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Studying a New Infrared Reflective Polymer Coating

A. Al-kawaz[1*], N. Hadi[1], Z. Al-husainy[2]

1. Material Engineering, Department of Polymer and Petrochemical Industries, University of Babylon, P.O. Box: 417, Babylon, Iraq.

2. Medical Physics Department, AL-Hila1 University, P.O. Box: 1619, Babylon, Iraq.

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ABSTRACT

Although, that the solar energy is important for life continuity, there is need to protect large buildings from these radiations in summer and if the buildings are permitted to take these radiations, the cost of cooling will be too much. One of the most effective methods used to solve this problem is to coat buildings with specific pigments that reflect the solar infrared radiation. This work studies a new infrared reflective coating containing carotene pigment. UV-Vis spectroscopy results for the films with different concentrations of carotene pigment showed that the reflectance of IR spectrum reaches to 92% while the reflectance in the visible range (400-500 nm) was decreased to 42% by increasing the concentration. The FT-IR results showed the bonds of the Polymethylmethacrylate (PMMA) and pigment, noted that the transmittance increased for PMMA and pigment almost 10% as compared with pure PMMA. The containing PMMA, indicating that the transmittance increased almost 10% for pigment-containing PMMA. The results confirmed that the prepared coatings could reflect UV-Vis spectrum. So, they can be used in the protecting the planet from this type of radiation. Prog. Color Colorants Coat. 12 (2019), 93-99© Institute for Color Science and Technology.

1. Introduction

The normal approach to give the light a chance to get inside is utilizing transparent windows such as glass because of its translucence to visible light. The issue in the glass is the capacity to assimilate IR and let entering the heat. Heat is wanted on colder days but in tropical climes need utilizing cooling to keep up an agreeable temperature. This issue was solved by employing the windows that have an ability to permit the sunlight and blocking near-infrared radiation (NIR) by cutting energy and reduces carbon emission [1].

Many studies have been done on glasses, which were semitransparent in near-infrared radiation NIR region, some study used crystal form of titanium dioxide (TiO_2) known as rutile as white pigment which its refractive index is higher than any fabricated material with value (2.76) logical cost and effective whit pigments, and zinc sulfide (ZnS), zinc oxide (ZnO), a mixture of barium sulfate ($BaSO_4$) and ZnS and basic lead carbonate ($2PbCO_3.Pb[OH]_2$) which represent their commercial white pigments that used in the earlier time [2]. The disadvantage of using these components as a coating was its solubility in water and toxic hazard [3].

Simon and McMahon discussed the fundamentals of relative cooling of glass slabs and sheets. Japanese companies (e.g., Asahi Glass Green-Tech Co. Ltd and Mitsui Chemicals Inc.) invented a variety of

*Corresponding author: emadammar79@yahoo.com

fluoropolymers and polyethylene (PE) based films and acrylic-based rigid sheets with NIR-reflection agents. [3, 4].

Hoffmann and Waaijenberg used pigments mixed with a polymer, which dismiss NIR using the absorption, reflection, or interference properties during manufacturing coating materials, and that contingent on the angle of solar beam radiation interface pigments reflect NIR. Thus, enhancing the orientation of the interference color in the polymer is important to get the most extreme NIR reflection and greatest PAR transmission [5]. Runkle et al. studied the effect of multilayer NIR-reflecting materials produced by 3 M (St. Paul, MN, USA). A solid screen and protective coating were fabricated from this modern materials, and their performance were compared with a neutral metalized commercial shade-screen [6, 7].

Hemming et al. used a novel plastic film. They examine the influence of many concentrations of NIR-reflecting pigments on the PE films. The results showed that the photosynthetically active radiation (PAR) transmittance and increases the NIR reflectance with increasing the weight percentage of the pigment. Newly, a metallic multilayered material (SOL-MOX Hilite from Bekaert, Zwevegem, Belgium) and a dielectric multilayer based on a plastic film (Ebiral from 3 M, St. Paul, USA) have been developed as a NIR-reflecting materials with a distinctive irradiative characteristics. These films are a very durable and acceptable lifetime [8]. Guangwen Wu and Demei Yu, prepared a low infrared-emissivity coating utilizing adjusted (Al) powder with polyethylene wax coating to reduce the emissivity and gloss of the coating and polyurethane as a metallic pigment. The results revealed that the adjusted Al powder reduces the gloss of the coating and its emissivity within the wavelength range of 8–14 μm. With increasing the thickness, in particular, more than 80 μm, the infrared emissivity of the composite coating fundamentally increased [9]. Huijuan Yu et al. studied the effect of size, shape, and floatage of copper (Cu) particles and ethylene–propylene–diene monomer (EPDM) binder. They concluded that the formation of low infrared emissivity coatings depends strongly on the floatage of the Cu particles, but not their size or shape [10]. Xiaoxing Yana, and GuoyueXub, chemically functionalized the surface of copper (Cu) by silane coupling agent (KH550) to enhance the interfacial bonding between Cu and polyurethane (PU) polymer. The resultant coating revealed low infrared emissivity and corrosion resistance [11]. Ignazio Roppolo et al. used photoactive filler Iriotec 9870 to prepare a multi-functional UV-curable epoxy coating to obtain both IR-reflecting and hydrophobic properties [12].

