

Role of Sand on Curing of Partex Surface by UV Radiation

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ABSTRACT: A partex surface was modified by a UV-curing system with epoxy acrylate (EB-600). A set of formulations was prepared with oligomer and the trifunctional monomer trimethylol propane triacrylate in different combinations of percentages (1–5%) of sand to study the role of sand in various physical properties of UV-cured thin films, as well as partex surfaces. Increased pendulum hardness (PH), gloss, adhesion, and abrasion values were obtained by the addition of sand into the partex surfaces. The best results were obtained with the formulation containing 3% sand. An

enhanced PH and a decreased percentage of gel content of the UV-cured film was observed with an increase of the sand concentration. A simulated weathering test was performed with partex surfaces cured by a formulation containing 3% sand in the base coat. The losses of the physical properties were found to be lower over the surface treated with the formulation containing sand. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 86: 2385–2392, 2002

Key words: sand; curing; partex; UV radiation

INTRODUCTION

Radiation curing is well known to be one of the most efficient methods for producing highly crosslinked glossy and abrasion resistant surfaces^{1,2} because insoluble polymers are readily formed by this technique. Because of its distinct advantages, this technology has found a large number of industrial applications, in particular for the surface protection of different materials by polymeric formulations. The recent surge in applications of UV-induced photopolymer ions is motivated by at least two factors such as environmental concerns about the production of volatile organic emissions and the need for a high-speed reaction to enhance production rates. Recently, most of the work on UV-initiated photopolymerization was focused on a free-radical system based primarily on acrylate monomers. These monomers polymerize rapidly and are easily modified at the enter functionality, allowing materials with a variety of properties to be obtained.³

Silicones provide excellent temperature, chemical, moisture, and environmental resistance; good electrical performance; and high ionic purity. These properties make them ideal for many coating and potting applications. The inherent properties of silicone materials are low surface energy, low intermolecular attraction, and large molecular free volume. Silicon acrylates combine the favorable material properties of silicones and the fast crosslinking rates of acrylates. The

drawback of such silicon derivatives is their high oxygen permeability.⁴ Considerable success was realized in crosslinking of polymers by modifying the macromolecules to incorporate active groups such as organofunctional silanes, which in the presence of water produced a crosslinked product.⁵ After the end product is fabricated the crosslinking is attained through hydrolysis that results in the formation of Si—O—Si bridges by the combination of two or more pendant silane groups. The use of silanes as adhesion promoters in polymer industries represents a relatively low-tech approach to obtaining material improvement in the initial and wet adhesion of adhesives and coatings and improved physical properties in some composites.⁶ However, the relatively low-tech requirements, principles of use, and technology must be understood or the use of silane may result in market deterioration in those properties, which we seek to improve.

Partex is made of jute stick; urea formaldehyde resin is used as a binder. Jute stick is a complex biopolymer composed of polysaccharides, which are principally cellulose and the aromatic polymer lignin. It is obtained from a renewable resource and may be aesthetically pleasing. However, jute stick is much more easily degradable by environmental affects, including fire, biological organisms, water, and light, than human-made materials. Because of the scarcity and high cost of wood and particleboard, partex is now used as an alternative furniture material. Work was done to improve the partex surface using fillers.⁷ The present article covers some aspects of the use of sand (SiO₂) as a promoter of different physical properties in the improvement of the partex surface by UV radiation.

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TABLE I
Composition of Different Formulations (% w/w)

Chemicals	Formulations						
	M1	M2	M3	M4	M5	M6	M7
Oligomer	50	18	48	48	48	48	48
TMPTA	48	79	47	48	47	46	45
Sand (SiO ₂)	—	—	1	2	3	4	5
IRG-369	2	2	2	2	2	2	2
MEK	—	1	—	—	—	—	—

EXPERIMENTAL

Epoxy diacrylate (EB-600) oligomer, a Radcure Product, was procured from Drogenbas. It is almost solid at room temperature, so the compound was diluted with monomer. Trimethylol propane triacrylate (TMPTA, glass-transition temperature of 250°C) was obtained from Radcure. Methyl ethyl ketone (MEK) was purchased from Merck and was used as an antibubbling agent. Sand (SiO₂), which acts as a filler, was procured from a local market. Irgacure 369 (IRG-369, Ciba-Geigy) was used as the photoinitiator. The partex (substrate) was bought from a local market.

Different formulations (Table I) were developed with the oligomer EB-600 in the presence of reactive TMPTA diluents. A fine powder sand filler, the antibubbling agent MEK, and the photoinitiator IGR-369

