed line in Figure 6). These positive deviations of specific gravity from the linear path are

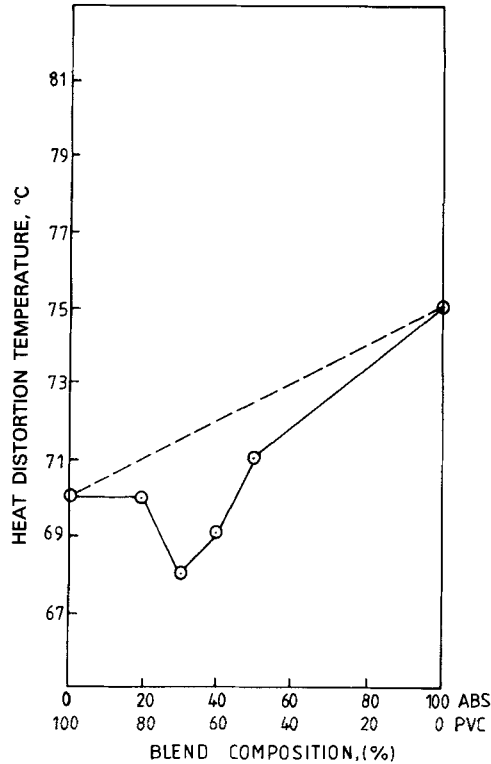


FIGURE 5 HDT vs. blend composition plot for PVC/ABS polyblends.

attributed²⁷ to better chain packing resulting from increased molecular interaction and compactibility. The data of Figure 6 can thus be understood that the compatibility between PVC and ABS is maximum at an ABS content of 20% and decreases with increasing ABS contents.

Solubility parameter information

The ABS terpolymer has a two-phase structure consisting of a rigid phase (SAN) and the rubber polybutadiene phase dispersed in it. The good agreement between solubility parameters²⁸⁻³⁰ of PVC (9.5-9.6) and SAN (9.3-9.8) predicts at least partial compatibility between them whereas polybutadiene rubber (solubility parameter 8.4) will always form separate domains. Thus, when PVC is blended

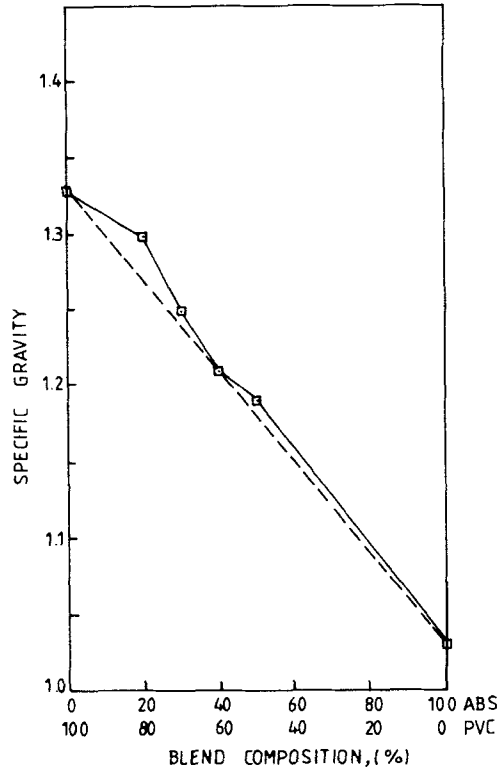


FIGURE 6 Specific gravity vs. blend composition plot for PVC/ABS polyblends.

with ABS, a two-phase morphology will always result, despite the compatibility between the rigid matrices of PVC and SAN.

Glass-transition versus composition curve

Compatible polyblends are known to give a single T_g , as per the expression for miscible polymer-polymer blends by the FOX (31);

$$\frac{1}{T_{g12}} = W_1/T_{g1} + W_2/T_{g2}$$

T_{g12} = T_g of the blend
 T_{g1} & T_{g2} = T_g of components 1 & 2 respectively
 W_1 & W_2 = Wt. fraction of components 1 & 2 respectively

which occurs at a temperature which is intermediate between the T_g 's of the parent polymer. Partially miscible systems show a shift of the T_g of one component towards the T_g of another. ABS is a multiphase system which has a low temperature transition³² (-90°C) which corresponds to the elastomeric polybutadiene phase and another transition above room temperature (100°C) which corresponds to the SAN matrix. When PVC and ABS are blended together, miscibility of PVC and SAN should occur in accordance with their solubility parameters discussed earlier, and a drop in the T_g of ABS component (i.e. SAN) should occur. The observed behaviour of the T_g of the SAN phase with changing blend composition is rather complex (Figure 7). For low contents of ABS

