Influence of Different Types of UV Absorber/UV Stabilizer Combination on the Photodegradation of PC/ABS Blend

Vipin V. Rajan,[1,2] Roy Wäber,[1] Jürgen Wieser[1]

[1]*German Institute for Polymers (DKI), Department of Technology, 64289 Darmstadt, Germany*
[2]*Dutch Polymer Institute (DPI), High Throughput Experimentation Cluster, 5600 AX Eindhoven, The Netherlands*

Received 7 January 2011; accepted 21 March 2011
DOI 10.1002/app.34560

ABSTRACT: The polycarbonate/poly(acrylonitrile butadiene styrene) blends, (PC/ABS), are mainly degraded by sunlight known as photodegradation when exposed to outdoor conditions. It is the ultraviolet (UV) radiation that is responsible for the degradation of the blend. To stabilize against the harmful UV radiation and to scavenge the radical species which arise from UV or thermally induced degradation of the PC or the ABS, UV absorbers, and UV stabilizers are used. In this article three different UV absorbers namely, Tinuvin 1577—hydroxyphenyl triazine type, Cyasorb 5411—benzotriazole type, Uvinul 3030—cyanoacrylate type, and two different UV stabilizers, Tinuvin 765—monomeric hindered amine type, Tinuvin 622—oligomeric hindered amine were compounded in different combinations with PC/ABS blend at 240°C using a twin screw extruder. Accelerated aging of the compounded sample was done by Atlas Suntest apparatus. The photodegradation studies were done using UV–vis, attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy, and Yellowing index measurement. The molecular weight of the compounded sample before aging was determined by gel permeation chromatography (GPC). It was found that samples protected with hydroxyphenyl triazine type UV absorber and oligomeric hindered amine show the best result for decreasing the degradation products, oxidation rate, and yellowing of the PC/ABS blend. © 2011 Wiley Periodicals, Inc. J Appl Polym Sci 124: 4007–4015, 2012

Key words: UV absorbers; photodegradation; UV–vis spectroscopy; ATR-FTIR spectroscopy; PC/ABS blend

INTRODUCTION

PC/ABS blends are used in many fields of engineering applications because of its excellent physical and mechanical properties such as high toughness and transparency. However, one of the main disadvantages of this blend when used in outdoor conditions is that it degrades due to sunlight, humidity, and oxygen.[1] In bisphenol A polycarbonate (BPA-PC) the chemistry underlying the photodegradation has been ascribed to two different mechanisms: photo-Fries rearrangement and photo-oxidation.[2–7] The relative importance of these mechanisms depends on the irradiation wavelengths used. When irradiation wavelengths which are present in terrestrial sunlight are used for degradation, the photo-oxidation reaction is the most important one and that photo-Fries rearrangements are irrelevant.[5–7] The polybutadiene component has been shown to be the prime reason for the fast degradation of ABS.[8,9] It is suggested that photo-oxidation of ABS leads to a crosslinking of the rubber component and then to destruction of the elastomeric properties of the rubber phase.[10]

To increase the life time of PC/ABS blends, these undesired photodegradation reactions need to be prevented. There are several ways to stabilize the blends. One way is by keeping the polymer out of sunlight, another method is to quench the excited states of the polymer before the photo chemical reactions occur and a third solution is by trapping the free radicals. This can be achieved by adding UV-absorbers, quenchers, radical scavengers, or a combination of these.[11]

Generally, the protection of polymers against photodegradation is achieved by using a combination of UV absorbers and UV stabilizers. An effective UV absorber strongly absorbs the UV light that is harmful to the polymers and dissipates this energy because their excited states can dissipate the absorbed energy as heat by a rapid internal hydrogen transfer.[1,12]

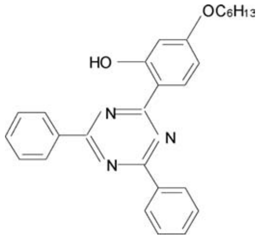
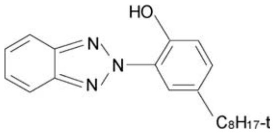
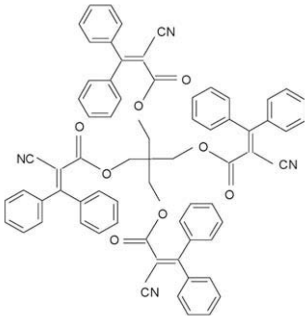
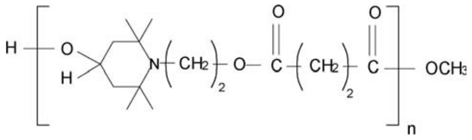
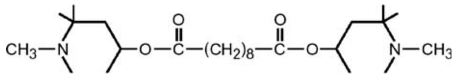
While the UV absorber is beneficial in shielding UV light, it does not act to scavenge radical species which arise from UV or thermally induced degradation of the PC or the ABS components in the blend. The hindered amine light stabilizers (HALS) are well

---

Correspondence to: V. V. Rajan (vipinvrajan@hotmail.com).

