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Compatibilization of ABS/PA6 Blends using SAGMA Copolymer: Study of the Mechanical Properties

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***Abstract:* - The Mechanical Properties of five different compositions of compatibilized blends of ABS and PA6 in varying ratios from PA6 15 wt% to 55 wt% incorporating styrene-acrylonitrile-glycidyl methacrylate (SAGMA) copolymer as compatibilizer were explored. DMTA analysis evidences partial dissolution of the blend components by the shifts of the damping peaks (Tg) of PB rich phase, SAN and PA6. Broadening of the damping peak of PB rich phase of ABS is attributed to increasing interfacial region due to PA6-g-SAGMA molecular layer at the interface. It is observed that while there are gradual positive modifications in physico-mechanical properties with increasing PA6 content, the most significant improvements are observed for room temperature izod impact strength and break elongation effected in the region of phase inversion on to the formation of a co-continuous phase. The low temperature impact strength at – 40^{0}C essentially remains comparable to that of control ABS.**

I. INTRODUCTION

There has been considerable interest in the development of multiphase polymer alloys in recent years to meet the requirements of continuously evolving applications and product designs and performance which offer several advantages through the combination of attractive properties of each component or by reducing deficiencies of either one component. Nylon 6 (PA6) constitutes a major share in the field of engineering plastics**.** Its inherent balance of properties includes good chemical resistance, good mechanical and thermal properties, good wear and abrasion resistance along with a high melting temperature (T_m=220^{0}C) and good solvent resistance. However certain drawbacks are associated with PA6 such as processing instability – high mold shrinkage and dimensional instability due to its moisture absorbance and high water affinity. On the other hand, acrylonitrile-butadiene-styrene copolymer (ABS) has some superiority [1-4] over PA6 in high water resistance, low mold shrinkage and high cost competition, although it lacks in mechanical and thermal properties in comparison to PA6.

Blending of ABS with PA6 is known commercially to offset the drawbacks of each polymer and broaden the performance spectrum of blends having a balance combination of specific properties. Blends of ABS and PA are of technological interest as they display inherent superior combination of properties from their parent polymers including good impact strength, modulus, heat, chemical and abrasion resistance [4-8].

PA6 is a crystalline polymer and ABS has SAN matrix which is an amorphous polymer hence simple blends of ABS and PA6 generally exhibit poor mechanical properties due to their unfavorable molecular interactions [1]. My interest in ABS/PA6 blends has been stimulated by the numerous options that are available for reactively coupling these two immiscible polymers. A particularly appealing strategy is the addition of a polymer that is miscible with the SAN phase and that can react with the amine end groups of the nylon phase. By introducing this third component which acts as an interfacial agent to reduce the interfacial tension and promote adhesion at the interfaces. This third component, generally known as compatibilizer [2-3, 9]; may be a block or graft copolymer. Examples of such compatibilizing additives that have been used previously include Styrene-maleic anhydride (SMA) copolymers], Styrene- acrylonitrile-maleic anhydride (S/AN/MA) terpolymers and SAGMA improve the mechanical properties of the polymer blends [10], as they effectively "stitch" themselves across the polymer/polymer interfaces thus reducing the possibility of interfacial failure [3,11-13]. The approach of reactive compatibilization retards dispersed phase coalescence via steric stabilization [14]. Both these effects promote a stable, fine distribution of the dispersed phase within the matrix phase.

The impact behaviors of nanoclay filled PA6 blended with ABS were investigated using polybutadiene grafted maleic anhydride as compatibilizer to enhance interface interaction [17]. It was observed that impact strength increased slightly at various ABS compositions, but increased to a certain degree for nano-PA6/ABS blend system. Similar effects were also observed with decreasing temperature, especially at a 80/20 PA6/ABS ratio. The observed discrepancies were attributed to a different degree of available reaction sites from amino group on nano-PA6 and PA6 as well as clay rigidity in deterioration of toughness. The heat distortion temperature showed marginal decrease in the nano-PA6/ABS blend. Morphology revealed that ABS particle sizes decreased with addition of PB-g-MA for both blends, but were larger with higher contents of ABS. These observations accounted for the impact behaviors of the blends. In another study of the physical properties of PA6/ABS blends compatibilized by maleated polybutadiene, the morphology revealed that ABS domain sizes decreased with increasing compatibilizer content suggesting good interaction between the PA6 matrix and ABS dispersed phase. Cooling conditions and compatibilizer contents strongly affected the crystalline structure of PA6 determined by X-ray diffraction and non-isothermal crystallization thermal analyses. The coexistence of α- and predominantly γ-form crystals for 10 phr compatibilized blends was observed. Isothermal crystallization kinetics suggested that the introduced compatibilizer impeded the growth rate of crystals, especially at higher content. The compatibilizer was shown beneficial in enhancing the thermal stability of the blends.