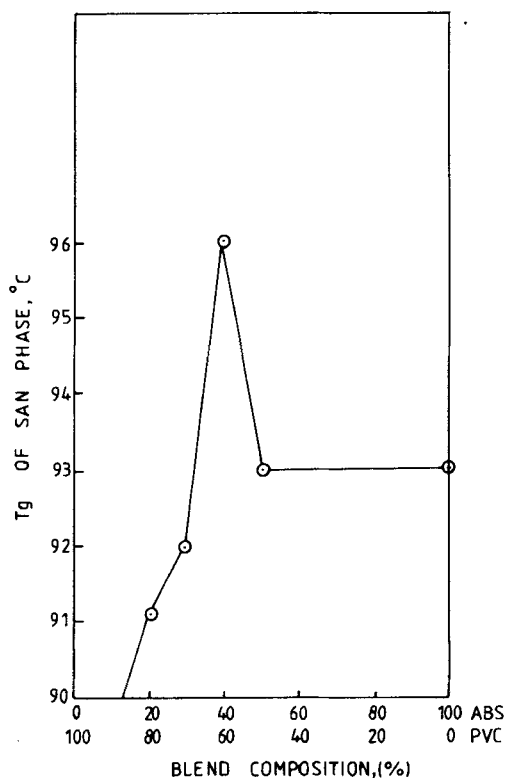


FIGURE 7 T_g 's of PVC and the SAN-phase of ABS plotted as a function of blend composition.

(20% & 30%), blend T_g is considerably less than the T_g of pure ABS, suggesting miscibility and partial compatibility between PVC and ABS. However, an anomalous behaviour is observed at an ABS content of 40%—blend T_g rises rapidly approaching the T_g of pure ABS within a few degrees. It is noteworthy that the impact strength of PVC/ABS blend is very high at this composition. This rise in T_g and accompanying high level of impact strength are indicative of the formation of a network structure in PVC/ABS blend at 40–60% ABS content.

Viscosity–composition curve

Figure 8 shows a plot of relative viscosity versus blend composition for various polyblends of PVC (K-67) and ABS-100 made by solution blending, to test their compatibility. Compatible mixtures of PVC and ABS should follow the straight line path³³ formed by joining the viscosities values of pure PVC and pure ABS. However, the experimental viscosities of solution polyblends deviate from this

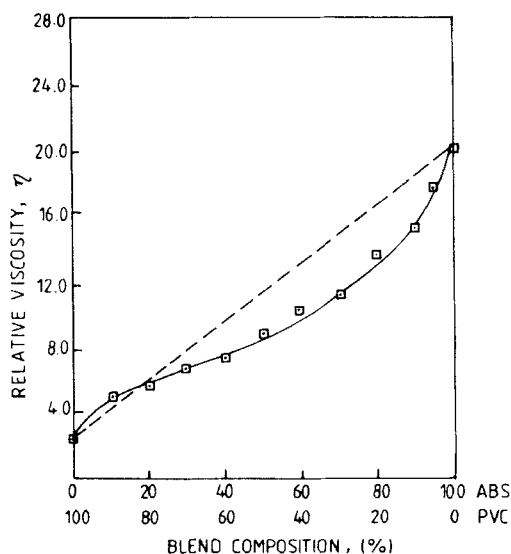


FIGURE 8 A plot of relative viscosity as a function of blend composition for PVC/ABS polyblends.

straight line, the deviation itself being a function of the blend composition (Figure 8). Such a negative deviation in viscosity data indicates a limited miscibility of PVC and ABS at their interfaces, and may even be accompanied by phase separation. The probability of phase separation would be maximum where the magnitude of deviation from the straight line path is maximum, i.e. at ABS contents of 30–50% (Figure 8). Good interfacial adhesion must exist in PVC/ABS polyblend, since the maximum deviations of viscosities from the linear plot (i.e. deviations from the compatible behaviour) fall within –20%.

Phase morphology

The blend of PVC and ABS resin form a 2-phase system composed of elastomeric polybutadiene phase and a rigid (SAN-PVC) phase.^{30,34} The DTA and DMA measurements^{25,32,35} of the blends also show a 2-phase system. This two-phase morphology observed for PVC/ABS system does not contradict earlier interpretation of property versus blend composition data in terms of compatibility between PVC and ABS. The effects of compatibility of PVC-ABS and blend ratio on the mechanical properties of blends are given in Table II. According to Cheng *et al.*²⁶ a (50:50) blend of Vinyl Chloride–Propylene Copolymer with ABS is “compatible” as seen from HDT data and still shows a two-phase morphology with ABS dispersed in a form of discrete particles (diameter 0.1 μ). A single δ peak is detected in this system.²⁶

PHYSICO-MECHANICAL PROPERTIES OF PVC/ABS POLYBLEND

A range of polyblends with different composition of the constituents were developed and characterised. At composition of 60:40 and 50:50 of PVC/ABS, the properties of the blend were found to be superior (Table III) and comparable to the commercially available similar blends from M/s. Borg-Warner and DSM.