Journal of Applied Polymer Science, Vol. 124, 4007–4015 (2012)

TABLE I
Schematic Overview of the UV Absorbers and Stabilisers Used with Their Structure and Supplier

Name, supplier	Chemical structure
Tinuvin 1577 (425.53 g/mol), Ciba	
Cyasorb 5411 (323 g/mol), Cytec	
Uvinul 3030 (1060 g/mol), BASF	
Tinuvin 622 [$(283)_n$ g/mol], $M_n = 3100–4000$ g/mol, Ciba	
Tinuvin 765 (509 g/mol), Ciba	

known to be radical scavengers for many classes of polymeric materials.[1] They are extensively used to protect PC/ABS blends from photo-oxidation and thermo-oxidative degradation.[13,14]

The influence of individual effect of different types of hindered amines and UV absorbers on PC/ABS blend are investigated[15,16] and it is found that tertiary amines either monomeric or oligomeric are less harmful to the PC backbone. The study on UV absorbers shows that triazine type of UV absorber has a better protection of the blend against the commonly used benzotriazole. The novelty of this article is to investigate the combination effect of the abovementioned hindered amines with different UV absorbers on the protection of PC/ABS blend against harmful UV radiation.

The objective of this article is to investigate the efficiency of three different UV absorbers and two UV stabilizers when they are used in combination in a PC/ABS blend. The UV absorbers used are Tinuvin 1577 (T1577)—hydroxyphenyl triazine type, Cyasorb 5411 (C5411)—benzotriazole type and Uvinul 3030 (U3030)—cyanoacrylate type where as Tinuvin 765 (T765), monomeric HALS, and Tinuvin 622 (T622), oligomeric HALS, are used as the stabilizers for this study. These are compounded in a twin screw extruder at 240°C. Accelerated aging of the compounded samples are done by Atlas Suntest apparatus containing xenon lamp. The degradation studies are done using UV–vis, Attenuated Total Reflectance (ATR) Fourier Transform Infrared (FTIR) spectroscopy, and Yellowing index measurement. The molecular weight of the compounded sample before aging is determined by gel permeation chromatography (GPC). Individual degradation studies of PC and ABS have been done by many researchers and mechanism of their degradation pattern is postulated, but here the main aim is to study the efficiency of different UV absorbers and UV stabilizers on PC/ABS blend when they are used in combination in a PC/ABS blend as a whole system and not the individual degradation mechanism.

EXPERIMENTAL

Material

The polymer used in the investigation was polycarbonate (Calibre 300-10, Dow Benelux) and ABS (Magnum F641, Dow Benelux). A schematic overview of the UV absorbers and stabilizers used is shown in Table I. The UV stabilizers exhibit no significant absorption within the wavelength used for the UV–vis spectroscopy, 350–900 nm. The concentration of additives varies from 0 to 1 wt %. PC and ABS were blended with a weight ratio of 65/35.

Compounding experiments

A corotating twin screw extruder (ZSK-32 Mc MEGA Compounder, Coperion Werner and Pfleiderer GmbH) with 32 mm screws with gravimetric feeding units (DDW-MDI, Brabender) was used for compounding. The *L*/*D* ratio of the screw was 46. The barrel temperature was 240°C and was controlled within a limit of ±2°C by cold water circulation. A screw speed of 600 rpm and throughput of 25 kg h^{-1} were chosen. A standard screw configuration was used for the compounding. The different recipes used in the experiments are shown in Table II.

The film extrusion line (Chill roll type 136-350S, Dr. Collin GmbH) had a roll face width of 350 mm preceding a slit die with a width of 250 mm and a lip which was adjustable between 0.3 and 2 mm. The roller conveyor, following the chill roll has a length of 3300 mm and can be adjusted to throughput velocities between 0.5 and 5 m min^{-1}. The PC/ABS film extrusion was done at a velocity of 5 m min^{-1} and the thickness of the film was 0.25 mm.

Testing procedure

The molar mass of unaged PC/ABS blend was determined by size exclusion chromatography (SEC; GPC) in tetrahydrofuran using toluene as internal flow marker. The GPC-setup consisted of a Waters 515 isocratic HPLC pump, a TSP AS 100 autosampler, a Waters UV 486 Detector operated at 254 nm, and a Waters 410 differential refractometer. Three SDV columns (PSS, Polymer Standard Service GmbH, Mainz, Germany) with nominal pore sizes of 10^6, 10^5, and 10^4 Å (30 × 0.8 cm^2 each) were used. Calibration was performed using narrow distributed polystyrene standards. Data acquisition and processing was performed using PSS WINGPC software version 6.2.

TABLE II
Compounding Experiments

Experiment name	PC/ABC (%)	Additive (%)	Additive name
E1	100	–	–
E2	99.0	0.5/0.5	T765/T1577
E3	98.5	0.5/1.0	T765/T1577
E4	99.0	0.5/0.5	T765/C5411
E5	98.5	0.5/1.0	T765/C5411
E6	99.0	0.5/0.5	T765/U3030
E7	98.5	0.5/1.0	T765/U3030
E8	99.0	0.5/0.5	T622/T1577
E9	98.5	0.5/1.0	T622/T1577
E10	99.0	0.5/0.5	T622/C5411
E11	98.5	0.5/1.0	T622/C5411
E12	99.0	0.5/0.5	T622/U3030
E13	98.5	0.5/1.0	T622/U3030
E14	99.0	0.25/0.25/0.5	T765/T622/T1577
E15	98.5	0.25/0.25/1.0	T765/T622/T1577
E16	99.0	0.25/0.25/0.5	T765/T622/C5411
E17	98.5	0.25/0.25/1.0	T765/T622/C5411
E18	99.0	0.25/0.25/0.5	T765/T622/U3030
E19	98.5	0.25/0.25/1.0	T765/T622/U3030

The film samples were aged in an Atlas Suntest XLS+ containing xenon lamps with daylight filters. The black standard temperature was set at 65°C. The irradiance level was 765 W m^{-2} at a band width of 300–800 nm. The samples were aged for 672 h under dry conditions.