A study [19] of PA6/ABS blends showed that the binary blends were immiscible and exhibited poor mechanical properties that resulted from unfavorable interactions among their molecular segments. This produced unstable coarse phase morphology and weak interfaces between the phases in the solid state. The use of glycidyl methacrylate-methyl methacrylate (GMA-MMA) copolymers as compatibilizer in the blends clearly led to a more efficient dispersion of the ABS phase and consequently optimized izod impact properties. However, the compatibilized blend showed poor toughness at room temperature and failed in a brittle manner at subambient temperatures.

The mechanical and rheological properties of PA6/ABS blends compatibilized by a random terpolymer of SANMA [18] have been studied in wet and dry states, TEM analysis revealed that morphology followed the general mixing rule with increasing PA6 sperical particles, interconnected network and matrix. Flow at low shear rates was mainly influenced by the low rubber content, 10 wt. %, of the ABS used in the study but not at higher shear rates. A stable morphology of spherical shape without agglomeration existed for the styrenic component in blends with PA6 70%. On the other hand when PA6 formed domains the dispersed domains tended to agglomerate and coalese at long times. Miscelle like compatibilized ABS and SAN droplets were stable in the PA6 matrix. The opposite occurred for PA6 domains in the ABS matrix. Morphological analysis indicated asymmetric properties of the interface between PA6 and ABS. The blends in wet state were less brittle than in dry due to the higher ductility of wet PA6 which initiated greater plastic deformation. The interphase between ABS particles and the PA6 matrix in a PA6 70% / ABS 30 % blend was weak and promoted debonding and void formation. A partly better interface adhesion yielded to fibrillation in the interphase which after fibril rupture created microvoids around the ABS particles. The SANMA compatibilizer was only partly concentrated at the interphase but was mostly distributed as small domains in the PA6 matrix.

For upgrading recycled engineering plastics by means of a blending technique [20, 26] the classical twin-screw extrusion has been compared to a new blending technique, where two polymers are combined together and then flow in several static mixers. It has been shown that this technique allowed for obtaining different morphologies of compatibilized ABS/PA or ABS/PC blends and the corresponding thermomechanical properties were evaluated. Experimental results demonstrated in particular that fibrilar morphology was obtained with the new blending technique (only with ABS/PA blends), which could lead to a mechanical enhancement if the adhesion between ABS and PA is optimized.

The above literature review shows that while a handful of approaches to the reactive compatibilization are evidenced, basic approach is to obtain an appropriate combination of good balanced and desirable properties along with superior performance.

In the present study, significant improvement of the physico-mechanical properties have been observed associated with ABS/PA6 blends in which PA6 is incrementally incorporated into an ABS matrix at a fixed compatibilizer weight ratio.

II. EXPERIMENTAL

General purpose molding grades of ABS Cycolac EX 10 U by UMG ABS Limited; Japan and PA6 Grade M-40 RC by GSFC; India were used to prepare the different blends of study. SAGMA copolymer (styrene acrylonitrile glycidyl methacrylate] having GMA 2 wt% was synthesized in the lab according to an adapted procedure [16].This SAGMA copolymer was used as compatibilizer at a fixed 10 wt % in the blends. The compositions of the blends prepared are given in Table 1. Melt blending for the preparation of the blends was performed by a conical intermeshing co-rotating twin-screw extruder, L/D =24 and 120 rpm, attached to a Haake Rheocord RC – 90 Torque Rheometer equipped with cooling bath and strand cutter using an extruder temperature profile **:** Feed zone: 215^0C**;** Compression zone : 225^0C; Metering zone: 235^0C; Die ring: 250^0C**;** Die: 240^0C employing the following sequential steps:

- PA6 pellets were size reduced by grinding to increase their surface area to enable intimate melt mixing with SAGMA copolymer followed by vacuum drying overnight at 80^0 C. PA6 and SAGMA copolymer were extruded using the above processing profile and pelletized.

