

Photografting of Acrylic Acid and Methacrylic Acid onto Polyolefines Initiated by Formaldehyde in Aqueous Solutions

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Received 23 September 2008; accepted 21 December 2008

DOI 10.1002/app.29938

Published online 20 April 2009 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: Formaldehyde aqueous solution can act as an effective photoinitiating system for water-borne photografting. The photografting of acrylic acid (AA) and methacrylic acid (MAA) onto high-density polyethylene (HDPE), low-density polyethylene (LDPE) and polypropylene (PP) initiated by formaldehyde aqueous solutions has been reported. The effects of formaldehyde content and monomer concentration on grafting varied with the polymeric substrates and monomers used. For the grafting of AA onto HDPE, the extent of grafting increased with increasing formaldehyde content in the solution, monomer concentration had a little effect on grafting. Whereas for the grafting of MAA onto HDPE, the grafting performed in 8% formaldehyde aqueous solution lead to the highest extent of grafting, the extent of grafting increased with monomer concentration till 2.5 mol/L. MAA was easier to be grafted onto the poly-

olefins than AA. The easiness of grafting occurring on the polyolefins was in a decreasing order of LDPE > HDPE > PP. Qualitative and semi-quantitative Fourier transform infrared (FTIR) characterizations of the grafted samples were performed. For both grafted LDPE and PP samples, at the same irradiation time, the carbonyl index of the samples grafted with MAA was higher than that grafted with AA. The FTIR results are in accord with the results obtained by gravimetric method. The water absorbency of the grafted samples increased almost linearly with the extent of grafting. The PE films grafted with AA adsorbed more water than those grafted with MAA. This study had broadened the water-borne initiating system for photografting. © 2009 Wiley Periodicals, Inc. *J Appl Polym Sci* 113: 2062–2071, 2009

Key words: graft copolymer; initiation; formaldehyde

INTRODUCTION

Polyethylene (PE) and polypropylene (PP) are the most widely used polymeric materials because they have many good properties. However, the surfaces of polyolefines are chemical inertness in nature, which strongly restrict their practical applications, such as printing, coating, adhesion, etc.¹ Therefore, it is very necessary to modify the surfaces of polyolefines. In recent years, the ultraviolet (UV)-induced grafting (photografting) has become a very popular technique for the modification and functionalization of polymeric materials and has drawn many attentions because it has many advantages: such as the reaction of graft polymerization only occurs on the surface or subsurface without affecting the bulk

polymer as well as the low cost of equipment and continuous operation.^{2–4}

Photografting reactions usually require a photoinitiator or photoinitiating system, except for some self-initiated grafting.^{5,6} Photoinitiator plays a key role in the grafting reaction. The most commonly used photoinitiators for photografting are benzophenone (BP) and its derivatives.^{7–9} However, most of them are water insoluble, and hence the photografting has to be performed in organic solvents or mixed solvents of water and organic solvent, which increase cost and induce environmental problems. Obviously, water-soluble photoinitiators are welcomed in the industrial applications of photografting.

In our previous work,^{10,11} we reported the use of simple aliphatic ketones as photoinitiators for photografting. The aliphatic ketones, especially acetone and butanone, can act as high efficient photoinitiators when they are mixed with water and alcohol in a proper volume ratio range. Our recent theoretical calculations proved that water plays a very important role in the photoinitiation effect of the aliphatic ketones, related results will be published later. The carbonyl group in the aliphatic ketones is the key functional group that can be excited under UV

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Contract grant sponsor: National Natural Science Foundation of China; contract grant number: 20574006.

Contract grant sponsor: Beijing Municipal Commission of Education.

irradiation to an excited state with sufficient energy to abstract hydrogen atoms from polymeric substrate and then initiate grafting reaction. Water forms hydrogen bond with the carbonyl group and alters formation pathways and the energy of the excited state.

