

Lights out! The conservation of polypropylene wall tapestries

Thea B. van Oosten*, Irina Fundeanu*, Clementine Bollard, Cristina de Castro and Anna Laganà

ABSTRACT Polypropylene (PP) as a manmade fibre shows excellent properties in constituents of fabrics, upholstery and carpets. Many industrial uses involve ropes, woven and non-woven fabrics and reinforcements. Like many plastics, PP has virtually endless uses, and its development has not slowed since its discovery. However, this polymer is prone to degradation by photo-oxidation, especially by UV radiation. Earlier studies confirmed the rather fast degradation of PP to be less than 40 years in the work of modern arts. Two wall tapestries, *Fête I* (1969) and *Fête II* (1969), woven by the Dutch artist Wil Fruytier, consist of PP ropes. These works of art have been exposed to daylight and UV radiation for more than 30 years, resulting in degraded, brittle fibres. Due to the fact that the objects will remain exposed under non-museum conditions, conservation treatment is necessary to preserve these important elements of cultural heritage.

The aim of this study was to investigate the application of a light-stabilising system on PP. Moreover, the effectiveness in preventing photodegradation of this consolidant containing UV absorbers, heat stabilisers and light absorbers, was studied. PP is an inert polymer with a low surface tension that makes the adhesion of other substances very difficult; hence, a method to activate its surfaces was researched first. Corona treatment and atmospheric plasma pretreatment were used to investigate the increase in PP surface activity through electrical discharge. To apply consolidants on activated PP surfaces, nebuliser and airbrush spraying systems were compared to establish the most useful method. To verify the strength of the adhesion of the applied consolidants on PP, cross-cut tests according to ASTM D3359 were performed. An Atlas Xenotest Alpha chamber was used to artificially light-age PP test samples. Fourier transform infrared (FTIR) spectroscopy was used to follow photo-oxidation by measuring the carbonyl absorption during ageing. Burst tests on textile PP were performed to establish the effectiveness of the consolidant in protecting the PP surface from photo-oxidation.

Atmospheric air plasma proved to be the best surface activation pretreatment for PP and Plextol D 498, an acrylic emulsion, combined with Tinuvin B72 was confirmed as the best applicable consolidant with the airbrush being the most useful application method. Six hundred hours of artificial ageing of a consolidated PP surface in the Xenotest did not show any photodegradation; 600 hours of ageing is comparable to 150 years of museum conditions (at 200 lux). Before implementing the above-described conservation treatment on the two wall tapestries, it will be tested on mock-up tapestries made from PP ropes. This investigation is currently ongoing.

KEYWORDS polypropylene, synthetic fibres, cross-cut test, corona treatment, atmospheric plasma treatment, Fourier transform infrared spectroscopy (FTIR), artificial light ageing, burst test

Introduction

Works of art

Wil Fruytier (1915–2007), one of the pioneers of modern art wall tapestries in the Netherlands, made most of her work in the period between 1950 and 1980. Until the 1980s, textile works of art had a handcrafted image. ‘Textile art is sculpture art’ is a citation from the end of the 1970s. Artists who chose textile as one of the materials as a means of expression were

fighting for a place in the established art world. They regarded their works as expressions of conceptual art, for which not only the appearance and the technique, but moreover, the concept of the artwork is central.

Internationally, Wil Fruytier is known from 1961 onwards and her works were shown in Venice at the Biennale. She became known for her tapestries of ropes, for which she used both natural materials as well as polypropylene. Due to the large sizes involved, her work is often exposed in large spaces such as entrances of universities, hospitals and commercial banks; however, her works are also exhibited in museums (Megens 1991; Boot 2001).



Figure 1. Wil Fruytier, *Fête I* (1969) (ING Collection, The Netherlands).

Two works of art by Wil Fruytier, *Fête I* (1969) and *Fête II* (1969) were submitted to ICN to research the possibilities for conservation/restoration. The artwork *Fête I* belongs to the art collection of the ING bank in the Netherlands. This wall tapestry has always been exposed in the hall of a bank and was 'donated to science', i.e. to the conservation research department of the ICN in 2005 in order to investigate the possibility of conserving the artwork (see Fig. 1). The other artwork, *Fête II*, was acquired by the University of Nijmegen in the Netherlands in 1971. This tapestry is still exhibited and, for more than 36 years, has been exposed in the hall of the university.

