

Thermal and Mechanical Properties of Copolymers of Methyl Methacrylate with *N*-aryl Itaconimides

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ABSTRACT: The article describes the preparation of cast copolymer sheets of methyl methacrylate with varying mole fractions of *N*-(*p*-methoxyphenyl) itaconimide/*N*-(2-methoxy-5-chlorophenyl) itaconimide/*N*-(3-methoxy-5-chlorophenyl) itaconimide monomers by bulk copolymerization using azobisisobutyronitrile as an initiator. The effect of incorporation of varying mole fractions of *N*-aryl-substituted itaconimides in poly(methyl methacrylate) (PMMA) backbone on the thermal, optical and physico-mechanical properties of cast acrylic sheets were evaluated. The glass transition temperature and the thermal stability increased with increasing amounts of itaconimides in the

polymer backbone. An increase in tensile strength, flexural strength, and storage modulus was also observed. The impact strength decreased marginally upon incorporation of imides into the polymer backbone. A slight decrease in the transparency and a significant increase (4–50%) in the haze was observed. The chemical resistance of PMMA remains unaffected by copolymerization. © 2009 Wiley Periodicals, Inc. *J Appl Polym Sci* 112: 1088–1095, 2009

Key words: addition polymerization; copolymerization; differential scanning calorimetry (DSC); mechanical properties; radical polymerization

INTRODUCTION

Poly(methyl methacrylate) (PMMA) sheets have a wide variety of applications due to its properties like light weight, excellent weather resistance, light transmittance, and good insulating properties.^{1,2} But the low softening temperature limits their applications.^{3,4} Methyl methacrylate (MMA) has been copolymerized with a variety of vinyl monomers to yield polymers with improved thermal stability, better impact strength and abrasion resistance.^{5–7}

Extensive work has been done in our laboratories on the copolymerization of MMA with *N*-arylsubstituted maleimides and itaconimides and a significant increase in the glass transition temperature has been observed.^{8–12} Several reports have been published on the physico-mechanical properties of MMA-*N*-aryl-substituted maleimide copolymers.^{8–10} However, the effect of incorporation of *N*-arylsubstituted itaconimide monomers on the physico-mechanical properties of PMMA has not been investigated. Since the increase in T_g was found to be much higher when MMA was copolymerized with *N*-arylsubstituted itaconimide when compared with corresponding *N*-arylsubstituted maleimides, it was therefore considered of interest to study the effect of comonomer

structure on the thermal and physico-mechanical properties of PMMA. Various copolymer sheets were therefore fabricated by taking varying mole fractions of *N*-(*p*-methoxyphenyl) itaconimide (PAI)/*N*-(2-methoxy-5-chlorophenyl) itaconimide (OMCPI)/*N*-(3-methoxy-5-chlorophenyl) itaconimide (MCPI) monomers and investigated their effect on the thermal, physico-mechanical and optical properties of PMMA.

EXPERIMENTAL

Materials

MMA (Merck, India) was washed with dilute sodium hydroxide to remove the inhibitor followed by repeated washing with distilled water until neutral. It was dried over anhydrous sodium sulfate overnight and distilled under reduced pressure. PAI, OMCPI, and MCPI monomers prepared and purified in the laboratory as reported in our earlier articles.^{11,12} Azobisisobutyronitrile (AIBN) (High Polymer Labs, India) was re-crystallized using chloroform. Methanol (S.D. Fine Chem., India) and chloroform (S.D. Fine Chem., India) were used as supplied.

Fabrication of PMMA and MMA-*N*-arylsubstituted itaconimide copolymer sheets

Preparation of prepolymer syrup

The prepolymer syrup was prepared by bulk polymerization of MMA and *N*-arylsubstituted itaconimide monomers in bulk at 60°C under nitrogen

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TABLE I
Details of Feed Composition and the
Sample Designation

Sample designation	Amount of AIBN added = 1% (<i>w/w</i>)	
	Mole fraction of	
	MMA	<i>N</i> -arylsubstituted itaconimide
SMMA	1.0	0.0
SPAI-1	0.9	0.1
SPAI-2	0.8	0.2
MCPI-0.5	0.95	0.05
SMCPI-1.0	0.90	0.10
SMCPI-1.5	0.85	0.15
SOMCPI-1	0.9	0.1
SOMCPI-2	0.8	0.2
SOMCPI-3	0.7	0.3
SOMCPI-4	0.6	0.4

atmosphere using AIBN as an initiator. The mole fraction of *N*-arylsubstituted itaconimides in the initial feed was varied from 0.05 to 2.0. MMA and *N*-arylsubstituted itaconimide was placed in a three necked round bottom flask equipped with a reflux condenser, CaCl₂ drying tube and a nitrogen gas inlet tube. The whole assembly was placed in a thermostatted oil bath and stirred using a magnetic stirrer. Nitrogen was passed through the reaction mixture to displace oxygen and the temperature was raised to 60°C. Polymerization was initiated by adding 1% AIBN (*w/w*) as an initiator. The reaction was arrested at low conversion ($\leq 20\%$) by cooling the mixture in ice cold water. The prepolymer syrup was then degasified and filtered using cheese cloth.