Yellowing index measurement of PC/ABS films was done using the Hunterlab Colorquest Colorimeter. On the samples, color can be measured in reflection and in transmission mode. In this case, as the samples were transparent, transmission mode were used for the assessment of color. As color data, the Yellowness Index YI D1925-70 was recorded.

UV–vis spectra were taken on a Perkin–Elmer Lambda 40 spectrometer from a wavelength of 1000–300 nm. Lower wavelength, <390 nm, of the UV–vis measurement was characterized by a large scattering occurred from the ABS phase and therefore was not suitable for any measurement. Infrared spectra were recorded using a Thermo Scientific Nicolet 8700 spectrometer in an attenuated total reflection (ATR) mode at 100 scans and a resolution of 4 cm^{-1}.

RESULTS AND DISCUSSION

The UV–vis, ATR-FTIR, and yellow index measurement of irradiated PC/ABS samples are studied to evaluate the effect of different UV absorber/UV stabilizer combination on the sample. The UV–vis measurement gives the degraded products formed during the photodegradation whereas ATR-FTIR is a measure of surface oxidation of the polymer blend during accelerated aging. The yellowing index

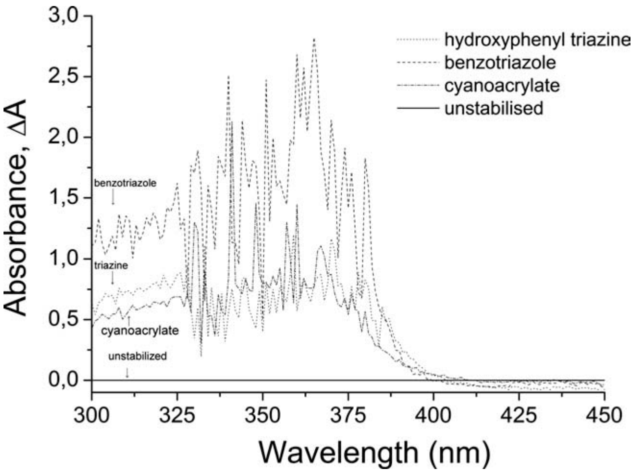


Figure 1 UV–vis absorption spectra (ΔA) of the nonirradiated stabilized and unstabilized PC/ABS films with different UVAs. ΔA = (absorption spectra of irradiated sample − absorption spectra of corresponding nonirradiated sample).

measurement provides a physical value to the extent of discolouration the samples manifest after degradation.

UV/vis spectroscopy analysis

The absorption of UV–vis radiation by polymers leads to transitions among the electronic energy levels and an electronic absorption spectrum results. In Figure 1 the spectra of nonirradiated samples of unstabilized and stabilized PC/ABS films are depicted. The absorption spectrum of unstabilized PC/ABS sample is taken as the baseline for the measurements. The concentration of stabilizers used is 1 wt %. The spectrum of unstabilized sample is taken as the reference spectrum for this graph. The absorption curves of the stabilizers show that the requirements for UV absorbers are met: strong absorption in the UV range between 325 and 400 nm and a large reduction in absorption in the visible range, above 400 nm. Comparing the absorption spectra, it can be observed that benzotriazole have higher absorption at wavelength below 400 nm than the other two UV absorbers. Since the molecular weight of benzotriazole is the lowest of the three absorbers used and these are compounded into the PC/ABS blend in weight percentage, benzotriazole has relatively large number of functional group present than the other two absorbers. This is attributed to the higher absorption level achieved by this UV absorber compared to the other two UV absorbers.

In Figure 2 the UV–vis absorption spectra of E1 (without UV stabilizer and UV absorber), E3 (T765/T1577), E5 (T765/C5411), and E7 (T765/U3030) are plotted. The samples are aged for 672 h in the Suntest apparatus. The concentration of UV stabilizer, T765, used is 0.5 wt % and UV absorbers—T1577, C5411, and U3030—is 1 wt %. Throughout the article, the UV–vis curves are plotted as difference spectra which are obtained by subtracting the irradiated spectra of the blend extruded with additives at different conditions from the spectrum of the corresponding nonirradiated blend. It is seen that for all samples with UV protection, samples compounded with UV stabilizer and UV absorber, the UV–vis absorbance level is much lower than the sample without UV protection at short wavelength region, at 390 nm. The degraded products formed during the photodegradation reaction mainly absorbs in the short wavelength region, therefore, the absorbance at short wavelength is directly related to the extent of photodegradation occurred in the sample. The sample protected with T765/T1577, E3, shows a sharp decrease in UV–vis absorption at 390 nm than the absorbance of samples E5 and E7. It is seen that the absorbance of E5 and E7 are the same at 390 nm. This shows that the combination of T765/T1577 has maximum protection against the harmful UV radiation than the other UV protection system used.

The UV–vis absorption spectra of E1, E9 (T622/T1577), E11 (T622/C5411), and E13 (T622/U3030) are plotted in Figure 3. A sharp decrease in the UV–vis absorbance at 390 nm is observed for the samples with UV protection. Samples E11 and E13 have the same UV–vis absorbance at 390 nm showing that T622/C5411 and T622/U3030 have similar UV shielding efficiency. A small decrease in the UV–vis absorbance at 390 nm is observed for T622/T1577 compared to E11 and E13.