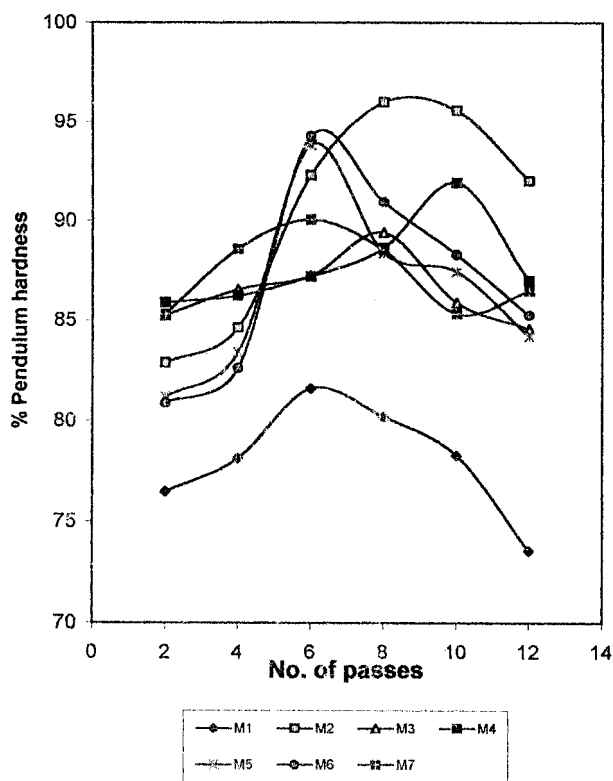


Figure 1 The pendulum hardness of UV-cured films versus the number of passes under the UV lamp as a function of the concentration of sand.

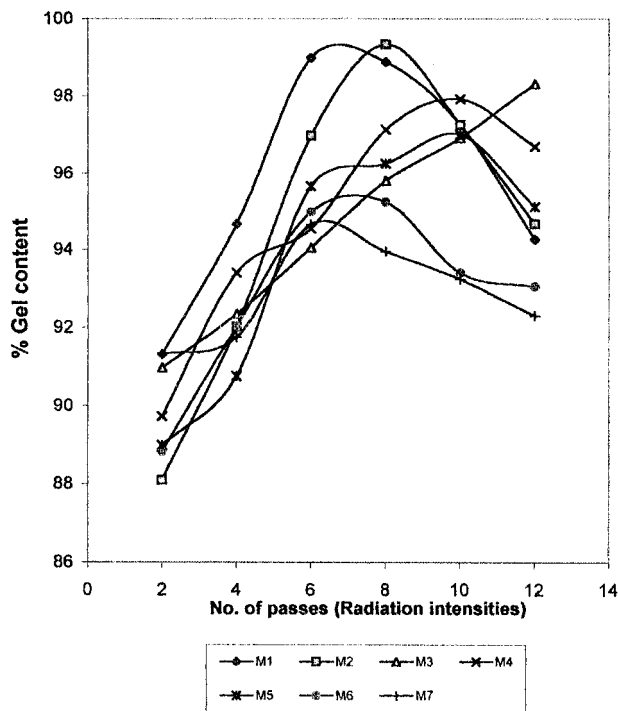


Figure 2 The gel content of UV-cured films versus the number of passes under the UV lamp as a function of the concentration of sand.

were also included in the solution in the proportions mentioned in Table I. The formulated solutions were applied onto a clean glass plate (4 × 4 in.) using a number 0.0018 draw down bar (Abbey Chemicals Co.) in order to prepare thin polymer films and onto the surface of the polished partex substrate (4 × 4 in.) in order to improve its surface by producing a thin polymer film. The coated glass plate and partex were passed through UV radiation under a 2-kW UV lamp (254–313 nm wavelength) using a UV minicure machine (IST-Technik) at a conveyor speed of 4 m/min. The minicure has the efficiency of ±1%. The cured films and partex substrates were then subjected to various characterization tests after 24 h of radiation. The surface hardness of the UV-cured films and coated partex substrates were determined by a digital pendulum hardness (PH) tester (model 5854, BYKE, Labotron). The micro- and macroscratch hardness test was performed using a universal hardness tester (model 413/E, Erichsen, GMBHS Co.). The indent length, indent depth, Buchholz resistance, and adhesion (percent chipped off area) were determined with a PIG universal hardness tester (model 3410, BYKE, Labotron). The adhesion strength in terms of force required to pull out the coating from the coated surface was measured with an adhesion tester (model 525, ASTM D 4541, Erichsen). The surface gloss was determined at angles of 20° and 60° of the plane of the coated surface with a digital microgloss meter (Sheen-155). In order to determine the gel content, the UV-