Both aldehydes and ketones contain the carbonyl group, and are often referred to collectively as carbonyl compounds. And they resemble each other closely in most of their properties. There is one or two (only for formaldehyde) hydrogen atom(s) attached to the carbonyl group of aldehydes, whereas there are two organic groups attached to the carbonyl group of ketones. Aldehydes usually have higher solubilities in water because of their higher polarities than ketones. Can aldehydes be used as water-borne photoinitiators for photografting? Yang and Ranby¹² found that formaldehyde and acetaldehyde have very low photoinitiation efficiencies for the bulk (no solvent) photografting of acrylic acid (AA) onto low-density polyethylene (LDPE). What will happen when aldehyde aqueous solution is used as the solvent in the absence of any other photoinitiator? Our experiments proved that formaldehyde aqueous solution can function as both photoinitiator and solvent for water-borne photografting.

The grafting of AA and methacrylic acid (MAA) onto high-density polyethylene (HDPE), LDPE and PP initiated by formaldehyde in water solution is described herein. Fourier transform infrared (FTIR), scanning electron microscopy (SEM) characterizations, and the measurements of the water absorbency of the grafted samples are also presented.

EXPERIMENTAL

Materials

High-density polyethylene (HDPE, Type 4000s), low-density polyethylene (LDPE, Type 100AC), and polypropylene (PP, Type 2401) were supplied by Yanshan Petrochemical Co., Ltd. Beijing, China. The polyolefin grains or powders were hot pressed into films (ca. 400–500 μm in thickness) and cut into 2 cm \times 3 cm rectangular samples, and then subjected to Soxhlet extraction with acetone for 24 h to remove impurities and additives before use.

Formaldehyde solution (40-w/w%, density: 1.081–1.085) (AR grade), monomers methacrylic acid (MAA, AR grade) and acrylic acid (AA, AR grade) were from Bodi Chemicals (Tianjin, China). All the chemicals were used without further purification.

UV equipment

The UV system with shutter assembly was supplied by RunWing, Shenzhen, China. The input power of

the high-pressure mercury UV lamp was 2 kW. No filter was used to isolate UV light.

Grafting procedure

Photografting was performed in an 8-cm diameter petri dish containing three film samples and 10.0 mL of solution. The petri dish was covered with PE foil to prevent the evaporation of solution. The petri dish was put at a fixed position 10 cm below the UV lamp, where the UV (254 ± 10 nm) intensity was 20 mW/cm². The reaction temperature was not controlled.

Because AA and MAA are water-soluble monomers, polymerized films were washed with water in an ultrasonic bath for 0.5 h and extracted with 90°C water for at least 14 h to remove homopolymer and unreacted monomer, and then dried at 50°C for 24 h. The extraction is known to be sufficient for removing most of the homopolymer in the film.

The extent of grafting, in $\mu\text{g}/\text{cm}^2$, was expressed as the weight increase per surface area of the sample, and was calculated from the following equation:

$$\text{Extent of grafting} = \frac{W_g - W_0}{S}$$

where W_g and W_0 are the weights of the PE sample after and before grafting; S is the surface area of PE sample. The mass was determined using an electronic balance (0.1 mg). Typical relative errors in extent of grafting of three samples were $\pm 5\%$.

FTIR characterization

Transmission FTIR spectra were obtained from pristine and grafted samples on an Avatar-360 spectrometer (Nicolet Instruments, Madison, WI). The number of scans was 32 at a resolution of 4 cm^{-1} .

Carbonyl index (CI) was used to study the grafting semi-quantitatively, it was calculated by the following equation:

$$\text{CI} = A_{\text{C=O}}/A_{\text{C-H}}$$

where $A_{\text{C=O}}$ is the absorbance of carbonyl C=O stretching vibration peak at about 1691–1713 cm^{-1} depending on the monomer and polyolefin used, $A_{\text{C-H}}$ is the absorbance of C–H stretch of $-\text{CH}=\text{CH}_2$ group in LDPE (1896 cm^{-1}) and PP (1892 cm^{-1}), which was used as the internal standard peak. The vinyl group in LDPE and PP had almost no change during grafting process. These peaks were auto-baselined before calculating the absorbance. The automatic baseline correction and the calculation of absorbance were treated with the EZ OMNIC 5.2 software accompanying the instrument.