MMA-*N*-arylsubstituted itaconimide copolymer sheets prepared by bulk polymerization have been designated by adding a prefix "S" to the letter designation of comonomer followed by a numerical suffix

indicating the mole percent of *N*-arylsubstituted itaconimide in the feed. For example sheets prepared by taking 2 mol % of OMCPI and PAI have been designated as SOMCPI-2 and SPAI-2, respectively. PMMA sheet has been prepared similarly and has been designated as SMMA. The sheet designation and the amount of monomers and initiator taken has been shown in Table I.

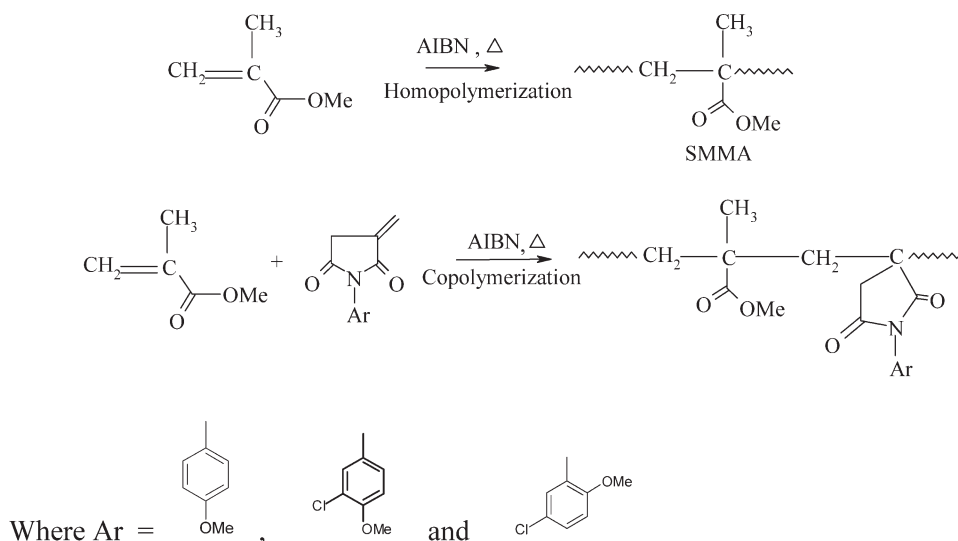
Casting of MMA-*N*-arylsubstituted itaconimide copolymer sheets

The deaerated prepolymer syrup was poured in the mold. The mold was prepared by placing a PVC gasket of diameter 3 mm between two toughened glass plates of area 35 × 30 cm². The glass plates were clamped together. One side of the mold was kept open for pouring the prepolymer syrup. The filled mold was kept in the preheated water bath at 40°C for 6 h. The temperature was then raised to 60°C and the mold was heated for another 6 h. The mold was then removed from the water bath and kept overnight in hot air oven at 90–100°C for post curing. It was then allowed to cool and the sheets were removed. Nine copolymer sheets were prepared by varying the mol % of MCPI, OMCPI, and PAI. The reaction scheme for homopolymerization of MMA and copolymerization of MMA with *N*-arylsubstituted itaconimides is shown below (Scheme 1).

Characterization and testing

¹H NMR

The structural characterization was done using ¹H NMR. ¹H NMR spectra of the copolymers were recorded on a Bruker spectropin DPX 300



Scheme 1 Reaction scheme for the synthesis of SMMA and copolymers of MMA with *N*-arylsubstituted itaconimides.

spectrometer using CDCl_3 as solvent and tetramethylsilane as an internal standard.

Molecular weight

The number average molecular weight (\overline{M}_n), weight average molecular weight (\overline{M}_w), and molecular weight distribution in the copolymer samples were determined using Waters GPC equipped with high-resolution and high temperature PL gel 5 μm mixed column size of $300 \times 7.5 \text{ mm}^2$ along with the refractive index detector. THF was used as eluent at a flow rate of 1.0 mL/min. The calibration curve was obtained by using polystyrene standards having molecular weight of 5,14,000, 1,56,000, 66,000, 28,500, 9200, 3250, and 1060.

Density

The density of the samples was determined by specific gravity bottle using the following formula

$$\rho_{\text{sample}} = \frac{m_{\text{sample}} \rho_{\text{methanol}}}{m_{\text{methanol}} - m_{\text{total}} + m_{\text{sample}}}$$

where ρ_{sample} is the density of sample, ρ_{methanol} is the density of methanol, m_{sample} is the mass of sample taken, m_{methanol} is the mass of methanol alone in the specific gravity bottle, m_{total} is the mass of the methanol and sample in the specific gravity bottle.