The UV–vis absorption spectra of E1, E15 (T765/T622/T1577), E17 (T765/T622/C5411), and E19 (T765/T622/U3030) are plotted in Figure 4. The UV–

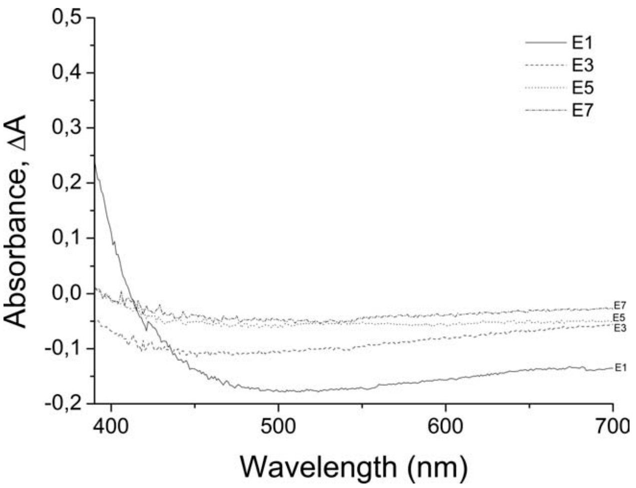


Figure 2 UV–vis absorption spectra (ΔA) of the irradiated samples as a function of T765 and different UV absorbers at 600 rpm. ΔA = (absorption spectra of irradiated sample − absorption spectra of corresponding nonirradiated sample).

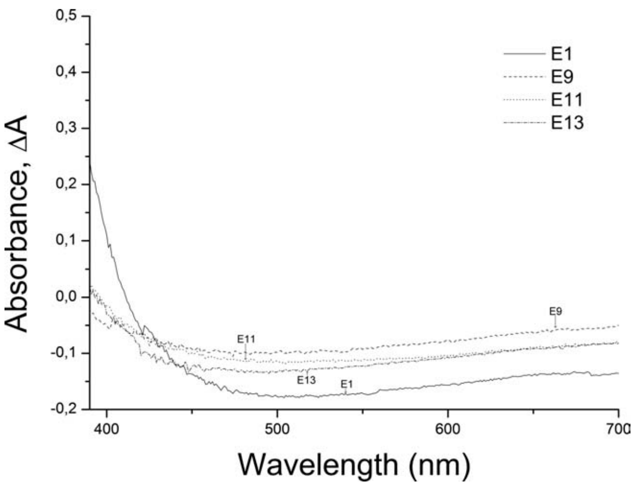


Figure 3 UV–vis absorption spectra (ΔA) of the irradiated samples as a function T622 and different UV absorbers at 600 rpm. ΔA = (absorption spectra of irradiated sample − absorption spectra of corresponding nonirradiated sample).

vis absorbance at 390 nm decreases with the UV protection of the samples and the lowest UV absorbance are observed for T765/T622/T1577 system and the highest with T765/T622/U3030. The UV–vis absorbance of T765/T622/C5411 system has value in between the other two systems.

In Figures 2–4 it is seen that the curves have negative absorbance values between 450 and 700 nm. This is attributed to the bleaching or degradation of the polymer after the light irradiation.

Infrared spectroscopy analysis

FTIR spectroscopy is an important tool for investigating polymer degradation, because of its ability to detect stable degradation products. The degradation of PC and ABS is a surface phenomenon, which extends about 25 μm into the exposed surface[17,18] therefore the PC/ABS films are analyzed with FTIR in ATR mode. This technique is used to investigate the influence of UV absorbers and UV stabilizers on the photo-oxidation rate at the surface of the PC/ABS film. Degradation produces oxygen-containing groups such as esters, hydroxyls, acids, and carbonyls. Chemical processes can be followed by observing the appearance of new peaks in the hydroxyl (3600–3200 cm^{-1}) and carbonyl (1800–1600 cm^{-1}) regions.

The degradation of ABS phase mainly gives peaks in the carbonyl and hydroxyl region whereas polycarbonate gives peaks in the carbonyl region. It is previously reported that the absorption band at 1713 cm^{-1} is ascribed to aliphatic acids, which are typical oxidation products for PC/ABS blend.[19] In this study, peak at 1713 cm^{-1} is used as a measure of the photo-oxidation rate.[19,20,21] When the spectra are normalized using the peak located at 1014 cm^{-1} the absorption as a function of concentration of UV absorbers can be quantified. The other important peaks seen in the spectra are described below. The PC shows following peaks; 2970 cm^{-1}: methyl asymmetric C—H stretch, at 1772 cm^{-1}: C=O stretch, 1505 cm^{-1}- ring C—C stretch, 1080 cm^{-1}: C—C—C deformation, 1015 cm^{-1}- symmetric O—C—O stretch and at 831 cm^{-1}: out of plane C—H deformation. The IR spectra of ABS shows distinctive -CH$_2$- rocking modes of two different polybutadiene structures i.e., one at 966 cm^{-1} which is due to the *trans*-1,4 structure and another at 913 cm^{-1} which is attributed to the 1,2 structure. Bands also form in the 3500–2500 cm^{-1} region due to the formation of hydroxyl, acid, and per acid species.

In Figure 5 the IR spectra of unaged and aged samples of unstabilized PC/ABS blend is shown. It is seen that with aging, new absorption peaks are formed at different wavelengths. There is no absorption band at 1713 cm^{-1}, carbonyl, and at 3450 cm^{-1}, hydroxyl, for the unaged sample whereas an increased absorbance at the same wavenumber is observed for the aged PC/ABS film. The hydroxyl peak appears as a broad signal with maximum at ≈3450 cm^{-1}, typical of an OH stretch. The tail of this band extends beyond 3000 cm^{-1}, suggesting the presence of OH groups from carboxylic acids. Since both phases, PC and ABS, degrade to give a final product of carboxylic acids the peaks obtained in the carbonyl and hydroxyl are taken as a cumulative peaks obtained from these two polymers. These bands can be used as a measure of oxidation for stabilized PC/ABS film. The concentration of UV absorber and UV stabilizer used is 1.0 and 0.5 wt %, respectively.