Measurement of water absorbency of grafted samples

The grafted samples (W_g , g) were immersed into deionized water at 50°C for 48 h to obtain equilibrium swelling. After the treatment, excess water on the each film surface was wiped off with paper tissue, and then the weight (W_s , g) of the treated film was determined immediately. The surface area (S) of each PE film was 6 cm². Water absorbency is defined as follows:

$$\text{Water absorbency} = \frac{W_s - W_g}{S} \text{ (}\mu\text{g/cm}^2\text{)}.$$

SEM investigations

The morphologies of the pristine polyolefin samples were examined with a Hitachi S-4800 scanning electron microscope (Tokyo, Japan). The samples were coated with gold.

RESULTS AND DISCUSSION

The formaldehyde solution used contains about 40 w/w-% formaldehyde and it has a density (1.081–1.085 g/cm³) close to that of water. Provided the volume change during the mixing of formaldehyde solution with water can be ignored, then the content of formaldehyde in the mixed solvent is close to $0.4 x / (x + y) \times 100\%$, where x and y are the volumes of the formaldehyde solution and water before mixing.

In most published works on grafting reactions, the grafting results are expressed in percent grafting or grafting percentage. However, obviously, the percent grafting varies dramatically with the original weight of the sample. Because the polyolefin films we used were not uniform in thickness and hence their weights, the usage of percent grafting or grafting percentage to express the grafting results will lead to significant errors. We think it is better to express the grafting results in the *extent of grafting* (weight increase per surface area of the sample) for the graftings on the surfaces of polymeric films or plates. Therefore, here we used the extent of grafting. The 500 $\mu\text{g/cm}^2$ (extent of grafting) is approximately equal to 1% (percent grafting) in this study.

Grafting on HDPE

Figure 1(a–c) shows the photografting of AA and MAA onto HDPE performed in different formaldehyde aqueous solutions. When AA was used as the monomer and the monomer concentrations were 1 mol/L [Fig. 1(a)] and 2 mol/L [Fig. 1(b)], in both cases, the extent of grafting increased with increas-