Thermal characterization

TA 2100 thermal analyzer having a 910 DSC module and Perkin-Elmer Pyris 6 differential scanning calorimeter (DSC) was used for the thermal characterization of copolymers. DSC scans were recorded in a static air atmosphere at a heating rate of $10^\circ\text{C}/\text{min}$ by using $5 \pm 1 \text{ mg}$ of powdered samples. Second heating scans were used for the determination of T_g .

Thermal stability was determined by recording TG/DTG traces in nitrogen atmosphere (flow rate = $60 \text{ cm}^3/\text{min}$) by using TA 2100 thermal analyzer having a 951 TG module and Perkin-Elmer Pyris 6 thermogravimetric analyzer. A heating rate of $20^\circ\text{C}/\text{min}$ and a sample size of $10 \pm 1 \text{ mg}$ was used in each experiment.

Tensile properties

Tensile properties were measured according to ASTM D-638, using Zwick Z-010 universal testing machine. The samples were conditioned for 48 h at $25 \pm 1^\circ\text{C}$ and relative humidity of 65% before testing. Dumbell shaped specimens (length, 112 mm; width of narrow section, 6 mm; gauge length, 30 mm) were made from the cast sheet by cutting

rectangular pieces and shaping them using a metal mold. The edges were smoothed by using fine sand paper. The following conditions were used for testing:

Full scale load: 10 kN
Cross head speed: 5 mm/min

For each composition a minimum of five samples were tested and the average value was taken.

Flexural properties

Flexural properties were determined in accordance to the ASTM D 790-81 on Zwick Z-010 universal testing machine using a three point bending method utilizing center loading on a simply supported beam.

The following conditions were used for testing:

Span length: 60 mm
Full scale load: 50 kg
Crosshead speed: 5 mm/min

Impact strength

Impact strength of notched specimens was measured according to ASTM D 256 using Impacts-15 Impact Tester. Sample dimensions were chosen in accordance with the standard and a 2.5 mm deep notch having an angle of $45 \pm 1^\circ$ and radius of curvature at the apex of 0.25 mm was cut with the help of a notch cutter in the middle. The samples were conditioned at a temperature of $25 \pm 1^\circ\text{C}$ and a relative humidity of 65% for 48 h before testing. Five samples for each composition were used for testing and an average value was reported.

Dynamic mechanical properties

Dynamic mechanical measurements on various polymer samples were carried out in the temperature range of $40\text{--}200^\circ\text{C}$ using DMA Q800 dynamic mechanical analyzer of TA Instruments in the resonance mode. A heating rate of $5^\circ\text{C}/\text{min}$ was used for recording DMA traces. Sample dimensions were such that on mounting the sample in the clamp assembly the L/T ratio of the sample was 10 (length = 30 mm, width = 10 mm, thickness = 3 mm). Oscillation amplitude of 0.2 mm was used for testing the dynamic mechanical properties.

Optical properties

ASTM D 1003 test procedure was used to measure percentage transmittance and percentage haze of the

sheets using BYK Gardner Haze-Gard Plus Instrument in the visible range (300–700 nm wavelength). The test specimens were conditioned at temperature of $23 \pm 2^\circ\text{C}$ and a relative humidity of $50 \pm 5\%$ for about 24 h before testing.

Chemical resistance

The resistance of the copolymer sheets to chemical reagents was evaluated in accordance to the ASTM D-543. Weighed samples having dimensions of $1 \times 1 \times 0.3 \text{ cm}^3$ were immersed in different solvents such as H_2O , 15% HCl (v/v), 25% H_2SO_4 (v/v), 25% CH_3COOH (v/v), 10% NH_3 (v/v), and 5% H_2O_2 (v/v). The change in weight after 7 days was noted.

RESULTS AND DISCUSSION

For the fabrication of sheets, a prepolymer syrup was used because it reduces internal stresses and shrinkage and also reduces the problem of trapped bubbles. Nine copolymer sheets were prepared by taking varying mole fractions of monomers in the initial feed. The mole fraction of PAI, MCPI, and OMCI in the feed was varied from 1 to 4%. Higher amounts of itaconimide could not be incorporated in the feed due to the low solubility of imide monomers in MMA.