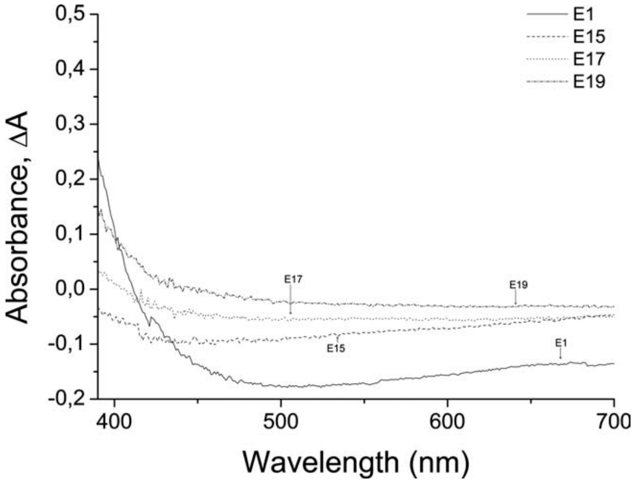


Figure 4 UV–vis absorption spectra (ΔA) of the irradiated samples as a function of different UV stabilizer/UV absorber combination at 600 rpm. ΔA = (absorption spectra of irradiated sample − absorption spectra of corresponding nonirradiated sample).

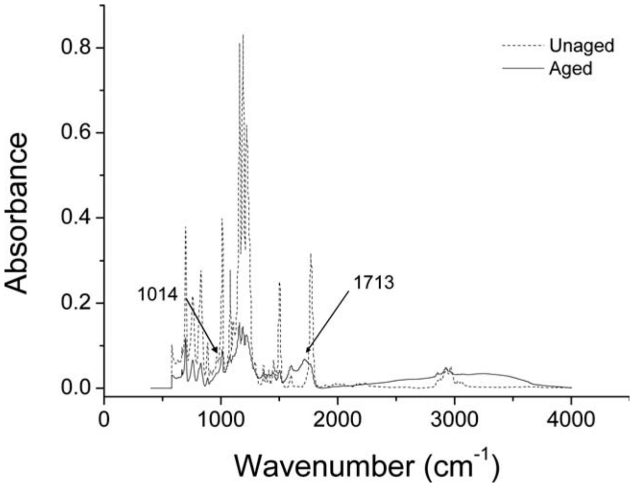


Figure 5 IR absorption spectra of unaged and aged PC/ABS films without any additives.

The quantified peak at 1713 cm^{-1} is plotted against irradiation time for samples E1, E3, E5, and E7 in Figure 6. It is seen that no absorbance at 1713 cm^{-1} is observed for all samples till 168 h. Afterward, there is a sharp increase in the absorbance value for all the samples but the rate of oxidation starts to decline for E1 and E7 after 336 h, whereas it continues for E3 and E5 till 504 h. After 504 h the rate of oxidation for protected and unprotected sample becomes identical. After an aging of 672 h, sample E3 has the lowest surface oxidation whereas unprotected E1 has the maximum value for surface oxidation. Samples E5 and E7 have similar values and lies in between E1 and E2. It is observed that the rate of oxidation for unprotected sample is much higher in the initial aging hours and afterwards it get decreased whereas for protected sample the rate of oxidation is much slower in the initial hours but sustains the same rate of oxidation for a longer aging period and finally it enters into a plateau region. Even though the protected sample has a prolonged linear region of oxidation before it reaches a plateau still it has lower overall oxidation level at all stages of aging compared to the unprotected sample. A comparison of absorbance value at 1713 cm^{-1} for E1 and E7 samples show that the latter has half the oxidation level of the former at 336 h revealing the effect of additives in delaying the aging process of the PC/ABS samples from photodegradation.

The absorbance at 1713 cm^{-1} against the irradiation time is depicted for samples E1, E9, E11, and E13 in Figure 7. Similar to Figure 6, a reduced rate of oxidation is observed for protected samples than unprotected sample. The rate of oxidation decreases after an aging period of 336 h for all samples. Sample protected with T622/T1577, E9, show lowest oxidation at all stages of aging process whereas the other two protected samples, E11 and E13 have similar pattern of degradation under the same conditions and within the domain of time scale used for the aging process.

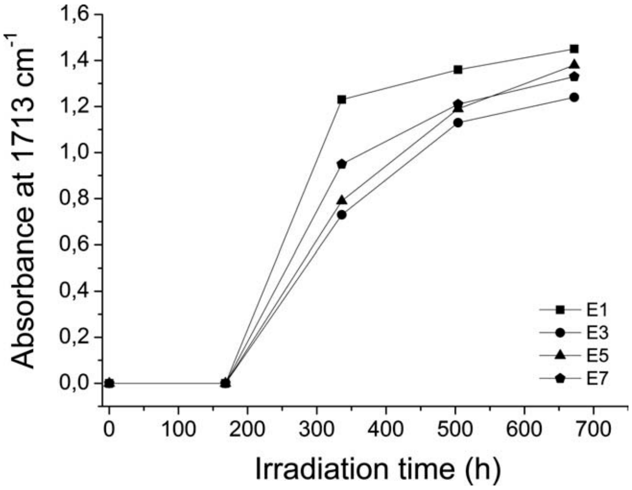


Figure 6 IR absorption of PC/ABS sample at 1713 cm^{-1} against irradiation time for T765 and different UV absorbers.