- ABS and SAGMA modified PA6 along with antioxidant Irgafos 168 in accordance to the blends of study were dry blended in a tumbler mixer for approximately 30 minutes to enable good distribution and dispersion of the compositions. The dry blends were then vacuum dried at 80^0 C overnight prior to extrusion compounding.

- The extruded and pelletized blends formulations were vacuum dried at 80^0 C prior to injection molding by a 120 ton Klockner Windsor Injection Molding Machine at 240^0C. The injection-molded specimens for testing of various properties in accordance to ASTM were conditioned for at least 40 hours at 23 ± 2^0C and 50% RH prior to testing.

Ambient and subambient notched impact resistance of notched 1/8 and ¼ inch specimens were determined in accordance to ASTM D 256-93 by a CEAST Impact Tester, RESIL 25. For subambient temperature testing the specimens were conditioned at -40 C in a low temperature conditioning chamber until they reached equilibrium. Specimens were quickly removed, one at a time, from the chamber and impacted.

Viscoelastic properties were studied using a Dynamic Mechanical Analyzer, Model 983 by Du Pont Instruments, USA. Rectangular bar specimens 16 x 5.9 x 3.3 mm were scanned for their internal friction (Tan δ) between -100^0C to + 220^0C at a heating rate of 2^0C/min and fixed frequency of 10.0 Hz.

Tensile properties were characterized by measuring stress at break, yield stress and corresponding elongation as a function of blend composition in accordance to ASTM D-638 using Type-1 dumbbells by an Instron Universal Testing Machine, Model-4302.

Flexural properties were characterized by measuring flexural strength and modulus at 5% strain as a function of blend composition in accordance to ASTM D-790 using test specimen having dimensions of 200 mm x 10 mm x 10 mm at a rate of 1.3 mm/min cross head speed by an Instron Universal Tester, Model-4302.

III. RESULTS AND DISCUSSION

Dynamic Mechanical Analysis

The viscoelastic behavior and temperature dependence of damping (Tan δ) for control ABS and the blends S_A to S_E at 10 Hz are given in Table 2 and Figure2.

The Tan delta peaks represent the Tgs of the blends components. For control ABS the Tgs for PB and SAN rich phases are –80.5 ^{0}C and 119.5 C respectively. As the nylon weight content in the blends increases from 15 wt% to 55 wt%, the Tg of PB increases within a narrow range from - 80 ^{0}C to - 76 ^{0}C shifting towards the nylon phase. At the same time the corresponding Tan δ peak intensities range from 0.056 to 0.070. This increment is in a very narrow range, and not considered significant. Also observed is a broadening of the PB Tg peaks in blends S_C to S_E incorporating PA6 35 wt% to 55 wt% respectively.

For the PA6 rich phase, as the weight content increases in blends from 15 wt% to 55 wt% an increase in Tg within a narrow range by 6 ^{0}C from 37 ^{0}C to 43 ^{0}C is observed. The peak intensities increase from 0.025 for blend S_A incorporating PA6 15 wt % to 0.07 for blend S_E incorporating PA6 55 wt %.

The Tg of SAN rich phase in control ABS is 119.5 ^{0}C. As the PA6 weight content increases from 15 wt% to 55 wt% in the blends, a gradual decrease in Tg is noticed ranging from 118.5 ^{0}C to 109 ^{0}C, showing a significant decrease by 10 ^{0}C. The Tan δ peak intensity of SAN in control ABS is 2.34. The intensities for the blends show an initial significant decrease from 2.34 for SAN in control ABS to 1.48 for blend S_A incorporating PA6 15 wt% to 0.81 for the blend incorporating PA6 25 wt%. Beyond this PA6 wt% the decrease tapers to 0.51 for the blend incorporating PA6 35 wt % through to 0.41 and 0.34 for the blends incorporating PA6 45 wt% and 55 wt% respectively.