Both works of art are the same size (355 × 250 cm) and were woven with black, white, yellow, orange and blue PP ropes. The ropes are made of slit film fibres and have all become brittle due to degradation (van Oosten *et al.* 2006). The white fibres, containing titanium dioxide (TiO₂), are the most seriously degraded; the yellow, orange and blue fibres are moderately degraded. The black fibres are in a rather good condition due to the fact that black pigments have an inhibitive effect on photo-oxidation (Davis and Sims 1986). Pigments are most effective ultraviolet (UV) absorbers and a concentration of 5% of various organic and inorganic pigments has been found to restrict degradation of PP to surface oxidation, thus increasing the time to failure (Davis and Sims 1986). However, the white ropes used for the warp are in a good condition, being protected from light and UV radiation by the coloured weft ropes. In total, the whole reverse sides of both tapestries are in a good condition because these sides were never subjected to light and UV radiation.

Polypropylene

Polypropylene, a highly crystalline thermoplastic polymer, is produced by the chain growth polymerisation of propylene, a gas obtained from petroleum cracking. PP can be produced with different molecular chain structures under controlled conditions (stereo-specific) but only the 'isotactic' form, in which the methyl side groups are arranged on the same side of the polymer chain, is produced in large quantities.

Isotactic polypropylene was successful from the early 1960s due to the new catalysts for polymerisation developed by Ziegler and Natta in 1954 (Brydson 1999). It became an important plastic being used in many different forms and applications through a range of manufacturing processes. A large proportion of PP is used in fibres as constituents of fabrics, upholstery and carpets. Many industrial uses involve ropes, woven and non-woven fabrics and reinforcements. PP is the lightest (0.91 g/cm³) and has the lowest moisture absorption of all manmade fibres. Dirt will not penetrate the fibre and can easily be removed from the surface. PP fibres have the same tensile strength wet or dry and are also highly resistant to acids and alkalis and to most organic solvents. The fibre does not rot and is not easily attacked by microorganisms or moulds.

Since the 1980s the production, consumption and applications of this polymer have increased through the application of even more efficient catalysts and property enhancements and today PP is the most common fibre used all over the world. The usefulness of PP depends on the retention of its properties during a prolonged service life. For instance, under mild conditions, unstabilised PP will retain its properties for long periods of time. However in most applications, exposure to heat and light will occur which accelerates oxidative degradation. The properties that make PP widely used as a fibre do not prevent the fibre from deteriorating over time when exposed to daylight and UV radiation (Lemaire *et al.* 1988).

Photo-oxidation

Polypropylene is highly sensitive to the incident UV part of the sun's radiation in the region 290–400 nm, which is responsible for the radiation-induced polymer photo-oxidation (Al-Malaika 1999). PP absorbs wavelengths above 285 nm due to absorbing impurities, particularly oxygen-containing species and trace levels of metals and other species present arising from production processes such as polymer manufacture, melt processing and fabrication. These impurities accelerate PP photodegradation under service conditions involving exposure to light.

The oxidation process of hydrocarbons is a free radical chain process characterised by three steps: initiation, propagation and termination. Free radicals that are formed during the initiation and propagation steps may undergo further reactions with atmospheric oxygen leading to insertions of various oxygen-containing groups, which will lead to changes in the physical characteristics of the bulk polymer (van Oosten *et al.* 2006).

Photo-oxidation of PP causes a development of surface cracks, discoloration, darkening and a decrease in molecular

weight which results in gradual loss of mechanical properties and, ultimately, embrittlement. The outdoor performance or performance under non-museum conditions can be improved by the appropriate choice of photo-stabilisers, used either separately or in synergistic combinations.

Light stabiliser system

Ultraviolet light absorbers function by absorbing harmful UV radiation and dissipating it as thermal energy. The stabilisers function according to Lambert Beers law, which specifies that the amount of UV radiation absorbed is a function of both sample thickness and stabiliser concentration (Allen 1985). High concentrations of absorbers and sufficient thickness of the polymer are required before enough absorption takes place to effectively retard photodegradation. Hindered amine light stabilisers (HALS) are extremely efficient stabilisers against light-induced degradation of most polymers. They do not absorb UV radiation, but act to inhibit degradation of the polymer. Significant levels of stabilisation are achieved at relatively low concentrations. The high efficiency and longevity of HALS are due to a cyclic process wherein the HALS are regenerated rather than consumed during the stabilisation process. Hindered amines and light absorbers are used in combination to provide a level of stability which is higher than would be provided by using either type of stabiliser by itself. Such combinations are effectively used in many plastics. Stabilising of PP can be achieved best using a three-component system containing a phenolic antioxidant, a UV absorber of the benzotriazole type and a light protection agent such as a steric hindered amine.¹ Research has shown that a three-component system has better workability than the sum of the separate components due to synergistic working of the system.