In the present work, we attempted to prepare a new infrared reflective polymer coating by incorporating carotene pigment (extracted from the carrot peel) in the PMMA matrix, which is a low cost, and environmentally friendly coating. PMMA was mixed with carotene after immersion in n-hexane for 18, 24, 30, 36 h. Samples were produced as films with a thickness between (0.3-0.4 μm), UV-Vis and FT-IR spectra were used to examine the optical properties and the structure of the films.

2. Experimental

2.1. Preparation of the coating

The sample was prepared by immersing carotene shield in n-hexane with (250 g carotene shield: 250 mL solvent) at different immersing times (18, 24, 30 and 36 h) (Table 1). The polymeric film was prepared by dissolving 1g of PMMA powder in 10 mL of n-hexane with and without pigment, after that the sample was cast in glass betray dish and left to dry at room temperature for 72 h. The resultant film thickness was (0.379 -0.44μm).

Table 1: Samples description.

Samplecode	Sample name
Sp0	Pure PMMA
Sp18	PMMA/pigment after immersing 18 h
SP24	PMMA/pigment after immersing 24 h
Sp30	PMMA/pigment after immersing 30 h
Sp36	PMMA/pigment after immersing 36 h

2.2. Characterization

Films were examined using UV-1800 Shimadzu UV-Viable spectrometer in the range of (190-1100 nm) to evaluate the absorbance, transmittance, reflectance and other optical properties of the films. FT-IR -8400s spectrometer was used to analyze the structure of the sample and it contains. In order to simulate the ability of a coating in reflecting the heat in real, a light source and homemade insulated box linked with two thermocouples were designed.

3. Results and Discussion

3.1. FT-IR spectroscopy

Figure 1 Shows the spectral absorbance of pure PMMA and PMMA film with different carotene pigment concentrations. The concentration of pigment is a function of the immersing time. The results showed that the transmittance to mid-infrared region decreased by almost 10% in comparison with pure PMMA as the concentration of pigment increased because of pigment scattering part of the spectrum in the mid-infrared region. It is also noticed that the phosphoric bond appeared with strong strength at (2667 cm^{-1}). This bond is responsible for the shinning color of carotene pigment.

Figure 2 shows the absorbance spectra of pure PMMA and PMMA with different carotene pigment concentrations. Carotene pigment has the ability to absorb the electromagnetic spectrum in the blue light region as well as a yellow and green region; therefore the absorbance was increased as the concentration of pigment increased. While the region of the near infrared region has a low absorbance and furthermore see absorbed reach to 0.2 in UV range in light of the fact that as a reality that the majority of polymer work in this range. The results are consistent with others studies, which reported that the carotenoids play a major role in capturing light, and in obtaining eliminated of excess light energy. The leaf extradites enormous amounts of energy because of exposure to full sun, and this energy can be demolished photosynthetic machinery if handled properly, and the carotenoids can absorb the excess energy and the later dissipated it as heat [13, 14].

Figure 3 shows the spectral transmittance of pure PMMA and PMMA with different carotene pigment concentrations. Notice that the transmittance of pure PMMA is higher than that of films containing pigment because PMMA is highly transparent in the viable region due to its amorphous structure. The transmittance of colored films decreased because pigments scatter the spectrum. The absorbance also increased in another region due to the concentration of pigment. It is worth mentioning, that the transmittance of the film in the UV region reaches zero which made it usable in the greenhouse [4].