The absorbance at 1713 cm^{-1} against the irradiation time is depicted for samples E1, E15, E17, and E19 in Figure 8. It is seen that all the protected sample have same oxidation rate till an aging period of 336 h and thereafter E15 have slower rate of oxidation whereas E17 and E19 ends up with similar absorbance value.

In Figures 2–4 and 6–8 only those experiments are plotted where the concentration of UV absorber is 1 wt %. This is because an obvious trend in the protection against UV light for the PC/ABS blend is observed with higher concentration of UV absorber; therefore, the lower concentrations have less scientific and practical importance compared to the higher levels.

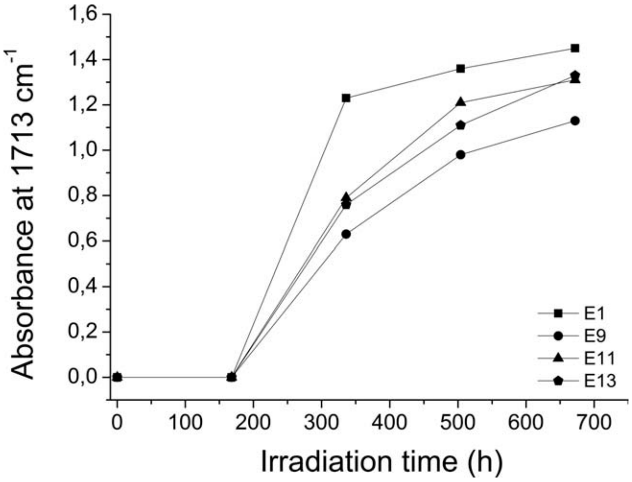


Figure 7 IR absorption of PC/ABS sample at 1713 cm^{-1} against irradiation time for T622 and different UV absorbers.

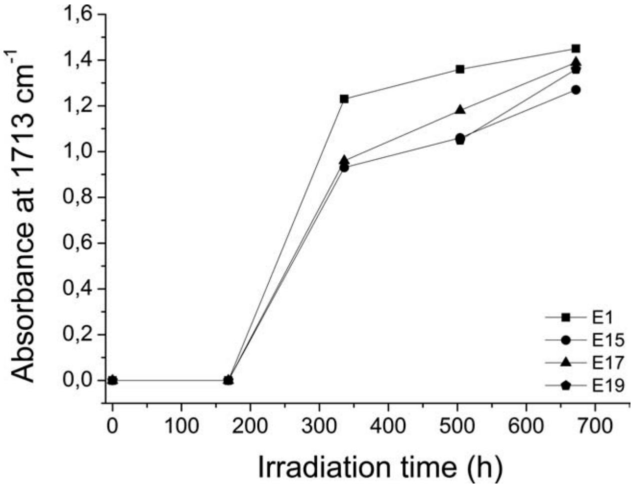


Figure 8 IR absorption of PC/ABS sample at 1713 cm^{-1} against irradiation time for different UV stabilizer/UV absorber combination.

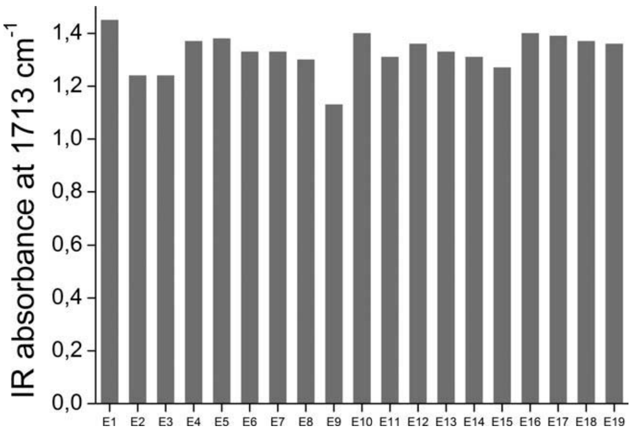


Figure 10 IR absorption of Suntest aged PC/ABS sample at 1713 cm^{-1} for different UV stabilizer/UV absorber combination at 672 h.

The absolute value of IR absorbance at 1713 cm^{-1} for the unstabilized and stabilized samples aged at 504 and 672 h in a Suntest XLS+ apparatus is shown in Figures 9 and 10, respectively. The concentration of UV absorbers in all cases is 1%. The maximum IR absorbance is observed for the unprotected sample in both cases. When PC/ABS film is protected with UV stabilizer/UV absorber combination a reduced oxidation is observed. The samples in which hydroxyphenyl triazine is used as the UV absorber show a better stabilization against surface oxidation for the PC/ABS samples compared to other samples. Sample E9 in which T622 and T1577 is used as UV stabilizer and UV absorber, respectively, shows the best result for resistance against surface oxidation in both 504 and 672 h aged samples. Surprisingly, in both cases, the effect of concentration of UV absorbers has no effect on T765 stabilized samples, however samples stabilized completely or partially with T622 shows concentration dependence with increasing amount of UV absorber. The concentration effect of UV absorber is more evident in samples where T622 is the lone UV stabilizer used.