Research

The aim of this study is to develop a conservation method by researching the effectiveness of the application of a light-stabilising system composed of a protective layer of consolidant containing UV-absorbers, heat stabilisers and light absorbers on PP, which will inhibit degradation. PP as a result of its hydrophobic property is very inert and has quite a low surface energy (30 mJ/m²). To obtain optimum adhesion, it is often necessary to increase the surface energy of the substrate to just above that of the material to be applied. A normal adhering bonding requires about 60 mJ/m². In order to apply a UV-protective coating, a physical surface treatment of PP is needed. Corona and atmospheric air plasma treatments are simple physical treatments commonly used in industry to improve adherence and printability. These systems lead to oxidising effects of the non-polar substrate and create carbonyl, carboxyl and hydroxyl groups at the surface which are polar and partly chemical reactive. Corona and atmospheric air plasma treatments result in good surface wettability of the material leading to an increase of the surface energy and a better adhesion of the UV-protecting coating.

Corona treatment

Corona treatment is an electrical process that uses ionised air to increase the surface tension of non-porous substrates. A corona treatment system consists of two electrodes of which one is connected to a high-voltage source. The high voltage causes ionisation of air, and a discharge is produced between the electrode; a purple-blue colour can be observed in the air gap (see Fig. 2).

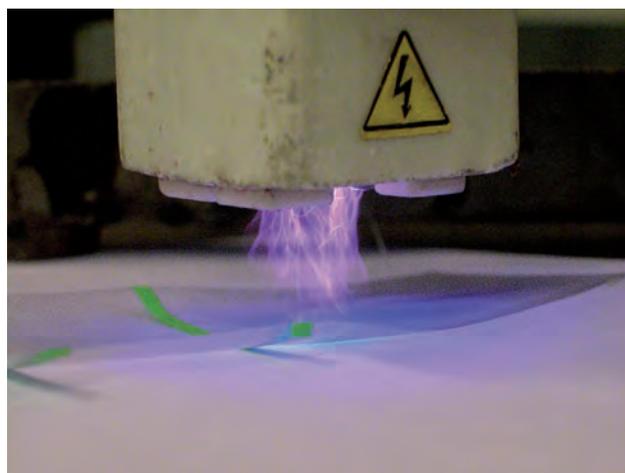


Figure 2 Corona treatment.

The surface properties of the treated films are related to the normalised energy (E) which can be determined from the net power and the film velocity: $E = P/wv$ where P is the net power, w is the electrode width, and v is the film velocity. The typical unit for E is J/cm² or mJ/m². Electrons, ions, excited neutrals and photons that are present in the discharge can react with the PP surface to form radicals. These radicals react rapidly with atmospheric oxygen and hydroperoxide is formed. The decomposition of the hydroperoxide groups produce oxygen functional groups on the surface including C-OH, C=O and COOH. The amount of oxidised materials created on corona-treated polypropylene surfaces increases as the energy input to the corona increases.



Figure 3 Atmospheric plasma treatment.

Atmospheric air plasma treatment

Like corona, plasma is the electrical ionisation of a gas. The plasma (glow) discharge creates a smooth, undifferentiated cloud of ionised gas with no visible electrical filaments. Variables for the treatment are the air to gas ratio, air and gas flow rates, the distance between the tip of the flame and the surface of the object to be treated, the nature of the gas, and the treatment time (see Fig. 3). Corona and plasma treatments produce approximately the same O/C ratios on the surface (Chi-Ming Chan 1999).

Substrates that have been plasma treated hold their treatment levels far longer than corona-treated surfaces. Films, foams, non-wovens as well as fibres are suitable for plasma surface treatment; thicker substrates, which do not usually respond well to the corona process, can also be treated by plasma.

Materials and methods

Test samples

Polypropylene test samples (24 × 8 cm) of white PP fabric, rough transparent PP film (4 µm), smooth transparent PP film (13 µm) and grey-coloured PP film (18 µm) were corona or atmospheric plasma treated, consolidated and artificially light aged. During ageing, at different intervals, test samples were examined to detect changes in visual and mechanical characteristics. Test samples were therefore observed using light microscopy (LM) and submitted to burst testing and cross-cut testing.

To record the changes in chemical microstructure occurring during the ageing process (build up of carbonyl, hydroxyl functions during photo-oxidation) of PP, FTIR spectra were taken at different intervals.

Corona and atmospheric plasma treatment

In order to remove dust particles and other contaminants such as finger grease, the surfaces of PP transparent films were cleaned with PFQD, a degreasing solvent based on liquid hydrocarbons, and dried in air. The cleaned surfaces were subjected to corona or atmospheric plasma treatment at different time intervals and different distances from the plasma guns. The white PP fabric test samples were surface activated without pre-cleaning.