From this data it is observed that as PA6 weight content increases from 15 wt% to 55 wt%, increase in its Tan δ peak intensity is affected. The shift in Tg towards higher temperature is due to compatibilization effect with the SAN rich phase (19) whose Tg shows a corresponding decrease along with a decrease in Tan δ intensities in the blends. The PB rich phase also exhibits a corresponding upward narrow shift in Tg with increasing PA6 wt% along with peak broadening but no significant change in Tan δ intensities. The shifts in Tgs of the blends components and observed peak broadenings illustrates that compatibilization is effected by partial dissolution of phases ,i.e., the shell surrounding the PB rubber core, as interfacial adhesion is enhanced between the SAN segment of the PA-g-SAGMA, the grafted SAN of the shell-core ABS particles and the SAN matrix. If the blend components were completely miscible a single peak representing intermediate T_g would have been observed [19-20]. Partial dissolution of the blend components are evidenced however by the narrow range of T_g shifts [21] for all three components which lie within a range of 6^0C for PB of ABS and PA6; and 10 ^{0}C for SAN of ABS. This dissolution is attributed to the compatibilizing effect of SAGMA copolymer which is quite efficient in enhancing the interfacial adhesion between the blend components. Also with the increase in PA6 wt% the ductile nature of PA6 begins to empower the blend properties as seen from the significant reduction in the Tan δ peak temperatures and intensities of the rigid SAN phase. This gradually increasing ductility of the matrices is reflected in the blends properties including increasing impact strength and break elongation; and decreasing heat deflection temperature (HDT) and hardness.

Izod impact strength

The notched 1/8” and ¼” izod impact strengths of control ABS and blends S_A to S_E determined at room temperature and at $–40^0$C, are presented in Figures 3and 4 respectively. From Figure 3 it is observed that at room temperature the 1/8” notched izod impact strength of control ABS is 335 J/m. Incremental incorporation of PA6 15 wt% through to 35 wt%

in the blends results in a gradual increase in impact strength to 450 J/m for the blend incorporating PA6 35 wt%. Beyond this PA6 wt%, there is observed a sharp increase in impact strength from 580 J/m to 715 J/m, at PA6 45 wt% and 55 wt% respectively. Impact strengths at 1/8" of the blends in comparison to control ABS show that incorporation of PA6 increases the toughness of the blends by 1.35 times at PA6 35 wt%. This further increases by 1.73 to 2.14 times at PA6 45 wt% and 55 wt%, respectively.

A similar trend is observed for the determinations at ¼". Impact strength of control ABS at ¼" is 402 J/m. Incorporation of PA6 through to 35 wt% results in a gradual increase in izod impact strength to 520 J/m. Beyond PA6 35 wt%, there is a sharp increase in impact strength to 638 J/m and 735 J/m at PA6 45 wt% and 55 wt% respectively. The blends in comparison to the control ABS show that incorporation of PA6 increases the toughness of the blends by 1.3 times at PA6 35 wt % which further increases by 1.6 and 1.82 times at PA6 45 wt% and 55 wt% respectively.

It is clear that dispersion of PA6 domains continue to improve progressively at the fixed compatibilizer weight ratio. As the amount of ABS and PA6 vary with respect to each other, the improvements in impact strength no doubt result from a combination of better dispersion and the enhanced interfacial coupling at PA6 and ABS interface which is explained in the discussion of morphology. When the ratio of PA6 exceeds 35 wt%, the observed sharp increase of impact strength is due to the evolution and formation of co-continuous phase in the blends. At a peak PA6 55 wt% the izod impact strength attained is 736 J/m resulting in a near super tough blend (800J/m) [1, 15].

The mean Izod impact strength of the blend samples across PA6 weight percentages at 1/8'' and ¼'' at –40^0C are near identical at 113 J/m respectively. These values are comparable to that of control ABS at 118 J/m. The lower values of toughness of control ABS and the blends at –40^0C depicts that at this very low temperature, segmental mobility of the constituents of ABS and the blend components essentially cease.

From the above data inference is drawn that toughened ABS/ PA6 blends can be achieved over a broad range of compositions thus establishing the efficiency of the compatibilizer incorporated.

Any possible reduction in impact strength caused by crosslinking reactions involving the SAG epoxide groups, induced by acidic impurities in the emulsion –made ABS, is essentially eliminated when PA6 and SAGMA copolymers are blended together prior to adding ABS in a second pass extrusion [22].