SMMA sheet prepared was transparent and colorless. The sheets for MMA-*N*-arylsubstituted itaconimide copolymers obtained were transparent and clear with a yellow tinge without any surface defects. The intensity of color in sheets increased with increasing amounts of comonomer in the feed. The color of the sheets could be due to the presence of impurities or unreacted *N*-arylsubstituted itaconimide monomers in the copolymer sheet. To investigate this aspect, a portion of the sheet was dissolved in THF and precipitated in methanol. The precipitated polymer obtained was colorless indicating that by total precipitation the impurities and the low molecular weight species (oligomers) which remained soluble in THF/ CH_3OH solution were removed. Similar observation has been reported earlier for MMA-*N*-arylsubstituted maleimide copolymer sheets.^{9,10}

Figure 1 show the ^1H NMR spectra of sheets of MMA-OMCPI copolymers. In the ^1H NMR spectra of MMA-*N*-arylsubstituted itaconimide copolymer sheets, the resonance signals due to aromatic protons of *N*-arylsubstituted itaconimides and $-\text{OCH}_3$ protons of MMA were observed at $\delta = 8.0\text{--}7.0 \text{ ppm}$ and $\delta = 3.59 \text{ ppm}$, respectively. The other characteristic signals observed at $\delta = 2.0\text{--}1.7 \text{ ppm}$ and $1.0\text{--}0.7 \text{ ppm}$ were due to $-\text{CH}_2$ and $-\text{CH}_3$ protons of MMA, respectively. The intensity of the signals due to aromatic protons increased with increasing con-

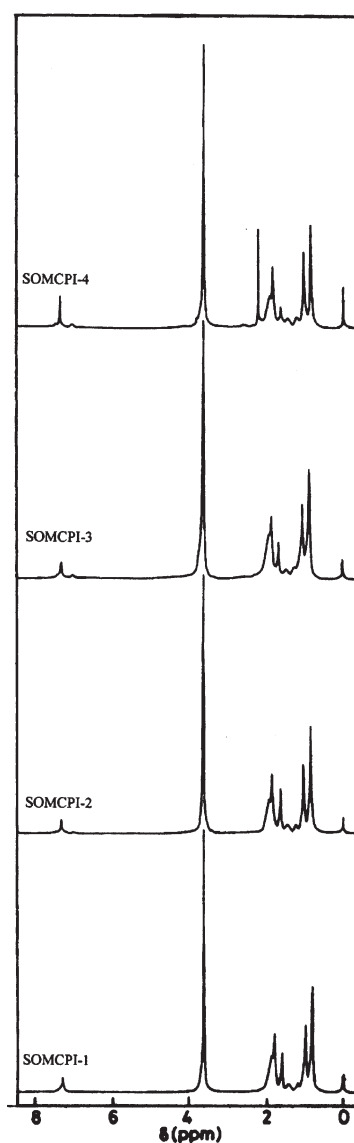


Figure 1 ^1H NMR spectra of sheets of MMA-OMCPI copolymers in CDCl_3 .

centration of *N*-arylitaconimide in the initial feed. No peak was observed in the region $\delta = 6.1\text{--}5.7 \text{ ppm}$ showing the absence of unreacted monomers.

The copolymers had molecular weight in the range of 0.7×10^5 to 10.0×10^5 (\overline{M}_n) and 1.0×10^5 to 15.0×10^5 (\overline{M}_w) with a polydispersity index in the range of 1.4–6.1. Molecular weight of the copolymers decreased with increasing amount of *N*-arylsubstituted itaconimide in the feed as shown in Table II.

The density of the copolymer sheets was observed in the range $1.28\text{--}1.39 \text{ g/cm}^3$ for MMA-MCPI sheets, $1.33\text{--}1.52 \text{ g/cm}^3$ for MMA-OMCPI sheets and $1.22\text{--}1.27 \text{ g/cm}^3$ for MMA-PAI sheets. The density of SMMA sheet prepared under the same condition was found to be 1.23 g/cm^3 . Thus the introduction of imides in the PMMA backbone increases the density (Table II).

TABLE II
 \bar{M}_n , \bar{M}_w , and PDI for MMA-*N*-arylsubstituted
 Itaconimide Copolymer Sheets

Sample designation	$\bar{M}_n \times 10^{-5}$ (g mol ⁻¹)	$\bar{M}_w \times 10^{-5}$ (g mol ⁻¹)	PDI	Density (ρ) (g cm ⁻³)
SMMA	3.0	10.0	3.3	1.23
SPAI-1	10.0	15.0	1.5	1.27
SPAI-2	8.0	13.0	1.6	1.22
	0.7	1.0	1.6	
SMCPI-0.5	0.8	5.0	6.1	1.28
SMCPI-1.0	5.0	10.0	2.0	1.30
SMCPI-1.5	3.0	10.0	3.3	1.39
SOMCPI-1	3.0	11.0	3.6	1.52
SOMCPI-2	5.0	12.0	2.2	1.33
SOMCPI-3	2.3	9.0	3.9	1.46
SOMCPI-4	9.0	12.0	1.4	1.52
	1.2	2.0	1.7	

The DSC scans of copolymer sheets were recorded primarily to study the effect of copolymer structure and composition on the glass transition temperature (T_g) of copolymer sheets which were prepared by carrying out copolymerization almost up to complete conversion. A shift in the baseline due to glass transition was observed in all the samples. To fully char-

acterize the glass transition region, the following temperatures were noted and the results of the DSC traces are summarized in Table III.