Contact angle measurement

The PP test samples were characterised prior to and after corona and plasma treatment by means of water contact angle measurements. Advancing water contact angles were measured at room temperature with a Krüss DSA-10MK2 drop shape analysis system. The drop size was 0.5 µL which was kept constant for all measurements. All angles reported

are averages over three separately prepared samples, while on each sample three droplets, placed at different positions, were measured. A sample table moves the sample to the right position. Single or double dosing systems deposit the drop on the surface. Illumination and image zoom ensure optimal drop presentation. The camera records the digital image and allows perfect drop shape analysis. Contact angle and surface free energy can be calculated by software.

Consolidants and application methods

For this research, various acrylic consolidants with added UV-light stabiliser systems were tested: Ciba Tinuvin B75, a liquid light stabiliser system consisting of a synergistic blend of Ciba Irganox 1135, Tinuvin 571 and Tinuvin 765, soluble in organic solvents; Ciba Tinuvin 770, a low molecular weight hindered amine light stabiliser, soluble in organic solvents and methanol; Ciba Chimassorb 2020, a hindered amine stabiliser soluble in organic solvents; ethanol/water (95/5) and isopropanol (see Tables 1 and 2). The applicability of the consolidating agents on the polypropylene fibres was tested using a nebuliser and an airbrush system.

Results and conclusion

Surface activity

Contact angle measurements were performed following atmospheric plasma treatments on PP both on smooth and rough film surfaces. The surface hydrophilicity is clearly improved with the irradiation time of corona or plasma treatment. PP is a hydrophobic polymer with a water contact angle of about 80 degrees. Upon pretreatment with corona or plasma, the water contact angle of the PP decreases considerably and the most hydrophilic surface was obtained after 20 seconds of irradiation, when a visible improvement of the adhesion of water droplets was also observed. However, as no significant differences in contact angle values were obtained when treating the test samples for 15 or 20 seconds, an irradiation of 15 seconds is recommended in order to prevent surface deterioration. The small water droplets on non-treated PP were unable to remain on the surface after tilting the PP at an angle of 90 degrees, however after plasma or corona treatment at 20 mm either for 15 or 20 seconds, the water adhered to the textile and could only be removed by shaking.

Cross-cut tape test

The adherence of the applied light stabiliser system was tested using the cross-cut test according to ASTM D3359-95a. Test samples, I.4, I.5, I.6 (surface activated using corona) and test samples I.9 and I.16 (no surface activity treatment) were chosen. Only the activated test samples showed good adherence (2B, 3B), while non-activated samples had no adherence at all (0B).

Table 1 PP test samples (first series).

Sample nos. Series I	Light stabiliser system	Application method/ consolidating agent	Corona treatment	Artificial light ageing (hours)	Cross-cut test according to ASTM 3359-95a	Visual and mechanical characteristics after artificial light ageing
I.1 transparent film	n.a.	blank	yes	310		upper part: warping and brittle; middle and under part protected from light by sample I.2
I.2 grey film	n.a.	blank	yes	310		no visual degradation phenomena
I.4 grey film	Plextol B 500 (10%)/Tinuvin 770 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/2 layers/1 layer	yes	310	2 layers = 3B/1 layer = 2B	discoloration of the middle part
I.5 transparent film	Plextol B 500 (10%)/Tinuvin 770 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/2 layers/1 layer	yes	310	2 layers = 3B/1 layer = 2B	upper part (Blanco) more translucent; middle and under part becoming less white
I.6 grey film	Plextol B 500 (10%)/Tinuvin 770 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/2 layers/1 layer	yes	310	2 layers = 3B/1 layer = 2B	discoloration in the middle part of all three areas
I.7 white PP fabric	Plextol B 500 (10%)/Tinuvin 770 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/2 layers/1 layer	yes	310		Blanco part powdery; 1 layer and 2 layers slightly discoloured
I.9 grey film	Plextol B 500 (10%)/Tinuvin 770 (5%)/water (42.5%)/ethanol (42.5%)	1 layer/ 2 layers/3 layers	no	unaged	1 layer = 0B/2 layers = 0B/3 layers = 0B	
I.11 transparent smooth sheet	Plextol B 500 (10%)/water/ethanol	Blanco/1 layer/2 layers	no	310		all parts start to become brittle
I.13 grey film	Plextol B 500 (10%)/Tinuvin B 75 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/ 1 layer/2 layers	no	310		discoloration
I.14 transparent film	Plextol B 500 (10%)/Tinuvin B 75 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/1 layer/2 layers	no	310		becoming more matt
I.15 transparent film	Plextol B 500 (10%)/Tinuvin B 75 (5%)/water (42.5%)/ethanol (42.5%)	1 layer/2 layers/3 layers	no	310		becoming more matt
I.16 grey film	Plextol B 500 (10%)/Tinuvin B 75 (5%)/water (42.5%)/ethanol (42.5%)	Blanco/2 layers/3 layers	no	unaged	2 layers = 0B/3 layers = 0B	
I.20 transparent	Paraloid B 72 (8%)/toluene	Blanco/1 layer/2 layers	no	310		becoming more matt and opaque