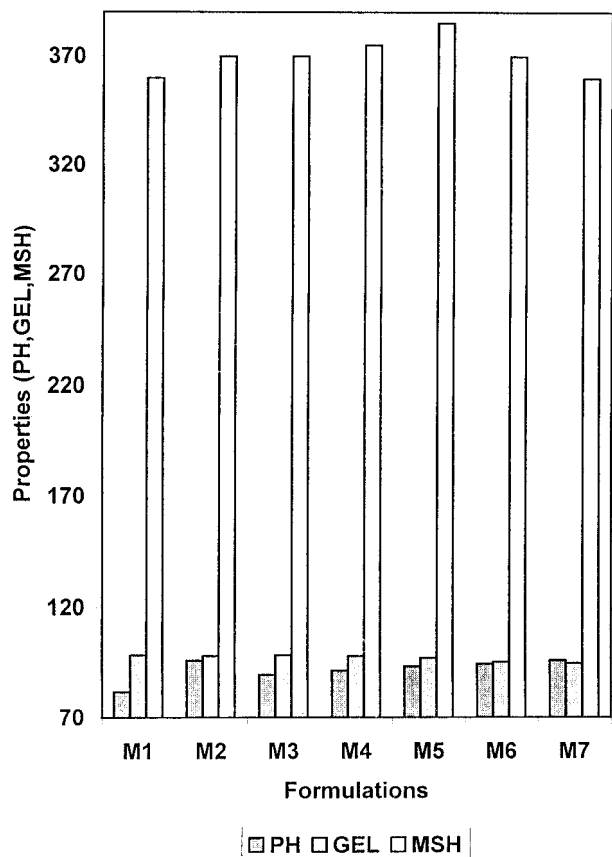


Figure 3 The properties (PH, gel, and macroscratch hardness) of UV-cured films versus the formulations under the UV lamp as a function of the concentration of sand.

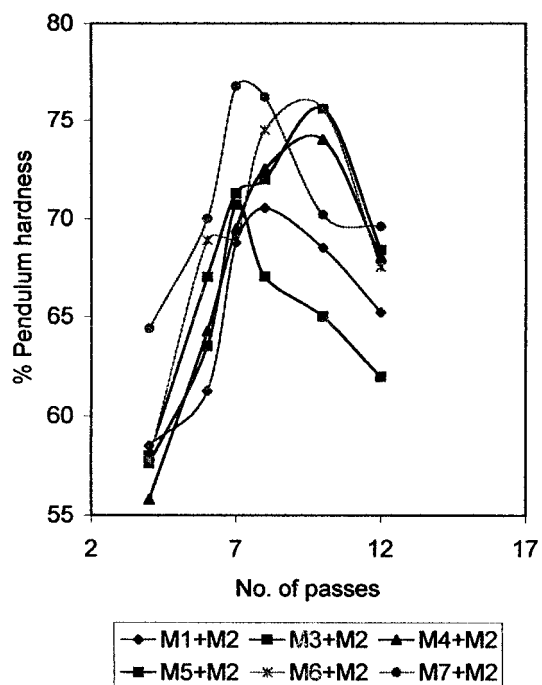


Figure 4 The pendulum hardness of UV-cured polymer coatings on partex versus the number of passes under the UV lamp as a function of the concentration of sand.

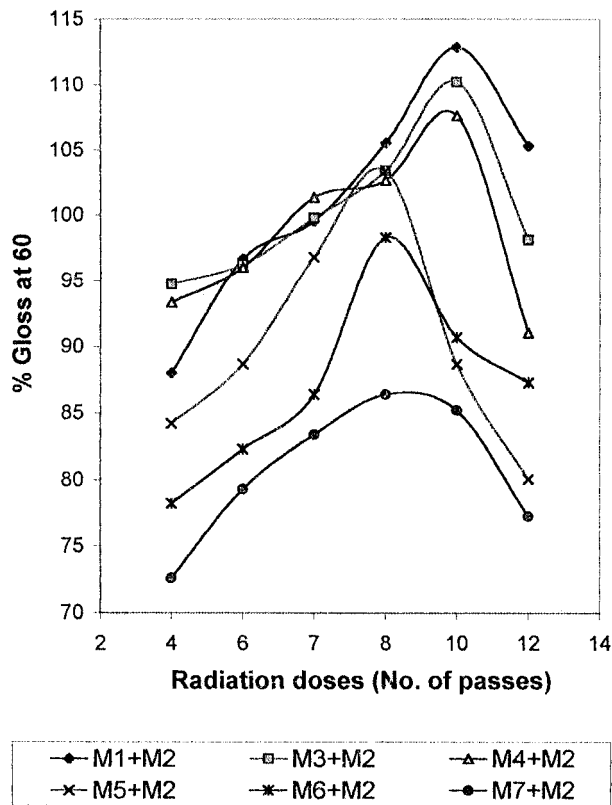


Figure 5 The microglosses at a 60° angle of UV-cured polymer coatings on partex versus the number of passes under the UV lamp as a function of the concentration of sand.

cured films were taken off the glass plate and put into a minibag of fine cloth. This bag was then put into a Soxhlet extraction apparatus and extracted with hot benzene for 48 h. The gel content (%) was determined by the weight loss of the film as follows:

$$\% \text{ Gel} = 100 - [(W_i - W_f / W_i) \times 100]$$

where W_i is the weight of the cured films before extraction and W_f is the weight of the cured film after extraction. The abrasion wear of the coated partex surface was measured by the Taber abrasion method using a Taber abraser (model 5130, Erichsen); the abrasion test was performed for 100 cycles. The results are expressed as a wear factor (Taber wear index) and are the loss in weight in milligrams per thousand cycles of abrasion.

$$\text{Taber wear index} = (\text{weight loss} / 100 \text{ cycle tests}) \times 1000$$

The effect of the weathering treatment on the properties of the coated partex that contained sand in the formulated solutions was determined by putting the