Tensile properties

Tensile properties were characterized by measuring stress at break, yield stress and corresponding elongation as a function of blend composition. The results are shown in Figures 5-7 where tensile stress at yield, tensile modulus and elongation at break are plotted as function of blend composition. The data points represent the mean value of several experimented samples (ten samples) tested.

From Figure 5 it is observed that the tensile yield stress of control ABS is 41 MPa. The yield stress values for the blends gradually increase over control ABS with incorporation of PA6 from 42 MPa. at PA6 15 wt% through to 47 MPa. at PA6 wt% 55 wt% respectively, representing an increase by a factor of 1.15. It is also observed that while the tensile yield stress increases gradually with incorporation of PA6, the values taper from PA6 45 wt% to 55 wt%. The observations indicate the stemming of adhesive forces arising from the graft reaction of the compatibilizer with PA6. Modification of PA6 with epoxide may be accompanied by partial cross-linking which ultimately increases the tensile yield stress of the blends [23]. Also chain lengthening can be a dominating positive effect of this partial cross-linking. Further decrease in crystallinity of PA6 resulted by blending might play a role as well [24]. Qualitatively, increase of tensile yield stress indicates increasing positive synergism that results from good interphase adhesion of discrete PA6 particles at lower weight percentages through to the evolution of co-continuity of the ABS and PA6 phases at higher PA6 weight percentages as supported by the SEM analysis of the blends. The results are also indicative that optimal yield stress values are obtained once a co-continuous phase is evolved as seen for the blends incorporating PA6 45 wt% and 55 wt%.

The tensile modulus of control ABS is 2,250 MPa. From Figure 6 it is observed that incorporation of PA6 15 wt% through to 55 wt% results in a gradual slight increase in tensile moduli of the blends from 2,280 MPa through to 2,390 MPa. Incorporation of PA6 55 wt% results in an insignificant tensile modulus (stiffness) increase by 1.06 times over the control ABS. The similar trend as observed for the yield stress values, i.e., taper from PA6 45 wt% to 55 wt% is also observed for the moduli values. The essentially comparable values of tensile moduli of the control ABS and the blends show that the evolving blends morphologies do not influence the moduli values.

Figure 7 shows that the elongation at break of control ABS is 20%. Incorporation of PA6 results in no significant change in values of elongation even at PA6 25 wt%. The first significant change in elongation at break, twice that of control ABS at 40 %, occurs for the blend S_C incorporating PA6 35 wt%. Increasing the PA6 ratio to 45 wt% (blend S_D) results in a sharp increase in elongation at break to 150% nearly 8 times that of control ABS. For blend Se incorporating PA6 55 wt%, the elongation at break begins to taper to an increase by 190% (nearly 10 times that for control ABS).

Doubling of break elongation over that of control ABS for the blend S_C incorporating PA6 35 wt% is attributed to phase inversion. The very high elongation at break values observed for the blends S_D and S_E incorporating PA6 45 wt% and 55 wt% respectively coincides with the co-continuous morphologies of these blends as is evident from the obtained data. The results strongly suggest that co-continuous morphology achieved via compatibilization is responsible for the significant enhancement in the elongation at break values [25]. In other words the compatibilizer constitutes bridges between the two phases and makes the links stronger.

Flexural properties

Flexural property expresses the stiffness and bending strength of the material in terms of its ability to withstand under load. Data for flexural strength and moduli of control ABS and the blends S_A to S_E are given in Figures 8 and 9 respectively. The flexural strength of control ABS is 70 MPa. Incorporation of PA6 15 wt% shows a very minor decrease in the value of flexural strength to 68 MPa and is considered comparable to control ABS. On incorporation of PA6 25 wt% through PA6 55 wt% in the blends, a gradual increase in flexural strength to 78 MPa for blend S_E incorporating PA6 55 wt% is obtained. The improvement in rigidity over control ABS is slight by 1.12 times over control ABS. The regular minor increases in values of flexural strength show a positive deviation from the additivity. The positive deviation is mainly caused by rich interfacial adhesion between the blend components. This enhancement in the interfacial adhesion is due to better compatibilization effect of the added SAGMA copolymer [10], which deeply protrudes into the two interfaces and plays major role for this synergistic effect. Thus strong interaction between ABS and PA6 phases leads to the improved flexural strength though minor.