Visual characteristics

Corona surface-treated test samples without a light stabiliser system (blank test samples) totally crumbled and became brittle after 310 hours of artificial light ageing (see Fig. 4, test sample 1). Test samples treated with only Plextol B 500, without corona surface treatment did not prevent photo-oxidation; the PP sheet was brittle and breakable after 310 hours of light ageing (see Fig. 4, test sample 11). Corona surface treatment and applying the light stabilising system Tinuvin B75 with Plextol B 500 did prevent the PP sheet from oxidation (see Fig. 4, test sample 5). After 310 hours of light ageing, only the light stabiliser system (Tinuvin B75 with Plextol D498) applied on the test samples remained transparent. The light stabiliser system (Tinuvin 770 and Plextol D498) and (Tinuvin B75 and Plextol B 500) became opaque after ageing.



Figure 4 PP test samples, artificially light aged.

A series of test PP sheets (13 μm) activated by atmospheric air plasma treatment, consolidated using the light stabiliser system Plextol D498 with 10% Tinuvin B75 and two different consolidating techniques, the airbrush and the nebuliser, gave the following results. For better workability with the light stabiliser system, the solutions were diluted (50%). After 634 hours of light ageing the blank series became brittle. These results are due to the film thickness of 13 μm of these test sheets, providing longer resistance to UV radiation before they become totally brittle than the thinner sheets from the first test series. No brittleness was observed on the PP test sheets consolidated with the light stabiliser system Plextol D498 combined with Tinuvin B75; moreover the test film also remained transparent (see Table 2). Microscopic observations show that the surface of the treated PP film is

more homogeneous when the protection layer is applied with the airbrush.

Burst test

Changes in physical properties (molar mass, mechanical properties, time to embrittlement) were observed using the burst test on consolidated and non-consolidated white PP fabric. According to the results of the burst test, the airbrush application of the light stabilising system gave a better result than test films with the nebuliser application. The samples with two layers of the light stabiliser system containing Plextol D498 with Tinuvin 75 B solution applied with the airbrush provided the best results (see Table 2 and Fig. 5).

Table 2 PP test samples (second series).

Sample nos. Series II	Application method/ consolidating agent (layers)	Plasma treatment	Artificial light ageing (hours)	Visual and mechanical characteristics	Burst test (kPa) on white fabric	Carbonyl index A 1711/A1890
II.2 white PP fabric	airbrush (2 layers)	yes	307	surface not brittle after ageing	320/463	
II.3 white PP fabric	airbrush (2 layers)	yes	475	surface not brittle when touched	103/164/121	
II.7 white PP fabric	nebuliser (2 layers)	yes	307	brittle surface when touched	106/108	n.a.
II.8 white PP fabric	nebuliser (2 layers)	yes	475	surface totally brittle when touched	25/24	n.a.
II.11 transparent smooth sheet	airbrush/Blanco/1 layer/2 layers	yes	643	brittle		6.36
II.12 transparent smooth sheet	airbrush/Blanco/1 layer/2 layers	yes	unaged			1.76
II.13 transparent smooth sheet	nebuliser/Blanco/1 layer/2 layers	yes	643	brittle		6.36
II.14 transparent smooth sheet	nebuliser/Blanco/1 layer/2 layers	yes	unaged			1.76
II.15 white PP fabric	no treatment/Blanco	no	307	surface is brittle when touched	100/103	n.a.