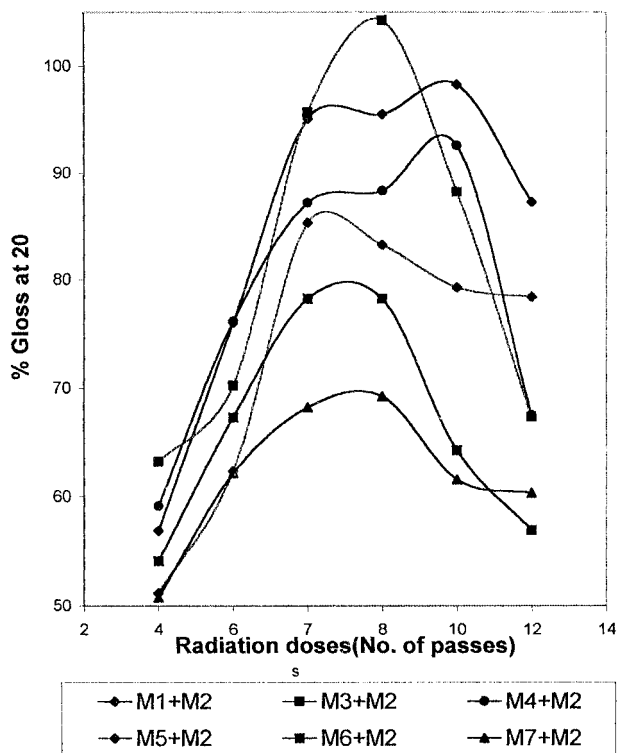


Figure 6 The microglosses at a 20° angle of UV-cured polymer coatings on partex versus the number of passes under the UV lamp as a function of the concentration of sand.

sample in an accelerated weathering tester (Q-UV, Q-Panel Co.) for a period of 650 h.

RESULTS AND DISCUSSION

Seven different formulations were prepared in the proportions mentioned in Table I using EB-600, TMPTA, and IRG-369. The M1 and M2 formulations were prepared without sand and M3–M7 were made by the incorporation of sand in different proportions (1–5%). MEK was added to the M2 formulation. The formulated solutions were used to prepare thin polymer films, as well as to improve the partex surface under UV radiation. Various films and coated partex substrates were studied, and the effects of sand on the coated partex were described. From that the best sand-containing formulation was evaluated.

Characterization of UV-cured polymer films

PH of film

The PH of the film was measured to determine the film hardness while the film was still on the glass plate after 24 h of UV radiation. Figure 1 represents the PH values of different films versus the radiation intensities represented by the number of passes with respect to the sand concentration (0–5%). The PH increases

with the UV dose, attains a maxima, and then decreases. The decrease of the PH may be caused by degradation of polymer crosslinking at higher doses.⁸ The maximum PH values are obtained between the sixth and eighth passes under UV radiation. Considering two formulations, M1 and M2 (without sand), the highest PH value (96%) is obtained from formulation M2, which contains a higher concentration of TMPTA (79%) than M1. TMPTA has trifunctional acrylated groups and thus has a branchlike behavior that creates more crosslinking among the ingredients of the formulation.⁹ The second highest PH value (94.29%) is obtained from the M6 formulation that contains 4% sand. However, observe from the figure that as the concentration of sand increases to 4%, the PH values also increase in the same direction. Sand probably acts as a coupling agent that may form a bond with the oligomer and monomer that are used. Beyond 4% sand it was found to decrease the values of the PH. It may be that excess polysiloxane hinders crosslinking with the oligomer and monomer molecule.

Gel content

The gel content represents the density of crosslinking through the whole polymer film. The gel contents

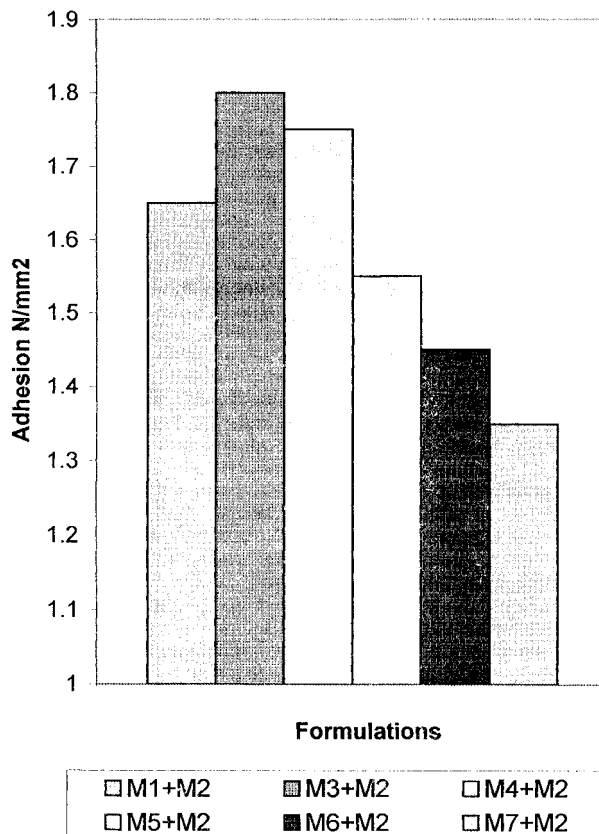


Figure 7 The adhesion strength (N/mm²) of UV-cured polymer coatings on partex as a function of different coatings (0–5% sand concentration in the base coat).