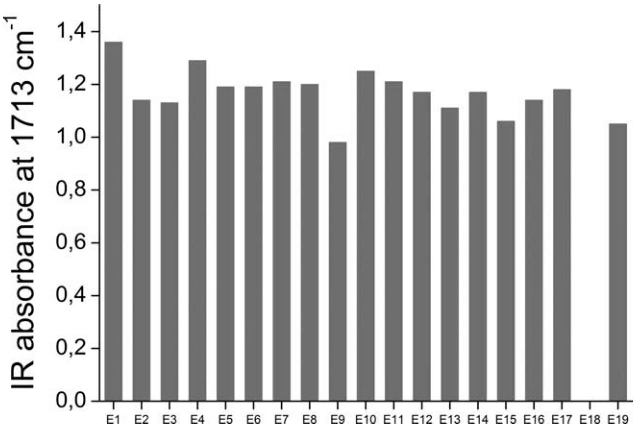


Figure 9 IR absorption of Suntest aged PC/ABS sample at 1713 cm^{-1} for different UV stabilizer/UV absorber combination at 504 h.

Yellowing index measurement

To compare the effect of the added stabilizers in the PC/ABS film, the yellowing index is measured. Yellowing index is a number calculated from spectrophotometric data that describes the changes in color of a test sample from white toward yellow. The test most commonly used to evaluate color changes in a material caused by real or simulated outdoor exposure, which causes photodegradation. In Figure 11 the delta yellowing index is shown for the unprotected and protected PC/ABS samples. The delta yellowing index is obtained by subtracting the yellowing index of the nonirradiated PC/ABS from the respective irradiated samples. The concentration of UV absorbers used is 1%. From this figure it can be

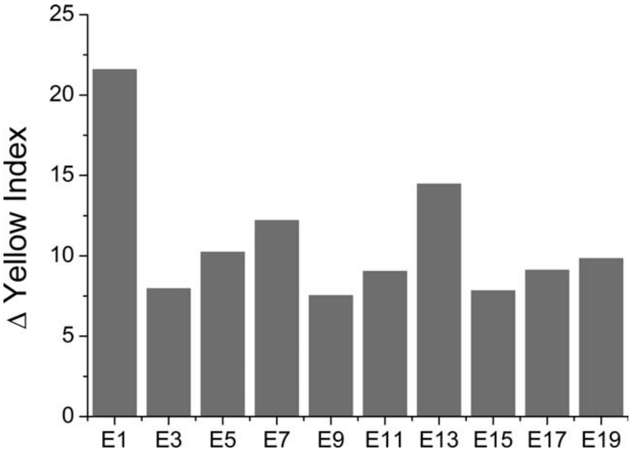


Figure 11 Yellowing index of Suntest aged samples as a function of different UV stabilizer/UV absorber combination.

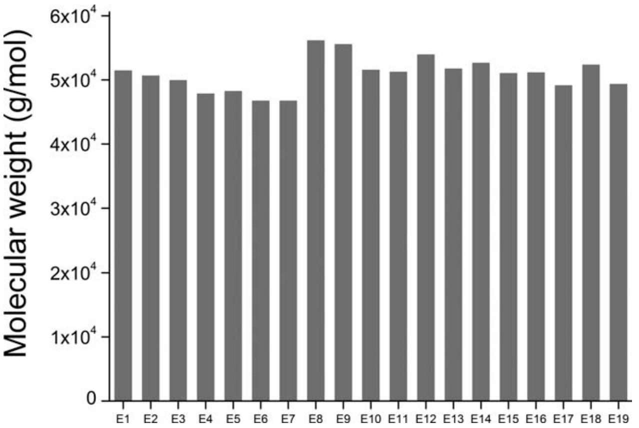


Figure 12 Molecular weight of unaged samples as a function of different UV stabilizer/UV absorber combination.

observed that the PC/ABS film protected with UV absorbers show less yellowing than the unprotected samples. Similar to the spectroscopic results hydroxyphenyl triazine, T1577, with T622 protected samples show the lowest yellowing index after an irradiation of 672 h in the Suntest XLS+ apparatus.

Molecular weight determination

Molecular weight, M_w of unaged PC/ABS samples and compounded with UV protectors is measured at different concentration and is depicted in Figure 12. It is surprising to see that in some cases the molecular weight of samples compounded with UV protectors are higher than that of pure PC/ABS sample. PC/ABS samples especially compounded with T622 show higher molecular weight than pure PC/ABS blend. The higher molecular weight of PC/ABS samples observed might be due to the better processing conditions offered by the oligomeric T622 stabilizer. Because of its oligomeric character it can act as a processing aid as well, which reduces the shearing force exerted on the polymer during compounding. It is also clear from the figure that, among UV absorbers, hydroxyphenyl triazine compounded samples accounts for the least decrease in molecular weight of PC/ABS samples during compounding.

The effectivity of hydroxylamine triazine-based UV absorber and oligomeric hindered amine UV stabilizer in the above experiments can be summarized as follows:

From literature[13] it is seen that the important step in the UV protection by UV absorber is the excited state intramolecular proton transfer (ESIPT) followed by radiationless deactivation processes. The structural element which is responsible for the electronic deactivation is the internal hydrogen bond. Therefore, a prerequisite for an efficient UV absorber is its intact intramolecular hydrogen bond and this depends on the chemical structure of the molecule.[12,1] From the X-ray crystal studies[22] it is found that the geometry of hydrogen bond bridge in hydroxyphenyl triazine is more stable than in other UV absorbers used in this research. A more stable intramolecular hydrogen bond is less likely to be broken and therefore hydroxyphenyl triazine acts as a better UV absorber than benzotriazole and cyanoacrylate.[23]

It is known that hindered amines cannot be used in polymeric substrates which are sensitive to chemical reaction with the basic nitrogen atom in the hindered amine. A severe reduction in mechanical properties is reported when hindered amines are incorporated into PC/ABS blend during the compounding stage as the hydrolysis reaction in PC is accelerated by the presence of weak bases such as HALS at elevated temperature.[24] The lower reactivity of Tinuvin 622 toward the polycarbonate phase compared to Tinuvin 765 is explained on the basis of the basicity of the stabilizers. The basicity, expressed by the pKa value, of hindered amine compounds has a strong influence on the hydrolysis of the PC backbone. It is reported that the hydrolysis of polycarbonate is fast under basic conditions and increases with the basicity.[14,25] Both Tinuvin 622 and Tinuvin 765 are tertiary amines but the basicity of both stabilizers is different. The basicity, pKa, of Tinuvin 765 and Tinuvin 622 is 9.0 and 6.5, respectively. Since the Tinuvin 765 has a higher basicity than the Tinuvin 622, it is able to hydrolyze the PC backbone to a higher extent than Tinuvin 622.