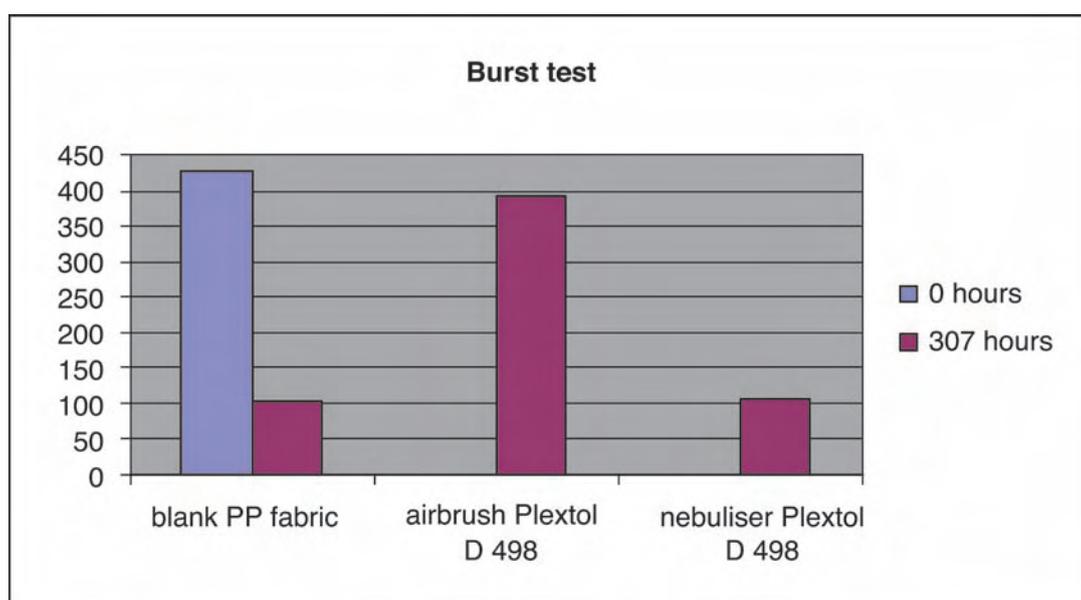


Figure 5 Burst test.

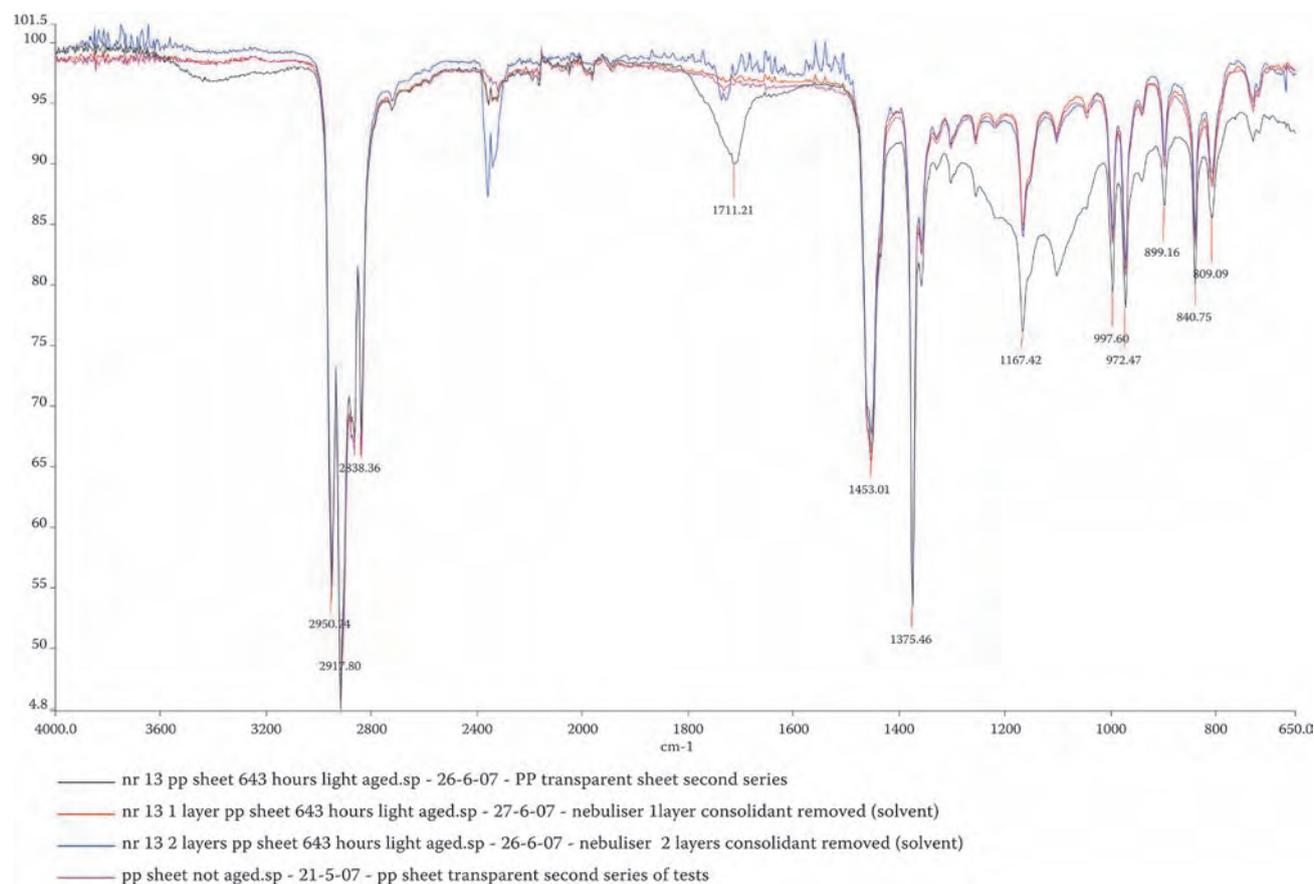


Figure 6 FTIR spectra of artificially light aged PP samples, treated and light stabilised.