TABLE II
Properties of UV Cured Coatings on Partex Containing Sand in Base Coat

Physical Properties	No. Passes	Formulations/Coatings					
		M1 + M2	M3 + M2	M4 + M2	M5 + M2	M6 + M2	M7 + M2
Hardness indent length (mm)	4	0.86	0.70	0.85	0.65	0.90	0.80
	6	0.71	0.75	0.90	0.70	0.85	0.80
	7	0.74	0.72	0.85	0.75	0.80	0.85
	8	0.60	0.75	0.67	0.72	0.75	0.85
	10	0.63	0.60	0.70	0.65	0.85	0.80
	12	0.80	0.65	0.95	0.70	0.75	0.80
Indent depth (μm)	4	6	<5	6	<5	7	5
	6	<5	<5	7	<5	6	5
	7	<5	<5	6	<5	5	6
	8	<5	<5	<5	<5	<5	6
	10	<5	<5	<5	<5	6	5
	12	5	<5	8	<5	<5	5
Indent Buchholz resistance	4	118	>125	118	>125	111	125
	6	>125	>125	111	>125	118	125
	7	>125	>125	118	>125	125	118
	8	>125	>125	>125	>125	>125	118
	10	>125	>125	>125	>125	118	125
	12	125	>125	105	>125	111	125
Adhesion (%) chipped-off area		2	0	2	4	4	8
	6	4	2	4	0	0	10
	7	0	2	2	0	0	4
	8	0	4	0	0	2	2
	10	0	0	2	0	0	0
	12	0	8	4	0	4	2

found from hot benzene extractions of the films are plotted in Figure 2. The gel content increases with the UV dose, attains a maxima at a particular dose, and then decreases. The highest value lies between the eighth and 10th passes. Formulation M2 shows the highest value at the eighth pass among all the formulations investigated. However, the lowest gel content is produced by formulation M7, which has 5% sand (SiO_2). Thus, a film having the highest film hardness (PH) should yield a higher gel content; but in this case it was found that increasing the sand concentration causes the gel content to decrease simultaneously. This is probably because SiO_2 does not take part in the crosslinking reaction with the polymer molecule, and it increases the adhesion properties and forms monomer-sand-oligomer bonds, which behave like coupling agents.

Surface hardness of film

The macroscratch hardness test of the cured film was performed while the film was still on the glass plate. The results for the macroscratch hardness and other physical parameters such as the PH and gel content are shown in Figure 3 for the sake of comparison; the highest value for the corresponding parameters are plotted against each formulation. The figure shows that the film prepared by the M5 formulation containing 3% sand shows the highest scratch resistance in terms of the load required to manifest a scratch.

Application of formulated solutions on partex surface

After characterization of the film properties, the formulated solutions were applied on the partex surface polished with suitable sandpaper. Formulations M1 and M3–M7 were applied to the partex surface as the base coat, and formulation M2 was chosen as the top coat because of its low viscosity and ease of applicability. The base coats are applied on the polished surface by bar number 0.0028 and partially cured under an UV lamp. The partially cured surface is polished again, and a final coating of M7 is applied by bar number 0.0018 and cured on the surface with different intensities under the same UV lamp. The effects of the inclusion of sand as a promoter of different properties on the cured partex surface in contrast to no sand were determined

Role of sand on PH

The surface hardness of the film coatings on partex as measured by the pendulum technique and containing 0–5% sand in the base coat are graphically represented in Figure 4 versus the intensities of the UV radiation. The PH increases with an increase in the UV radiation doses; this reflects that there is an increase of the crosslinking density in the polymer with the increase of the radiation intensities. The figure also shows that increasing the sand concentration in the formulation

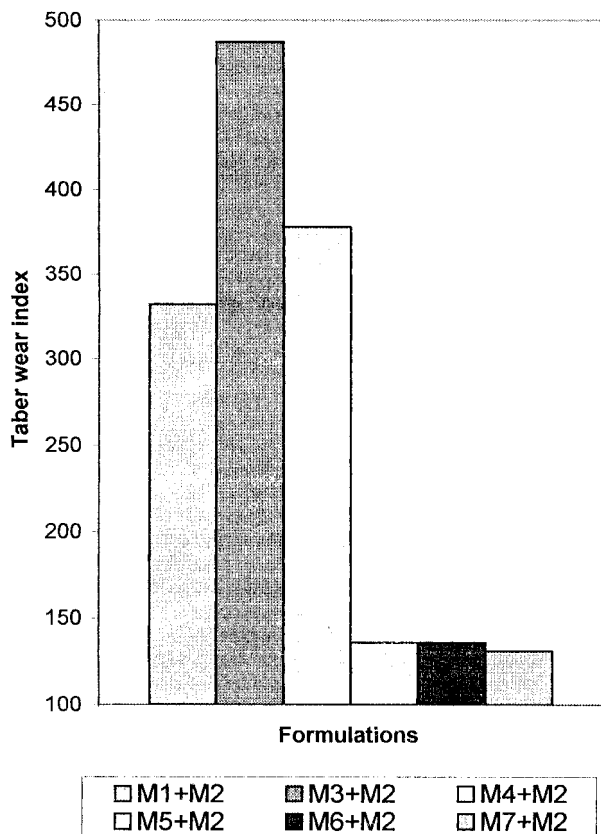


Figure 8 The abrasion resistance (Taber wear index) of UV-cured polymer coatings on partex as a function of different coatings (0–5% sand concentration in the base coat).