It can be seen from Table III that (50:50) composition represents an optimum increase in impact, tensile and flexural properties as seen from the local maxima observed at this blend ratio. However, lowering the ABS content to 40% would be a good trade-off between properties on one hand and the cost on the other, with the

TABLE II
Structure-property correlation and determination of optimum blend ratio

| Sr. no. | Property | Deviation | Trend | Remark |
|---------|---------------------|--|---|---|
| 1 | 2 | 3 | 4 | 5 |
| 1 | Impact strength | Positive, with peak at 50% ABS | Increasing with ABS content | Shows synergistic behavior at (50:50) blend ratio |
| 2 | Tensile strength | Positive, with peak at 50% ABS | Decreasing almost linearly with ABS content | Partial compatibility between PVC-ABS |
| 3 | Tensile modulus | Positive, with peak at 30% ABS content | Decreasing almost linearly with ABS content | Partial compatibility between PVC-ABS |
| 4 | Elongation at yield | Positive, with peak at 60% ABS and negative with minima at 40% ABS | Decreasing | Some kind of structural reinforcement occurs at 60% ABS |
| 5 | Flexural strength | Negative with minimum at 40% ABS | Linearly decreasing | Partial compatibility between PVC & ABS |
| 6 | Flexural modulus | Negative with minimum at 40% ABS | Decreasing | — |
| 7 | HDT | Negative with minimum at 30-40% ABS | Increasing | — |
| 8 | Specific gravity | Positive, with maximum at 20% ABS | Linearly decreasing with ABS content | Partial compatibility between PVC & ABS |
| 9 | T_g (PVC) | Shows a maximum at 50-60% | increasing | Indicative of a network structure at 50-60% ABS |
| 10 | T_g (SAN) | Shows a minimum at 20% ABS | — | Indicative of PVC/ABS miscibility |
| | | Shows a peak at 40% ABS | — | Indicative of a network structure at 40% ABS |
| | | Lower T_g values at 20-30% ABS | — | Indicative of partial compatibility of PVC and ABS |
| 11 | Viscosity | Negative, maximum deviations occur at 60-80% ABS | Linearly increasing with ABS content | Partial compatibility of PVC and ABS |

TABLE III
Physico-mechanical properties of PVC/ABS polyblends

| Sr. no. | Property | Unit | IPCL PVC/ABS Polyblends | |
|---------|-----------------------------------|--------------------|-------------------------|---------|
| | | | (60:40) | (50:50) |
| 1 | Specific gravity | — | 1.21 | 1.19 |
| 2 | Tensile strength (ASTM D-638) | kg/cm ² | 455 | 468 |
| 3 | Tensile modulus (ASTM D-638) | kg/cm ² | 19 800 | 19 000 |
| 4 | Strain at yield (ASTM D-638) | % | 3.4 | 3.16 |
| 5 | Flexural strength (ASTM D-790) | kg/cm ² | 670 | 704 |
| 6 | Flexural modulus (ASTM D-790) | kg/cm ² | 18 000 | 18 850 |
| 7 | Izod impact strength (ASTM D-256) | kg-cm/cm | | |
| | 3 mm | | 73 | 115 |
| 8 | Heat distortion temp (ASTM D-648) | °C | 69 | 71 |
| 9 | Rockwell hardness | R-Scale | 109 | 4108 |

added bonus of improved flame retardance. The addition to these properties, PVC/ABS blends have good hinge properties.³¹

CONCLUSIONS

Good property relationships in PVC/ABS polyblends are due to components which have a stronger affinity for each other, but not so great so as to cause miscibility: they exhibit high interfacial adhesion/low interfacial tension. They are a system with significant partial miscibility. PVC/ABS polyblends give good processability, high gloss, very high impact strength, flame retardance and hinge properties. Elastomeric domains of ABS provide domains of a spherical shape and fixed diameter due to crosslinking and can be uniformly dispersed in PVC. These elastomeric domains enhance the impact strength of PVC considerably but lower its tensile and flexural properties. Contraction of free volume or densification occurs on mixing PVC and ABS which is the expected consequence of the energetic interactions responsible for miscibility in PVC/ABS

system. Such densification may benefit in improving the chemical resistance of the polyblends. Selection of systems on the edge of miscibility is a means of reaping the benefits of phase separation without incurring disadvantages. The successful implementation of physical blends requires little sophisticated knowledge and technology. The blends so developed had properties comparable to the commercially available such blend systems.

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