Fourier transform infrared spectroscopy

FTIR spectra were recorded of all test PP samples that were artificially light aged, surface activated and consolidated with a light stabiliser system as well as the non-treated test PP samples. Infrared spectra of all artificially light-aged PP test samples showed the presence of carbonyl (C=O), hydroxyl (C-OH) and ester (C-O-C) functional groups (see Fig. 6).

The increase of photo-oxidation was determined by calculating the relative absorbance (A_{1711}/A_{1850}), which is the intensity of the absorption peak at 1711 cm^{-1} (A_{1711}) divided by the intensity of the absorbance at 1850 cm^{-1} (A_{1850}). The degradation, due to photo-oxidation, of all PP test samples surface treated and protected with a light stabiliser system, expressed as the relative absorbance (A_{1711}/A_{1850}) was plotted against ageing in hours (see Fig. 7).

Test PP samples of untreated white fabric and smooth transparent film showed that PP was oxidised during ageing (see Fig. 7). The PP surface of the untreated transparent smooth film was oxidised after 600 hours of ageing, having a carbonyl index of 6.4, at which point the PP sheet became completely brittle. Test PP samples (11 and 13) treated with atmospheric air plasma, consolidated with the light stabiliser system Plextol D 498 (5%) and Tinuvin B75 (2.5%), applied by

either the airbrush or the nebuliser, showed a carbonyl index of 1.8 meaning that no PP oxidation had taken place under the protective layer (see Fig. 7). The absorbance was measured in a small area under the protective layer after removal of the consolidating layer with alcohol.

Discussion

Corona as well as atmospheric plasma treatment of PP test samples, prior to immediate consolidating with a layer of a light stabiliser system, provided good adhesion of this layer and the PP surface. Protection against photo-oxidation was established and confirmed by the results from the burst tests and the FTIR spectra: no oxidation was observed underneath the protection layer, while unprotected PP sheet degraded until brittleness.

The light stabiliser system (5% Plextol D498, 2.5% Tinuvin B75, 12.5% water and 12.5% ethanol) gives the best result. Applying this layer with an airbrush proved to be more workable, resulting in more even distribution on the activated PP surface. Future research will focus on longer artificial ageing and on the application method of the light stabiliser system on a mock-up tapestry, before applying it on the two artworks.