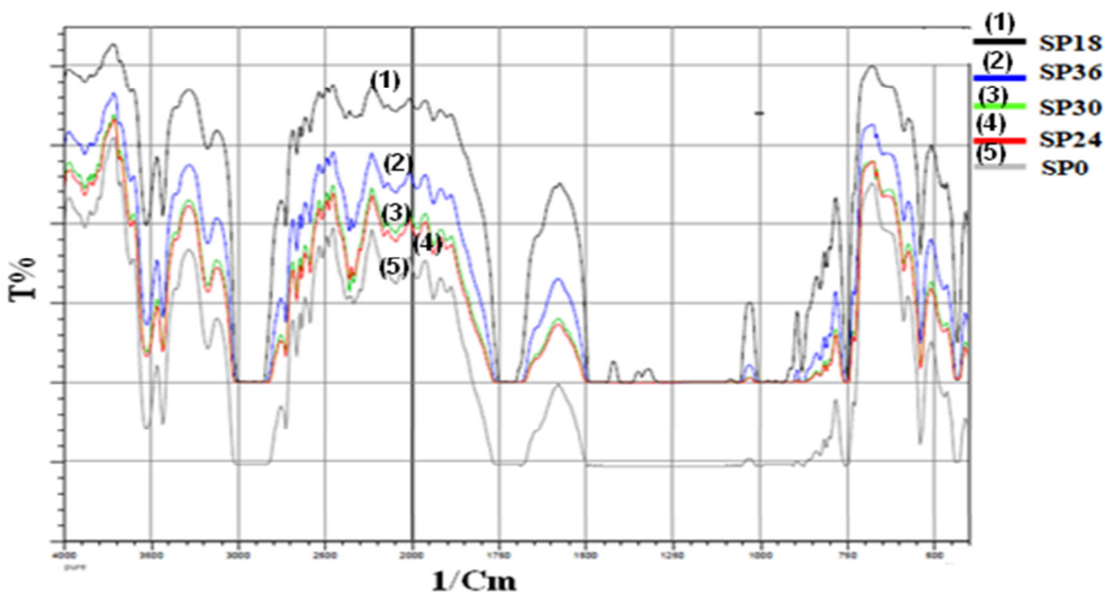

Figure 1: FT-IR spectra of pure PMMA and PMMA with a different carotene pigment concentrations.

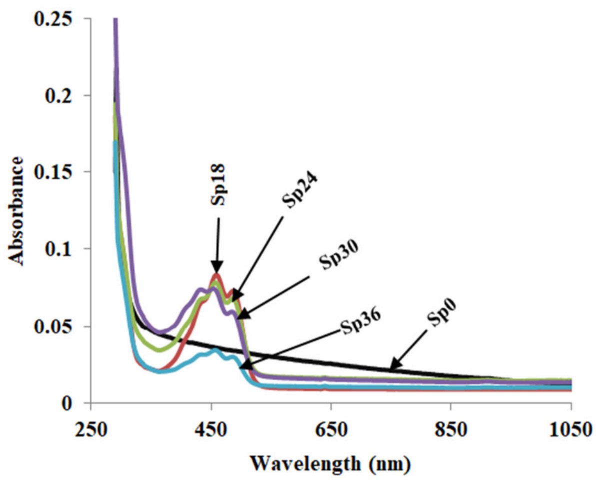

Figure 2: Spectral absorbance of pure PMMA and PMMA with a different carotene pigment concentrations.

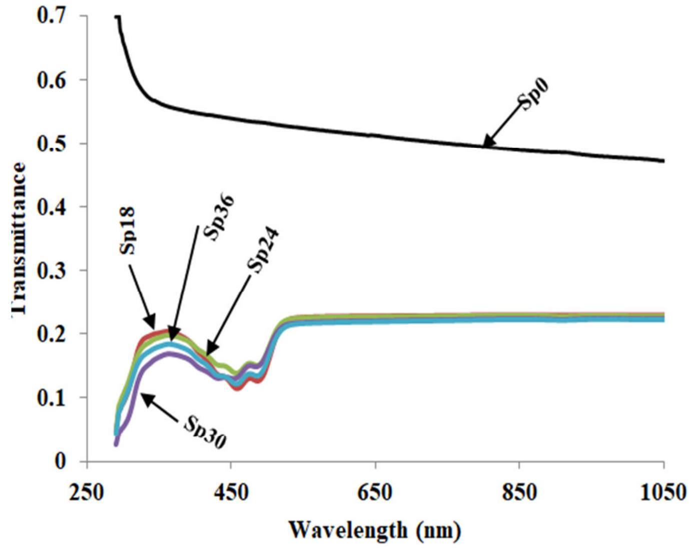

Figure 3: Spectral transmittance of pure PMMA and PMMA with different carotene pigment concentrations.