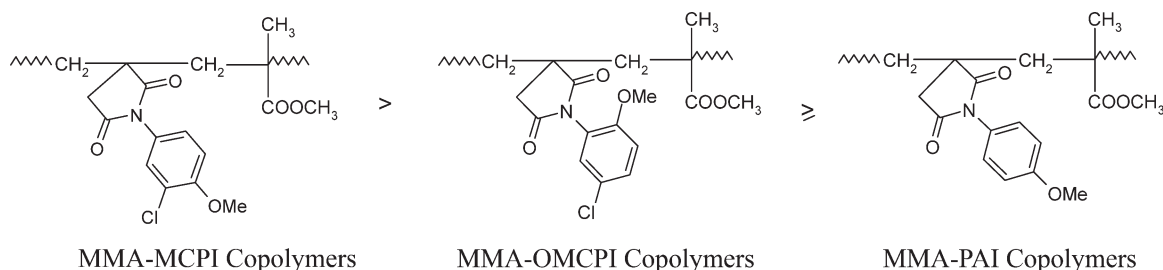
T_e = extrapolated onset temperature

T_g = glass transition temperature

T_f = extrapolated end set temperature

To have a similar thermal history, second heating scans were used to determine the glass transition temperature. The powdered samples were first heated in a DSC cell from room temperature to 100°C followed by cooling. The quench cooled samples were used for recording DSC scans at a heating rate of 10°C/min. The second heating scans were used in all the samples for characterizing the glass transition temperature. Figure 2 show the DSC scans of copolymer sheets. T_g of all the copolymer sheets was higher when compared with SMMA.

To investigate the effect of structure of comonomers, T_g of the copolymers was compared for copolymers having equivalent mole fraction of comonomers in the copolymer. For any given composition the following trend is expected



But for the same feed composition the following trend was observed



This could be due the higher molecular weight of SPAI-1 than SMCPI-1.

In all the copolymer samples, T_g increased with increasing mol % of comonomer up to 2% and maximum increase was observed in SOMCPI-2. Further increase of OMCPI content resulted in a decrease in T_g . This could be due to the formation of low molecular weight polymers with a high polydispersity.

The relative thermal stability of the copolymers was assessed by comparing initial decomposition temperature (T_i), final decomposition temperature (T_f), temperature of maximum rate of mass loss (T_{max}), and integral procedural decomposition temperature (IPDT). The results are summarized in Table IV. Figure 3 show the TG/DTG traces of SMMA and copolymer samples.

It is observed that the incorporation of even small amounts (1–4%) of itaconimides in the feed prevents the formation of weak linkages i.e., head to head linkages and end unsaturation and the major weight loss is due to unzipping of the main chain. All the

TABLE III
 Results of DSC Scans of MMA-*N*-arylsubstituted
 Itaconimide Copolymer Sheets (Heating Rate 10°C/min)

Sample designation	T_e (°C)	T_g (°C)	T_f (°C)
SMMA	111	122	132
SPAI-1	113	130	137
SPAI-2	115	130	137
SMCPI-0.5	112	123	128
SMCPI-1.0	115	129	137
SMCPI-1.5	120	128	135
SOMCPI-1	112	127	140
SOMCPI-2	118	134	139
SOMCPI-3	117	132	140
SOMCPI-4	115	130	151

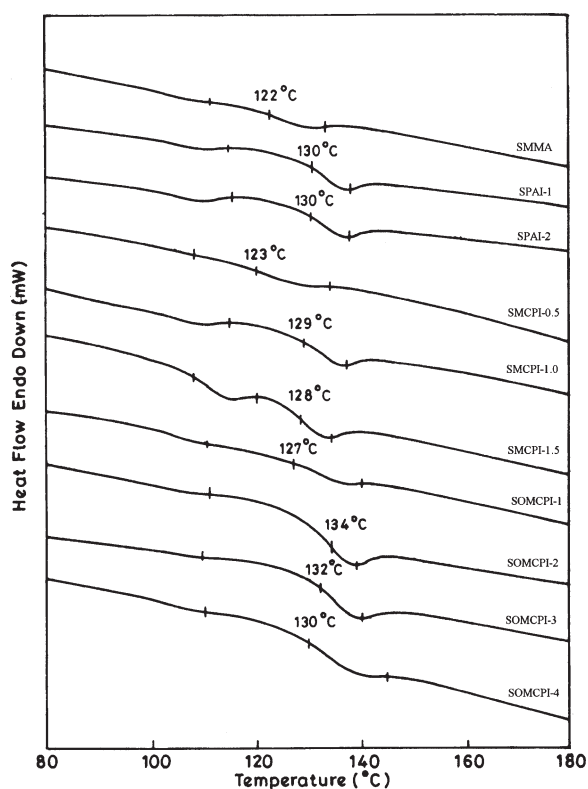


Figure 2 DSC scans of SMMA and MMA-*N*-arylsubstituted itaconimide copolymers.