as applied in base coating on the partex surface linearly increases the PH values, which means that the action of sand as a coupling agent is forming a new bond with the oligomer and monomer that subsequently increases the PH value. The highest PH value is given by the (M7 + M2) formulation (76.74%) at the seventh pass containing 5% sand followed by the (M5 + M2) and (M6 + M2) formulations at the eighth and 10th passes.

Role of sand surface gloss

The surface gloss of the cured surfaces was measured at 60° and 20° angles and is graphically shown in Figures 5 and 6, respectively. The surface gloss is related to the extent of curing of the film; thus, the gloss increases with an increase in the crosslinking density (i.e., an increase in the UV dose). The gloss at the 60° angle decrease slightly to 3% sand, the rate of reduction is negligible, and the values obtained were still good for surface coatings. For the formulations containing sand in the base coat, the highest gloss (110.21%) at a 60° angle is given by the (M3 + M2) coating followed by (M4 + M2). However, at a 20° angle with 1% sand content no adverse effect on the gloss is shown. Better gloss at 20° was observed by the

(M1 + M2) coating, but a higher concentration of sand decreases the gloss value at the 20° angle and the maximum value (104.26%) of gloss at 20° having sand in the base coating is shown by (M3 + M2).

Role of sand in adhesion strength

Figure 7 shows the adhesion strength measured to pull the cured film from the partex substrate containing 0–5% sand in the formulating solutions. More strength is required for better adhesion of the film. The coating of formulation (M3 + M2) containing 1% sand shows the highest adhesion (1.80 N/mm²), which is better than that of the formulation having no sand (M1 + M2). The values of adhesion then decrease with increasing sand content from 2 to 5%. Formulations (M6 + M2) and (M7 + M2) containing 4 and 5% sand, respectively, show the minimum adhesion strength of 1.25 N/mm². This is also consistent with the adhesion in terms of the percentage of chipped-off area measured by the cross-cut technique as shown in Table II.

Role of sand in abrasion property

Abrasion is important for surface coatings. If the wearing resistance is high, the surface is considered to last

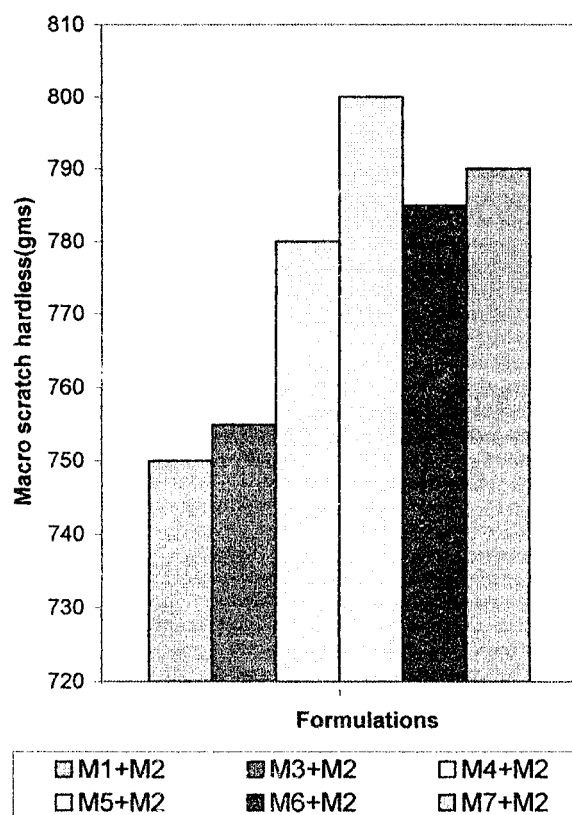


Figure 9 The macroscratch hardness (GMS) of UV-cured polymer coatings on partex as a function of different coatings (0–5% sand concentration in the base coat).