Figure 4 shows the spectral reflectance of pure PMMA and PMMA with different carotene pigment concentrations. The figure shows that the reflectance in near infrared region with a value reaches to 52 %, while decreased close to the ultraviolet region because polymer has high absorbance to this region and as the law of conversation (A+T+R=1). After dissolving the polymer in pigment the reflectance increased almost 40% and reach 92% near-infrared region due to the role of carotene pigment in scattering the red region as well as the orange region. The reflectance in the range of 400-520 nm decreased and reach 50% which means that it is transparent to this region. So beta-carotene appears orange because the red/yellow colors are reflected back [15].

Figure 5 shows the spectral absorption coefficient of pure PMMA and PMMA with different carotene pigment concentrations. The results indicated that the absorption coefficient in the region of 350-500 nm in the presence of high pigment concentration increases because it depends on the absorbance and film thickness.

Figure 6 shows that the refractive index increased by the concentration of pigment because it is related to film reflectance, and pigments can resist photon movement inside the film, hence increasing the refractive index.

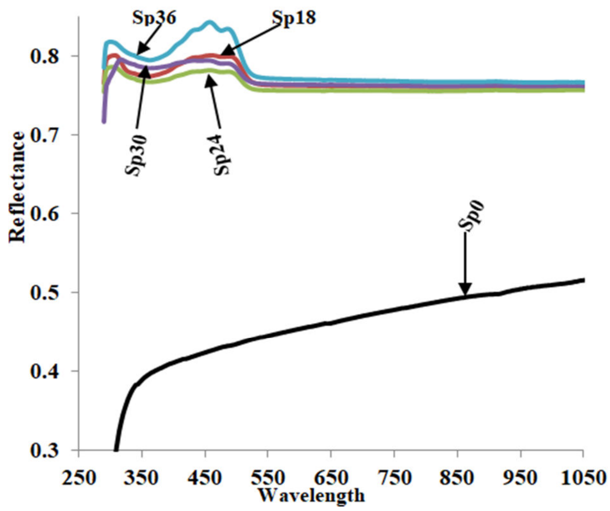

Figure 4: Spectral reflectance of pure PMMA and PMMA with a different carotene pigment concentrations.

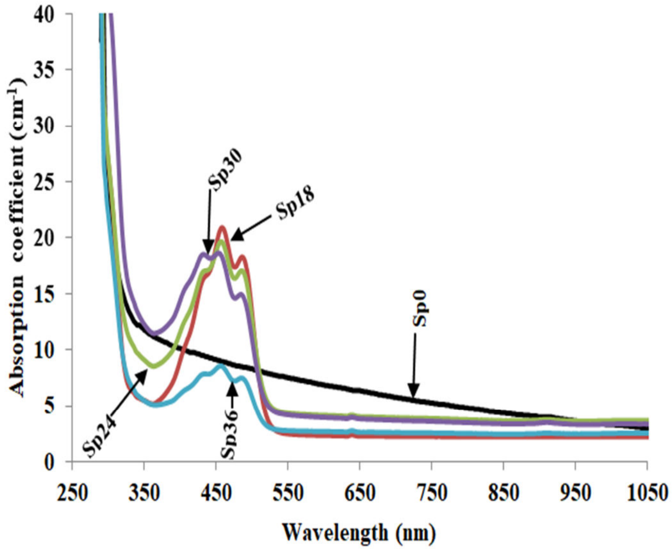

Figure 5: Spectral absorption coefficient of pure PMMA and PMMA with different carotene pigment concentrations.

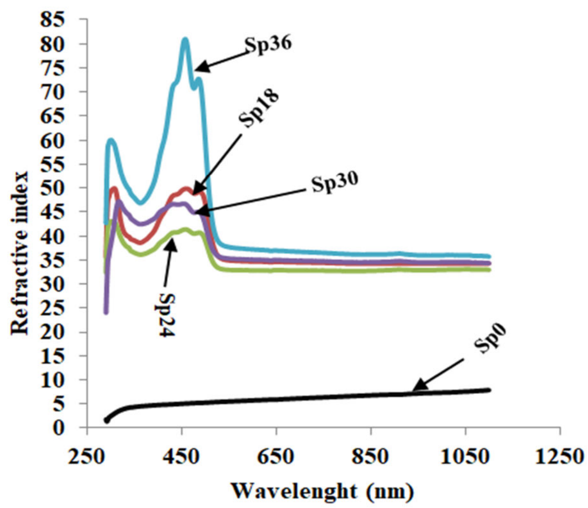

Figure 6: Spectral refractive index of pure PMMA and PMMA with different carotene pigment concentrations.