copolymers were stable up to 300°C. IPDT which sums up the shape of the thermogravimetric trace in the whole temperature range indicated an increase in overall stability of the copolymers when compared with SMMA. It was calculated according to the method of Doyle.¹³ The IPDT for SMMA was 341°C whereas for MMA-*N*-aryl itaconimide copoly-

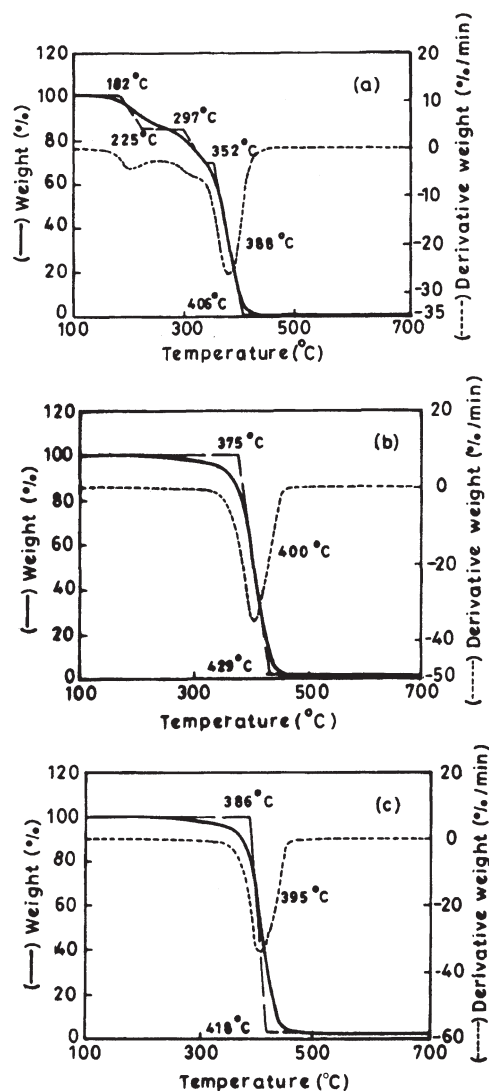


Figure 3 TG/DTG traces in nitrogen atmosphere (heating rate 20°C/min) for (a) SMMA, (b) SPAI-1, and (c) SPAI-2.

TABLE IV
Results of Thermogravimetric Analysis in Nitrogen Atmosphere for Sheets of MMA and *N*-arylsubstituted Itaconimide Copolymers (Heating Rate 20°C/min)

Sample designation	T_i (°C)	T_{max} (°C)	T_f (°C)	Mass loss (%)	IPDT (°C)
SMMA	171	189	226	29	341
	226	256	323	45	
	323	361	401	19	
SPAI-1	375	400	429	98	398
SPAI-2	386	395	418	98	405
SMCPI-0.5	175	199	230	10	361
	358	358	412	90	
SMCPI-1.0	242	312	352	12	392
	352	401	428	86	
SMCPI-1.5	386	403	422	98	397
SOMCPI-1	377	393	419	96	397
SOMCPI-2	377	398	432	96	430
SOMCPI-3	383	400	429	94	423
SOMCPI-4	290	314	374	25	394
	374	402	437	63	
	437	526	619	5	

mer sheets, it was observed in the range of 361–430°C.

The stress-strain curves of MMA-PAI copolymers are shown in Figure 4. From the stress-strain curves, tensile strength, percentage elongation, and modulus of elasticity were evaluated (Table V). As expected the tensile strength and the tensile modulus increased upon incorporation of imide in the polymer backbone and increased with the increase in the amount of itaconimide in the copolymer backbone. Increase in tensile strength and modulus was maximum in SOMCPI-4. All other copolymer samples had tensile strength and modulus higher when compared with SMMA. All the sheet samples had percent elongation of $6 \pm 1\%$. For the same feed compositions the tensile strength and modulus as well as the flexural strength of the SPAI copolymers was higher than SMCPI and SOMCPI copolymers. It could be due to the more symmetrical structure of