The load displacement curve for flexural modulus (Figures 9) shows that the value of modulus for control ABS is 2440 MPa. Incorporation of increasing PA6 wt% in the blends shows a gradual minor increase in moduli from 2470 MPa for blend S_A incorporating PA6 15 wt% through to 2590 MPa for the blend S_E incorporating PA6 55 wt% which is an insignificant 1.06 times over that of control ABS. The results again show that the evolving blends morphologies attributed to the increase in domain dispersion due to greater extent of intermolecular interaction between the blend components effected by the synergistic effect of the compatibilizer does not influence the flexural characteristics of the blends

IV. CONCLUSION

Evolution of Pysicomechanical properties of five different compositions of blends of ABS and PA6 in varying ratios from PA6 15 wt% to 55 wt% incorporating SAGMA copolymer as compatibilizer have been observed. To overcome incompatibility of the blend component, blends were prepared by a two step extrusion compounding procedures. DMTA analyses support partial dissolution by the observed shifts in Tgs of the blends components towards each other accompanied by broadening of the Tg peak of PB of ABS. Increasing ductility is also observed by reducing Tan delta peak intensities of SAN with increasing PA6 incorporation. Of the physicomechanical properties studied the most significant improvements are observed for the room temperature impact strength which increases by over nearly two fold (near super tough) at PA6 55 wt% over control ABS and break elongation which increases by nearly 10 times over control ABS. Significant improvements in these properties are effected in the region of phase inversion, i.e., PA6 35 wt% on to formation of a co-continuous phase. The obtained results show that optimal properties are obtained when the blend components exist as co-continuous phase. Other physicomechanical properties including tensile yield strength and modulus; and flexural strength and modulus are not influenced by the changing PA6 wt% even though they display positive deviation from additivity and are very slightly improved over those of control ABS. Onset degradation temperatures of the blends lie between that of ABS and PA6 thus not influenced by the presence of compatibilizer.

Table 1 Composition of blends

S. No.	Sample Notation	ABS wt%	PA6 wt%	SAGMA copolymer wt%
1	Control ABS	100	0	0
2	S_A	75	15	10
3	S_B	65	25	10
4	S_C	55	35	10
5	S_D	45	45	10
6	S_E	35	55	10

Table 2 Glass transition temperatures of ABS/PA6/SAGMA blends measured by DMTA at 10 Hz

S. No.	Sample Notation	PA 6 wt %	Tan Delta δ					
			Peak Temp. (^{0}C)			Peak Value		
			PB rich phase	SAN rich phase	PA6 phase	PB rich phase	SAN rich phase	PA6 phase
1	Control ABS	0	-80.50	119.65	---	0.056	2.34	---
2	S_A	15	-79.80	118.5	36.80	0.062	1.48	0.025
3	S_B	25	-78.80	115.35	37.85	0.063	0.81	0.031
4	S_C	35	-77.85	112.6	41.30	0.061	0.51	0.041
5	S_D	45	-76.80	110.85	42.50	0.060	0.41	0.053
6	S_E	55	-76.00	109.2	43.00	0.070	0.34	0.070

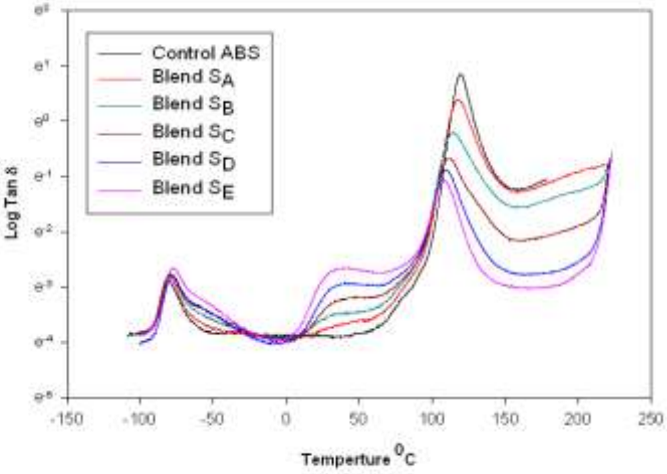

Fig.3 Effect of PA6 wt% on the damping behavior of ABS/PA6/SAGMA blends S_A to S_E at a frequency of 10 Hz