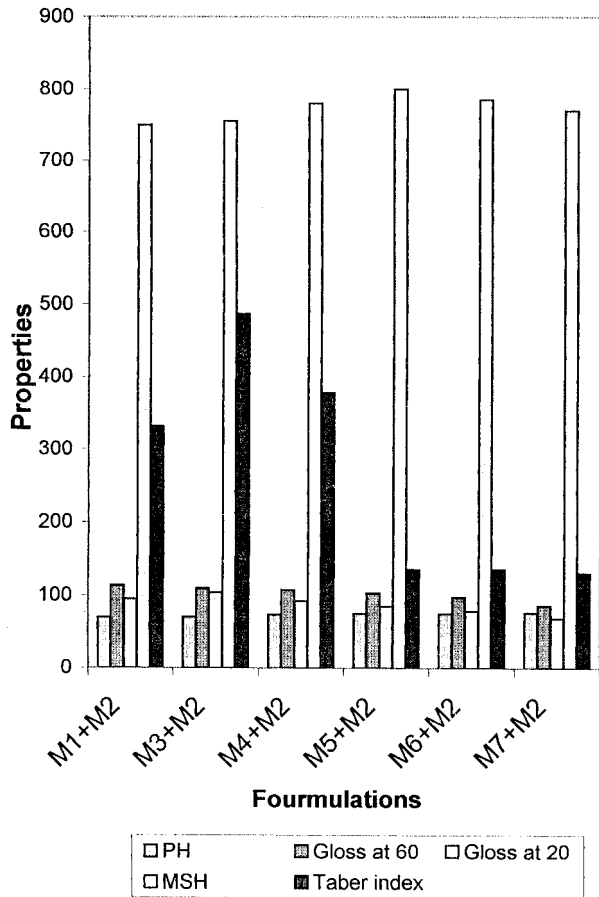


Figure 10 The various physicochemical properties of UV-cured surface coatings on partex as a function of the sand concentration.

longer. The wearing resistance of the coated partex was determined by the application of a Taber abrasion test through the weight loss method. The partex surface improved by radiation curing and containing sand was abraded between two revolving abrading wheels applying a force 1000 g/cycle. However, the lower the wear index was, the better the surface coatings. The values of the Taber wear index of the coatings are graphically plotted in Figure 8. The figure shows that, as the inclusion of sand (SiO₂) increases from 1 to 5%, the resistance toward abrasion also increases. A lower Taber index (131) is shown by the (M7 + M2) formulation. The (M5 + M2) and (M6 + M2) formulations had a similar index value (136). It can therefore be concluded that inclusion of sand in the formulating solutions also increases the resistance to abrasion.

Role of sand on macro- and microscratch hardness

The macroscratch hardness indicates the hardness of the surface. The load required to manifest a scratch on the surface is the macro- and microscratch hardness. The microscratch hardness values for each of these coatings

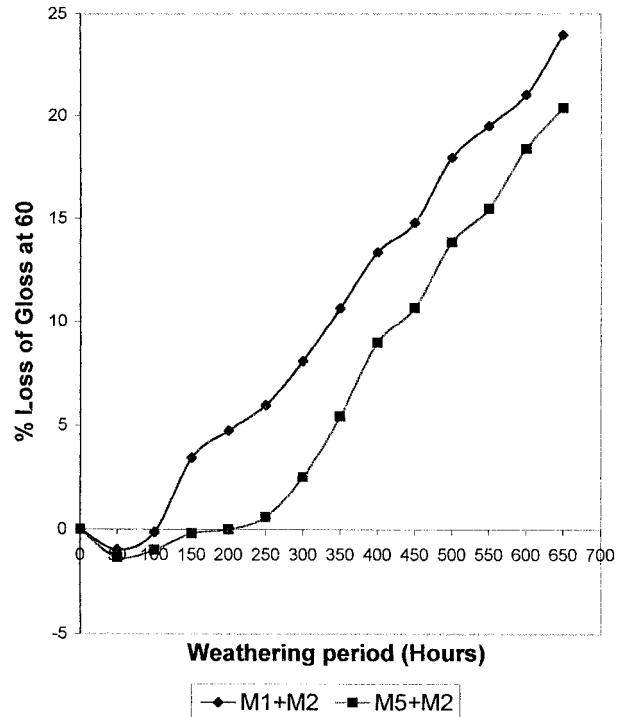


Figure 11 The weathering effect at 60° on the gloss (% loss) of the (M1 + M2) and (M5 + M2) coatings.

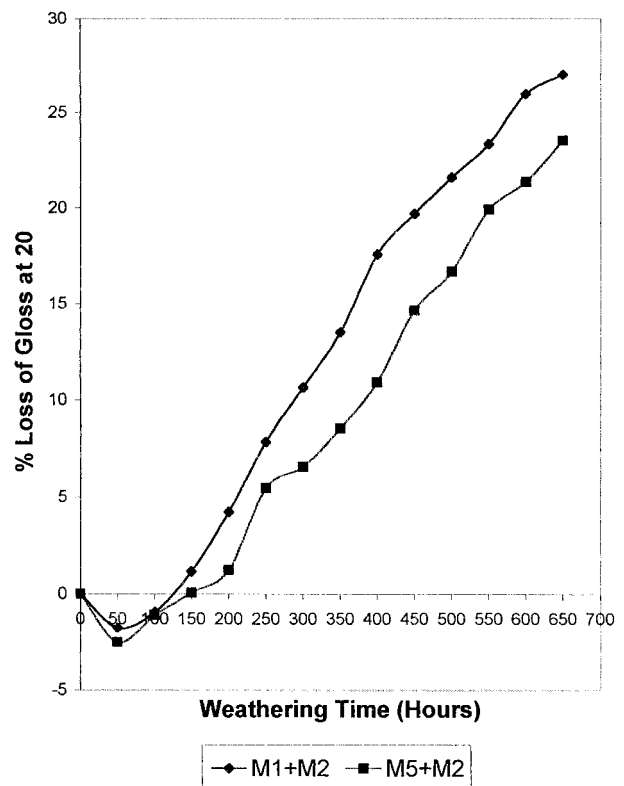


Figure 12 The weathering effect at 20° on the gloss (% loss) of the (M1 + M2) and (M5 + M2) coatings.

are out of range and are not shown in Table II. The values of the macroscratch hardness are plotted in Figure 9. The macroscratch hardness increases with the increase of the sand content up to 3% in the base coat and then decreases slightly with more sand content. The maximum macroscratch hardness (800) is observed with the (M5 + M2) formulation with 3% sand and the lowest macroscratch hardness (750) was observed by the (M3 + M2) formulation containing 1% sand.