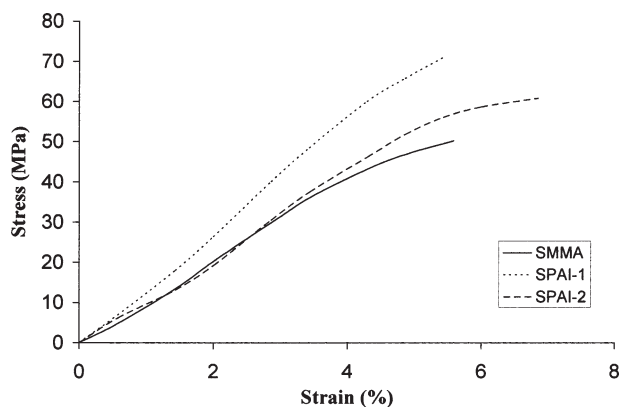


Figure 4 Stress-strain curves for MMA-PAI copolymers.

the *N*-*p*-methoxyphenyl itaconimide, which leads to better packing of the polymer chains thus increasing the rigidity.

The results of flexural strength, flexural modulus and impact strength are summarized in Table VI. As expected, incorporation of rigid imide linkages in the polymer backbone resulted in a significant increase in flexural strength and modulus. The impact strength of copolymers decreased marginally with the incorporation of imides in the polymer backbone. The impact strength decreased as the amount of imide in the feed was increased.

The variation of storage modulus (G') and dynamic loss modulus or damping ($\tan \delta$) with temperature for SMMA and copolymer sheets having 1 mol % of *N*-arylsubstituted itaconimide is shown in Figure 5. The storage modulus determines inherent rigidity and depends on the ability of the material to store mechanical energy. The dynamic loss modulus is sensitive not only to many kinds of molecular motion but also to various transitions, relaxation processes, structural heterogeneities and to the morphology of multiphase systems.

As expected the storage modulus and softening point increased with increasing amount of itaconimide in copolymers. Table VII shows the glass tran-

TABLE V
Tensile Properties of SMMA and the Copolymers of MMA and *N*-arylsubstituted Itaconimides

Sample designation	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation (%)
SMMA	51	1014	6.6
SPAI-1	73	1436	6.0
SPAI-2	62	1221	6.7
SMCPI-0.5	58	1118	6.3
SMCPI-1.5	56	1125	7.5
SOMCPI-1	53	1140	4.8
SOMCPI-2	71	1361	5.7
SOMCPI-4	82	1592	6.0

TABLE VI
Flexural Properties and Impact Strength of SMMA and the Copolymers of MMA and *N*-arylsubstituted Itaconimides

Sample designation	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (kJ m^{-2})
SMMA	64	2186	2.2
SPAI-1	97	3350	—
SPAI-2	90	3324	1.3
SMCPI-0.5	65	2532	1.9
SMCPI-1.0	70	2591	1.5
SMCPI-1.5	94	3180	—
SOMCPI-1	75	2599	1.9
SOMCPI-2	76	2617	1.8
SOMCPI-3	85	2993	1.6
SOMCPI-4	95	3135	1.4

sition temperature determined from the traces obtained from DMA curve.

The transparency of the sheets was determined in the visible range (300–700 nm) (Table VIII). Percent transparency decreased with increasing amount of

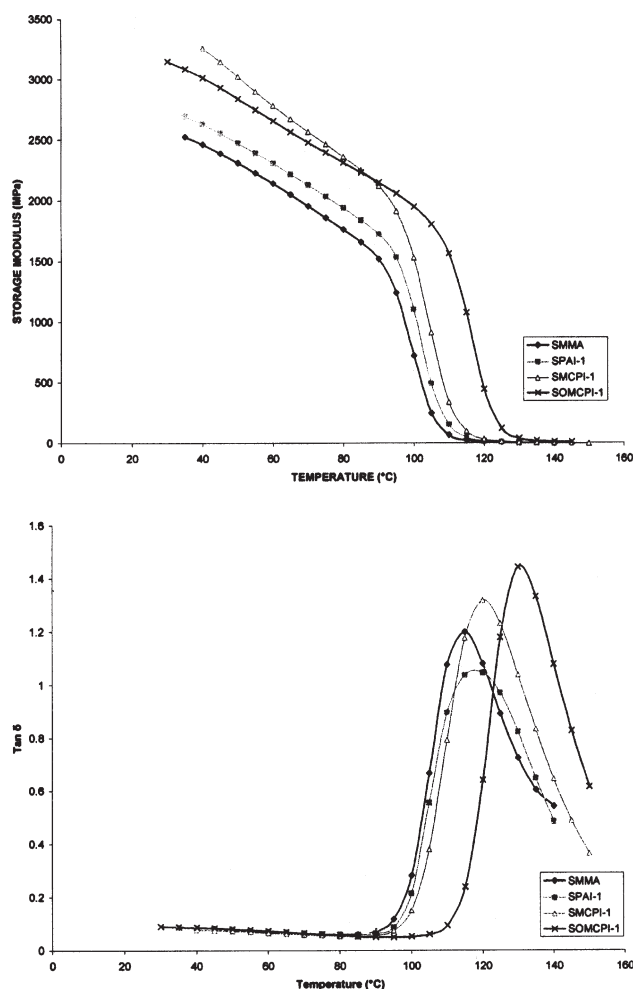


Figure 5 Plot of (a) storage modulus and (b) $\tan \delta$ versus temperature for SMMA, SPAI-1, SMCPI-1, and SOMCPI-1.