3.2. Evaluation of coating performance

A homemade device (isolated box) was used to check the performance of coating films applied on glass panels with 5 mm thickness. The samples were exposed to light from Philips 250 W lamp. The distance between the panel and the lamp was about 30 cm (Figure 7).

A thermocouple was placed before and after the light entrance to record the difference in temperature. The distinction in the temperatures explained whether the pigment utilized are reflected the infrared or not. Figure 7 displays the infrared reflectivity of coating films and Table 1 shows the list of samples, which were coated with polymeric films and colored with different pigment concentrations.

Table 2 shows the reflectance of the coatings at the infrared (800-1100 cm^{-1}) and ultraviolet (250-350 nm) regions. The temperature of the light outside and inside the box is also presented in the table. The results showed that the sample Sp18 has the ability to scatter a high percentage of heat as compared with the pure polymer Sp0, while for Sp36 sample, the percentage of scattered heat was decreased and this may be due to the heterogeneity of the pigment in the sample, as a result of presence water (polar component) and the later was immiscible with the n-hexane solvent (non-polar solvent) which causes accrue the pigment.

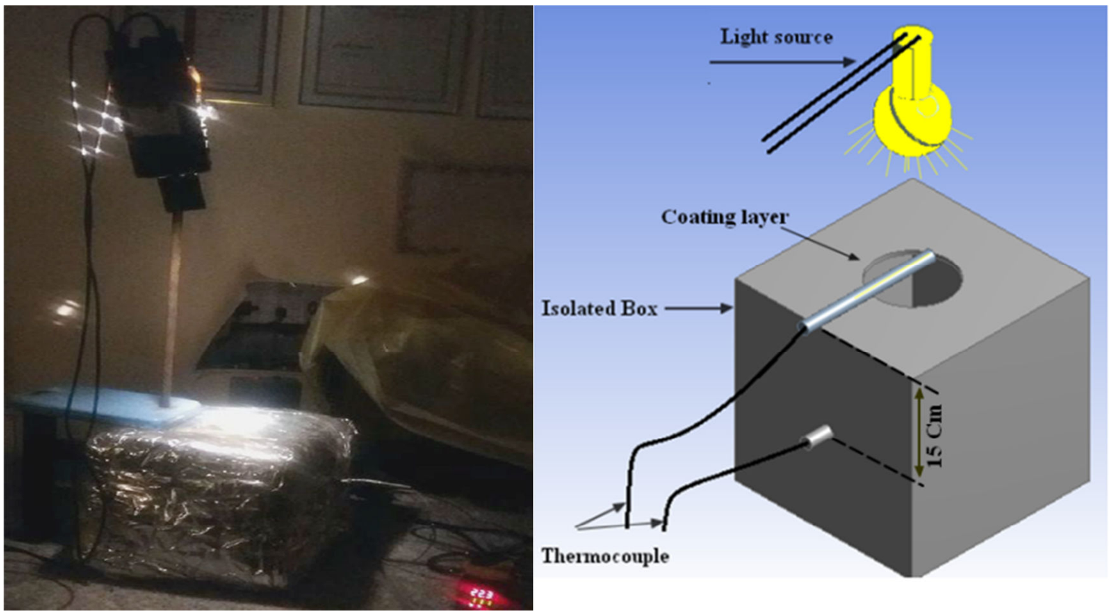

Figure 7: Homemade isolated box.

Table 2: The reflectance and the temperature of coatings.

Sample	Temp.(T_1) outside box (°C)	Temp. (T_2) inside box (°C)	U.V	IR
Glass	39	37.3	-	-
Glass/Sp0	39	38	0.58-0.45	0.52-0.4
Glass/Sp18	39	33.1	0.92-0.83	0.9-0.77
Glass/Sp24	39	36.5	0.89-0.79	0.85-0.74
Glass/Sp30	39	34.3	0.91-0.83	0.89-0.8
Glass/Sp36	39	37.1	0.93-0.82	0.92-0.84

4. Conclusion

The specific coating for windows which can transmit the light and reflect the infrared light from the sun's radiations can improve the appearance of the building and, also decreasing the cost of cooling for structures during summer. A new infrared reflective PMMA coating material was made using carotene pigment. The UV-Vis spectra of the films with different carotene pigment concentrations showed that the reflectance of IR spectrum reaches to 92% and the reflectance increased by the concentration of the pigment. The temperature dressed almost 3-8 degree when beam passing through the coating layer. The film is transparent in the region of 400-500 nm.

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