The results of other properties such as the indent length, indent depth, Buchholz resistance, and adhesion percentage of chipped-off area are shown in Table II. The maximum values of the different properties such as the PH, gloss, macroscratch hardness, and Taber index are plotted in Figure 10 for a comparative study. This reveals that the coating of the (M5 + M2) formulation containing 3% sand shows the best performance on partex.

Simulated weathering effect

The coated partex samples treated with the (M1 + M2) formulation without sand and the best formulation containing 3% sand (M5 + M2) were put into the accelerated weathering machine for a period of 650 h. The simulated weathering consists of simulating sunshine, dew, and condensation in alternating cycles. After every 50 h of weathering treatment the properties such as the PH, gloss, and adhesion were mea-

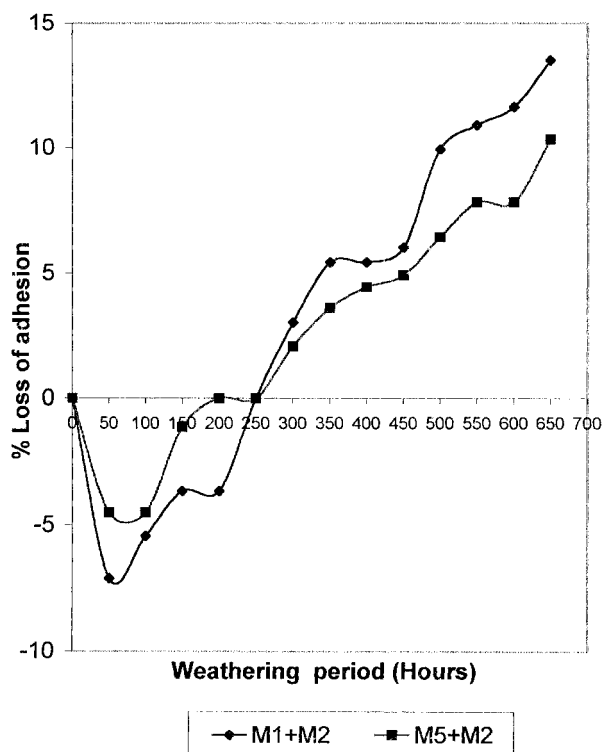


Figure 13 The weathering effect on the adhesion strength (% loss) of the (M1 + M2) and (M5 + M2) coatings.

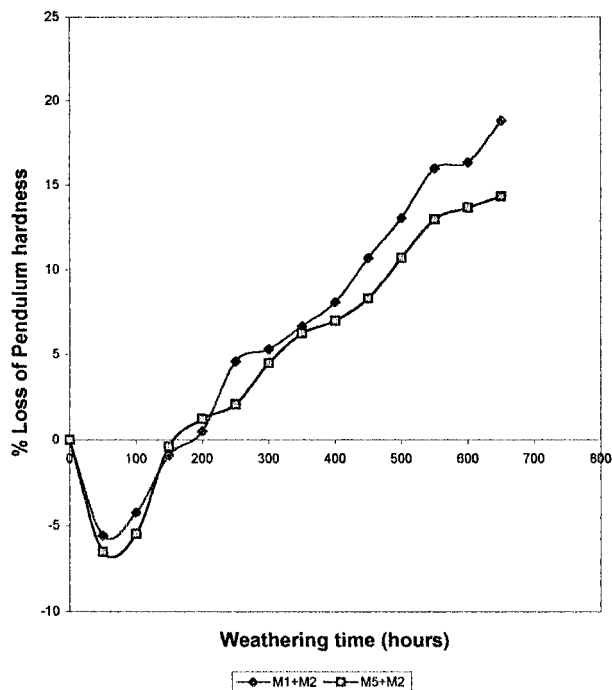


Figure 14 The weathering effect on the pendulum hardness (% loss) of the (M1 + M2) and (M5 + M2) coatings.

sured and are graphically represented in Figures 11–14 versus the weathering time (h). We observed that almost all the properties increase initially and then begin to decrease because of the treatment under different weather conditions. The initial improvement of these properties was most probably due to the reaction of the unused free radicals at the time of the initial curing procedures.¹⁰ From these four figures we clearly observe that the loss of properties of the formulations having no sand content in the base coat were higher than the formulation containing 3% sand with the polymeric formulation. Thus, the use of sand in the surface modification of partex made it more resistant under different atmospheric conditions.

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