TABLE VII
 T_g of SMMA and Copolymer Sheets Determined from DSC and DMA Curves

Sample designation	Mole fraction of <i>N</i> -aryl itaconimide in feed	T_g (°C) Determined from		
		DSC	Storage modulus plots ^a	tan δ ^b
SMMA	0	122	99.7	115.2
SPAI-1	0.014	132	102.6	118.0
SPAI-2	0.028	130	101.4	117.4
SMCPI-0.5	0.007	130	107.1	121.5
SMCPI-1.0	0.014	130	103.7	120.3
SMCPI-1.5	0.056	123	100.8	114.8
SOMCPI-1	0.014	129	116.7	131.2
SOMCPI-2	0.028	128	112.3	127.0
SOMCPI-3	0.042	127	113.0	127.4
SOMCPI-4	0.056	134	114.8	130.3

^a T_g was determined from storage modulus vs. temperature plots by extrapolation.

^b T_g was noted as peak position of tan δ vs. temperature plots.

imide in the copolymer backbone. A significant increase in haze (5–56%) was observed upon incorporation of imide which increased with increasing amount of imide in the copolymers. This could be due to the presence of unreacted itaconimide or due to the formation of oligomers during the fabrication of sheets.

Chemical resistance of the copolymer samples was determined by immersing the copolymer samples in the chemical reagents for 7 days¹⁰ and calculating the weight change. It was observed that all the samples showed a marginal increase in weight (i.e., <1%). All the copolymer sheets remained intact and transparent after immersion in different solvents for 7 days. The results are summarized in Table IX. Percent change in weight was quite low in 25% H₂SO₄ (*v/v*) and it decreased with increasing amount of itaconimide in copolymers.

TABLE VIII
 Transparency and Haze Measurements

Sample designation	Transparency (%)	Haze (%)
SMMA	84 ± 0.4	6 ± 0.1
SPAI-1	78 ± 0.8	11 ± 0.5
SPAI-2	72 ± 0.9	13 ± 0.8
SMCPI-0.5	82 ± 1.8	10 ± 0.6
SMCPI-1.0	80 ± 0.6	17 ± 0.1
SMCPI-1.5	76 ± 0.2	19 ± 0.1
SOMCPI-1	74 ± 0.2	36 ± 0.1
SOMCPI-2	68 ± 0.8	57 ± 1.2
SOMCPI-3	58 ± 0.9	57 ± 1.2
SOMCPI-4	74 ± 0.5	35 ± 0.1

TABLE IX
 Percent Weight Change of Copolymer Sheets After Immersion for 7 Days

Sample designation	% Weight change					
	25% H ₂ SO ₄	15% HCl	20% CH ₃ COOH	H ₂ O	10% NH ₃	5% H ₂ O ₂
SMMA	0.77	0.59	1.44	0.89	0.99	0.95
SPAI-1	0.90	0.89	0.75	0.73	0.92	0.71
SPAI-2	0.74	0.90	0.79	0.74	1.09	0.81
SMCPI-0.5	0.34	0.96	1.03	0.89	1.02	0.88
SMCPI-1.0	0.36	0.91	1.61	1.10	1.04	1.01
SMCPI-1.5	0.47	1.11	1.11	0.79	0.77	0.83
SOMCPI-1	0.37	0.65	1.24	0.75	0.79	0.98
SOMCPI-2	0.90	0.76	0.75	0.66	1.16	0.84
SOMCPI-3	0.65	0.51	0.93	0.68	0.78	0.72
SOMCPI-4	0.04	0.80	1.11	0.21	0.80	0.87

CONCLUSIONS

The sheets obtained for MMA-*N*-arylsubstituted itaconimide copolymers were transparent and clear with a yellow tinge and can be used as a replacement of PMMA in inner glazing in solar collector covers. The incorporation of the itaconimide rings in the backbone increased the rigidity of the copolymers thus increasing the tensile strength and modulus as well as the flexural strength and glass transition temperature.

For the same feed compositions the tensile strength and modulus as well as the flexural strength of the SPAI copolymers was higher than SMCPI and SOMCPI copolymers. From these results, it can be concluded that SPAI copolymers are preferred candidate materials for solar collector covers.

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