CONCLUSIONS

PC/ABS blend were compounded with three different UV absorbers and two UV stabilizers in different combinations to study the combined shielding efficiency of these absorbers and stabilizers against photodegradation. The UV absorbers used were hydroxyphenyl triazine, benzotriazole as well as cyanoacrylate and the UV stabilizers were monomeric and oligomeric hindered amines. Accelerated aging of compounded samples were done in an Atlas Suntest apparatus for 672 h. After aging, the degradation was studied using spectroscopic and chromatographic techniques. UV–vis, ATR-FTIR spectroscopic studies show that hydroxyphenyl triazine and oligomeric hindered amine contained samples were able to protect the blend against the harmful UV light than the other combinations of UV absorber and stabilizers. The blend surface studies done using ATR-FTIR shows that photo-oxidation was minimal with hydroxyphenyl triazine and oligomeric hindered amine. The results from the spectroscopic studies were confirmed by the yellow index measurement. The same orders of efficiency for UV absorbers and UV stabilizers obtained with the spectroscopic studies were found with the yellow index values. Molecular weight of the unaged PC/ABS blend was measured using GPC. It was observed that samples containing oligomeric UV stabilizers had higher molecular weight than samples containing no UV protectors. It was also found that hydroxyphenyl triazine contained sample had lowest molecular weight reduction among the PC/ABS samples with different UV absorber and stabilizers. Combination of different UV stabilizers brings no extra stabilization compared to the individual usage of the stabilizers together with UV absorber.

This research forms part of the research program of the Dutch Polymer Institute (DPI), project #613. The authors thank Dr. Jan Torfs for his valuable discussion.

References

1. Zweifel, H. Stabilization of Polymeric Materials; Springer-Verlag: Berlin Heidelberg, 1998.
2. Hrdlovic, P. Polym News 2004, 29, 187.
3. Pankasem, S.; Kuczynski, J.; Thomas, J. K. Macromolecules 1994, 27, 3773.
4. Rivaton, A. Polym Degrad Stab 1995, 49, 163.
5. Rivaton, A.; Sallet, D.; Lemaire, J. Polym Photochem 1983, 3, 463.
6. Lemaire, J.; Gardette, J. L.; Rivaton, A.; Roger, A. Polym Degrad Stab 1986, 15, 1.
7. Torikai, A.; Mitsuoka, T.; Fueki, K. J Polym Sci Polym Chem 1993, 31, 2785.
8. Shimada, J.; Kabuki, K. J Appl Polym Sci 1988, 12, 671.
9. Beavan, S. W.; Phillips, D. Eur Polym J 1974, 10, 593.
10. Scott, G.; Tahan, M. Eur Polym J 1977, 13, 981.
11. Diepens, M.; Gijsman, P. Polym Degrad Stab 2007, 92, 397.
12. Pickett, J. Polym Prepr 2001, 42, 344.
13. Lucarini, M.; Pedulli, G. F.; Lazzari, D.; Vitali, M.; Andrews, S. M. Macromol Chem Phys 2002, 203, 2239.
14. Gaines, G. L., Jr. Polym Degrad Stab 1990, 27, 13.
15. Rajan, V. V.; Steinhoff, B.; Alig, I.; Wäber R.; Wieser J. J Appl Polym Sci 2010, 118, 3532.
16. Rajan, V. V.; Steinhoff, B.; Alig, I.; Wäber, R.; Wieser, J. J Appl Polym Sci 2011, 119, 491.
17. Factor, A.; Chu, M. L. Polym Degrad Stab 1980, 2, 203.
18. Nagai, N.; Okumura, H.; Imai, T.; Nishiyama, I. Polym Degrad Stab 2003, 81, 491.
19. Diepens, M.; Gijsman, P. Polym Degrad Stab 2007, 92, 397.
20. Diepens, M.; Gijsman, P. Polym Degrad Stab 2008, 93, 1383.
21. Diepens, M.; Gijsman, P. Polym Degrad Stab 2009, 94, 34.
22. Stueber, G. J.; Kieninger, M.; Schettler, H.; Busch, W.; Goeller, B.; Frauke, J.; Kramer, H. E. A.; Hoier, H.; Henkel, S.; Fischer, P.; Port, H.; Hirsch, T.; Rytz, G.; Birbaum, J. L. J Phys Chem 1995, 99, 10097.
23. Woessner, G.; Goeller, G.; Rieker, J.; Hoier, H.; Stezowski, J. J.; Daltrozzo, E.; Neureiter, M.; Kramer, H. E. A. J Phys Chem 1985, 89, 3629.
24. Denisov, E. T. Polym Degrad Stab 1991, 34, 325.
25. Schaller, C.; Rogez, D.; Braig, A. J Coat Technol Res 2009, 6, 81.