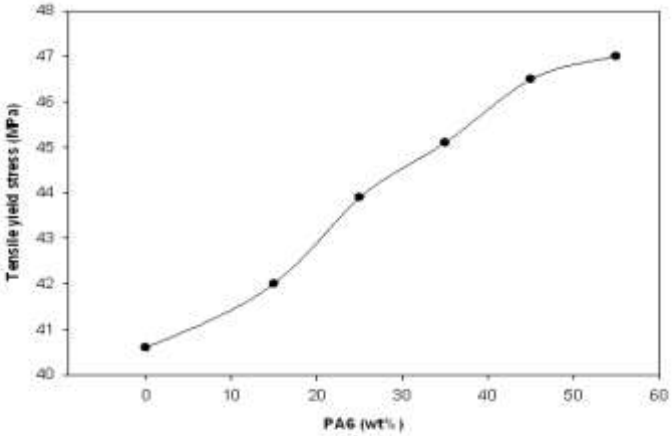

Fig.6 Effect of PA6 wt% on tensile yield stress of ABS/PA6/SAGMA blends S_A to S_E

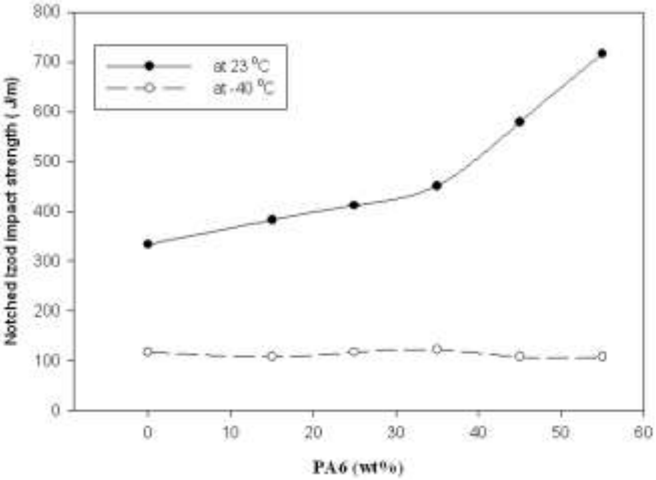

Fig.4 Effect of PA6 wt% on the 1/8" Izod impact strength of ABS/PA6/SAGMA blends S_A to S_E at room temperature and at – 40 ^{0}C

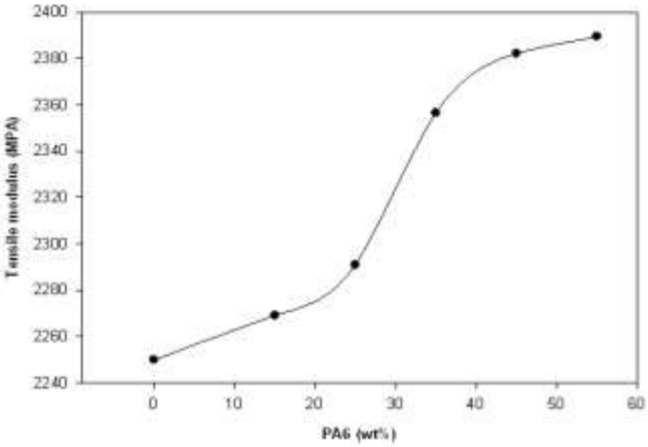

Fig.7 Effect of PA6 wt% on the tensile modulus of ABS/PA6/SAGMA blends S_A to S_E

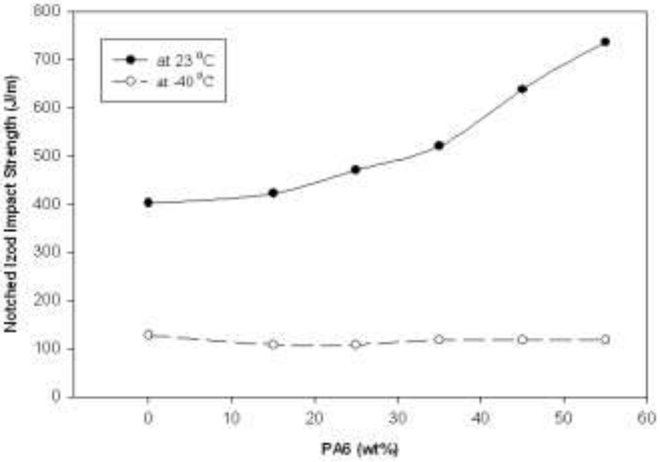

Fig.5 Effect of PA6 wt% on the 1/4" Izod impact strength of ABS/PA6/SAGMA Blends S_A to S_E at room temperature and at – 40 ^{0}C