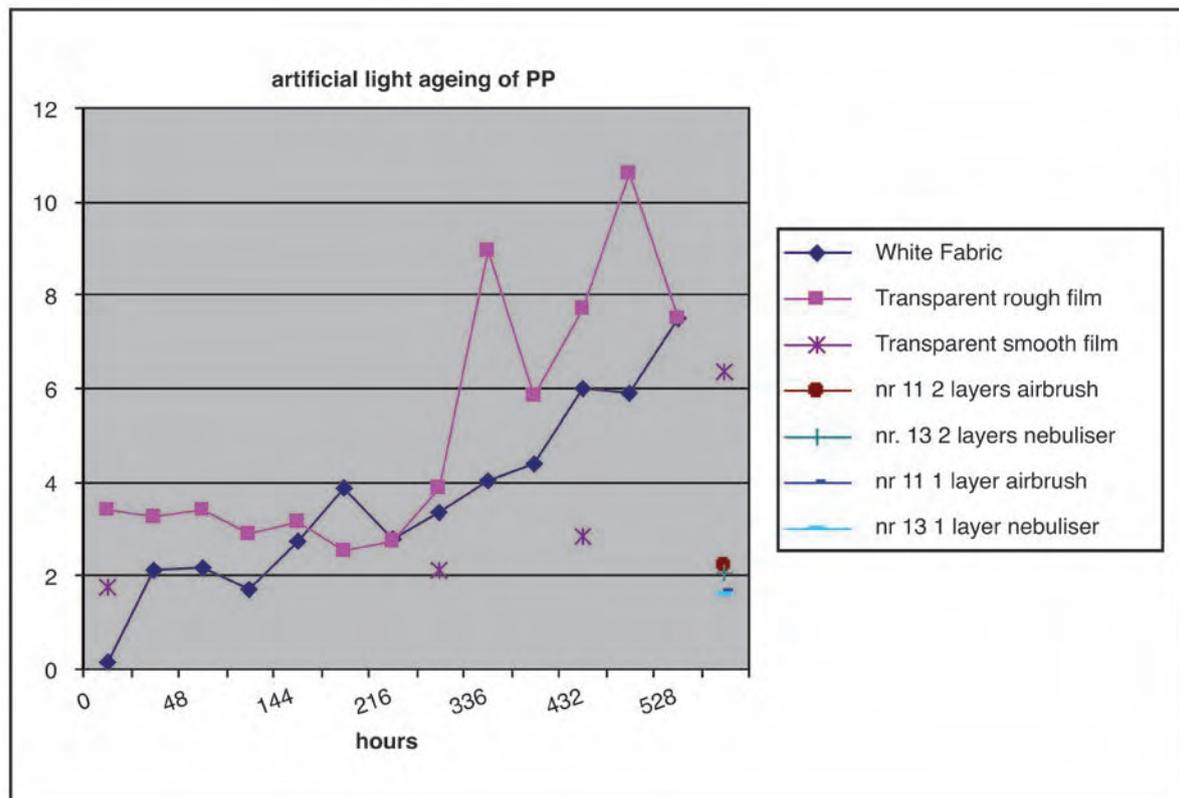


Figure 7 Carbonyl index of artificially light aged PP samples.

Appendix

Corona discharge

The corona discharge experiments were performed using a corona discharge gun (Tigres GmbH, Rellingen, Germany) at atmospheric pressure. The samples were placed underneath the equipment at a distance of 2 cm for one minute at each 4 cm².

Atmospheric plasma

The air plasma experiments were performed at atmospheric pressure using a plasma-blaster (Tigres GmbH, Rellingen, Germany) equipped with three separated plasma guns. Plasma is supplied and controlled by a 300 W power generator. The pressure needed to produce stable and uniform plasma was 4 bars at a gas consumption of 17 litres/minute. The degreased samples were placed underneath the plasma guns and to obtain a complete and homogeneous surface activation, the samples were moved constantly underneath the plasma guns.

Nebuliser

An air pressure nebuliser (Inhalations-set VE 125, Medisize) developed for medical treatment allowing the size of the droplets to be regulated at about 10 µm was used (van Oosten *et al.* forthcoming). The nebuliser is placed very close to the PP surface with a pressure of around 2.5–3.

Airbrush

An airbrush, a compressed air tool that dispenses a fine mist of consolidant, was used. For both application techniques, the advised air pressure of about 2 bars was provided by an air compressor (Whispair, CW 50/24 AL) (Pataki *et al.* 2003). The airbrush was used at the distance of around 20 cm with pressure of 2.5 bars. The small screw that sets the entering of the air pressure has to be turned (1 turn) clockwise.

Cross-cut tape test

Adhesion testing was performed after the consolidation process. This cross-cut tape test will quantify the strength of the bond between a PP surface and a coating. With this test method the resistance of a coating to separate from a substrate, when a right-angled lattice pattern is cut into the coating through the substrate, is assessed. Detachment with Scotch tape of the coating is classified using a visual standard according to ASTM D3359-95a.

Burst test

An automatic, digital burst tester (Model BT-10, Tappi T-403 method) for use on paper, paperboard and corrugated board was used to measure the decrease in strength after artificial light ageing of the white PP fabric test samples. Using this method, the white fabric PP sample is clamped between two standard ring clamping surfaces and hydraulic force is exerted against the bottom of the sample until it fails. The maximum pressure exerted at failure is the test result.

Light microscopy

The surfaces of consolidated textile fabric test samples using the airbrush and nebuliser were examined at a 100× magnification by LM using a Zeiss Axioplan 2 imaging microscope equipped with a AxiaCam MRc digital camera (1388–1040 pixels).

Fourier transform infrared spectroscopy

To study molecular changes due to photo-oxidation, FTIR spectra were obtained of plasma or corona surface activated test samples as well as consolidated, not consolidated, aged and unaged test samples. Spectra were recorded from 4000 to 600 cm⁻¹, with 40 scans at a resolution of 4 cm⁻¹ using a Perkin Elmer Spectrum 1000 FTIR spectrometer combined with a Golden Gate single reflection diamond ATR unit (sample size 0.6 mm²).

Artificial light ageing

Test samples (both impregnated and not impregnated) were artificially aged in a Xenotest, Alpha High Energy (Atlas), and exposed to the radiation of a filtered xenon-arc lamp (105 Klux, T 50 °C, 40% RH) for up to 643 hours to induce photo-oxidation.

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Note

1. Ciba Specialty Chemicals Inc., www.cibasc.com.

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