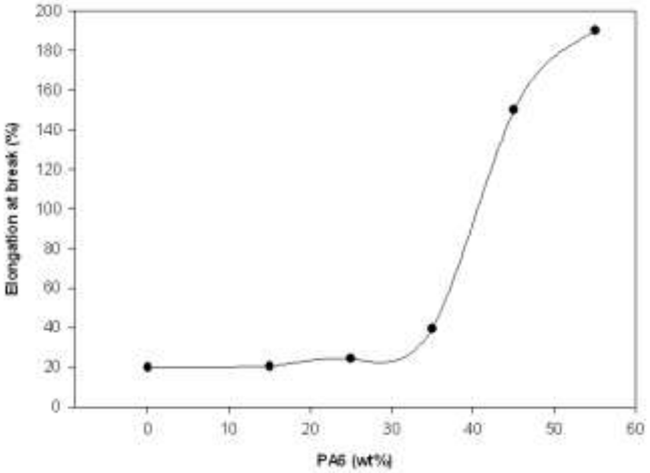

Fig.8 Effect of PA6 wt% on the break elongation of ABS/PA6/SAGMA blends S_A to S_E

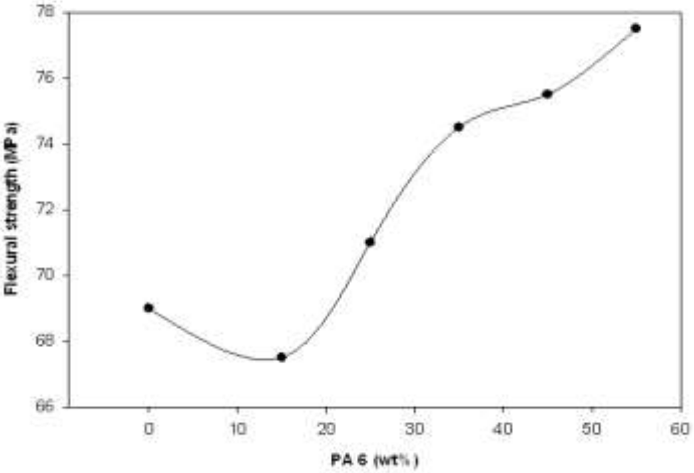

Fig.9 Effect of PA6 wt% on the flexural strength of ABS/PA6/SAGMA blends S_A to S_E

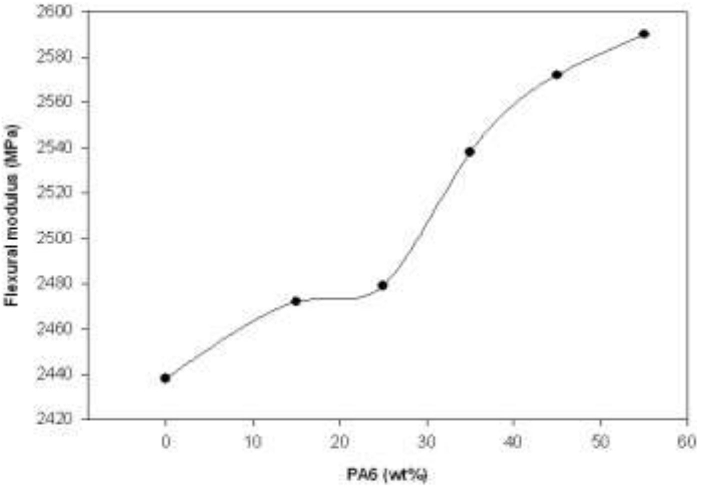

Fig.10 Effect of PA6 wt% on the flexural modulus of ABS/PA6/SAGMA blends S_A to S_E

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