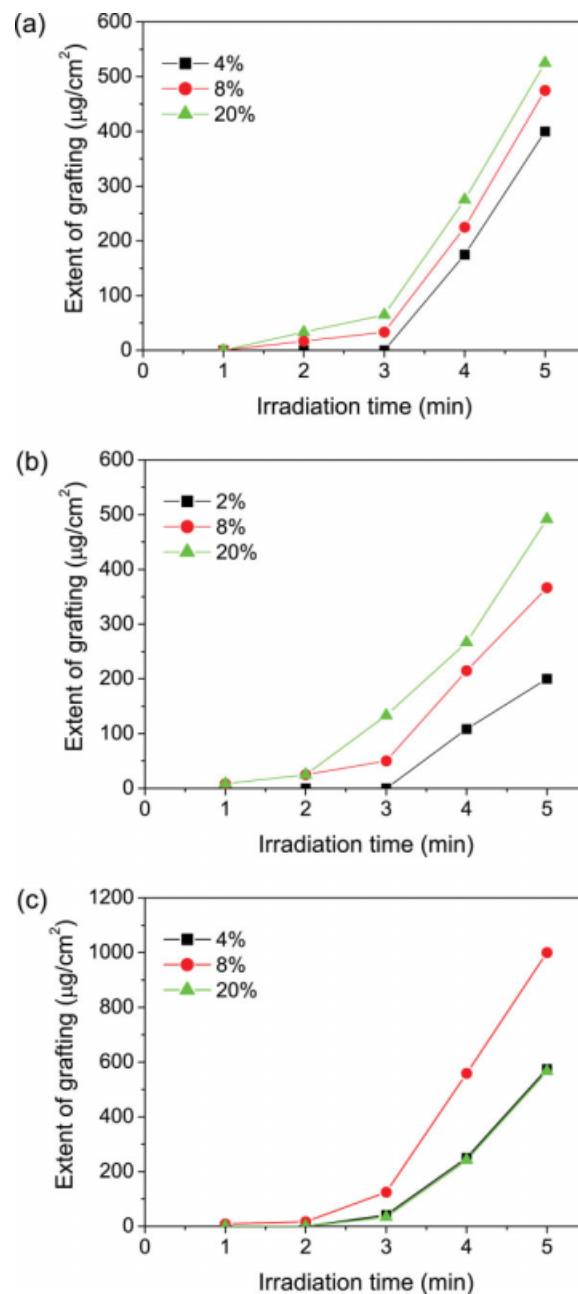


Figure 1 The grafting of AA and MAA onto HDPE surface performed in different formaldehyde aqueous solutions. (a) AA, 1 mol/L; (b) AA, 2 mol/L; (c) MAA, 2 mol/L. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

ing formaldehyde content and a corresponding decrease in water ratio in the tested range. When MAA was used as the monomer, as shown in Figure 1(c), the extent of grafting first increased with the increase of the content of formaldehyde and then decreased. The grafting of MAA performed in the 8% formaldehyde aqueous solution lead to the highest extent of grafting.

The data shown in Figure 2 are selected from Figure 1(b,c) to show the effect of monomer type on the

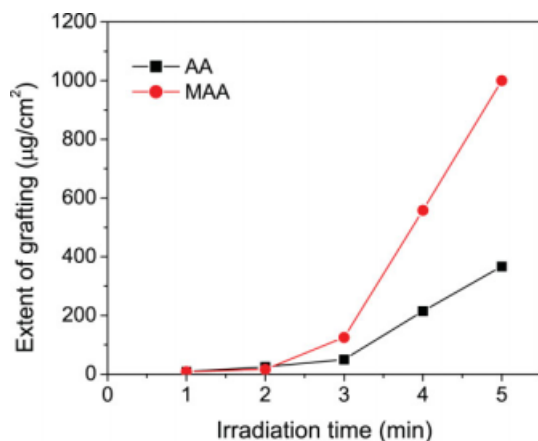


Figure 2 The effect of monomer on grafting. Polymer substrate: HDPE; monomer concentration: 2 mol/L; mixed solvent: 8% formaldehyde aqueous solution. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

grafting initiated by formaldehyde. At the same irradiation time, the extent of grafting was higher for MAA than AA. The former is twice more than the latter. Similar results have been obtained for the grafting of AA and MAA onto HDPE performed in acetone/water mixed solvents.⁸

Monomer concentration also affected the grafting, but its effect varied with monomer. As a general rule, the grafting rate should increase with increasing monomer concentration in a proper range. However, for AA, the effect of monomer concentration was not very significant. The extent of grafting of the HDPE sample grafted in 1 mol/L AA solution was even a little higher than that in 2 mol/L AA solution at the same irradiation time [Fig. 1(a,b)]. For MAA, the effect of monomer concentration in a wide range on the grafting was studied and the results are presented in Figure 3. To simplify the experiments, only the 4% formaldehyde aqueous solution was used and the irradiation time was fixed at 5 min. The extent of grafting first increased with monomer concentration to a maximum of 2.5 mol/L and then decreased.

Grafting on LDPE

Figure 4 shows the grafting of AA and MAA onto LDPE surface performed in different formaldehyde aqueous solutions. When AA was used as the monomer (2 mol/L) [Fig. 4(a)], the extents of grafting of LDPE sample grafted in the three solutions were very close at the same irradiation time. The grafting performed in the 4% formaldehyde aqueous solution led to a little higher extent of grafting than the grafting reactions performed in the 8% and 20% formaldehyde aqueous solutions when the irradiation time was 5 min. When MAA was used as the monomer,

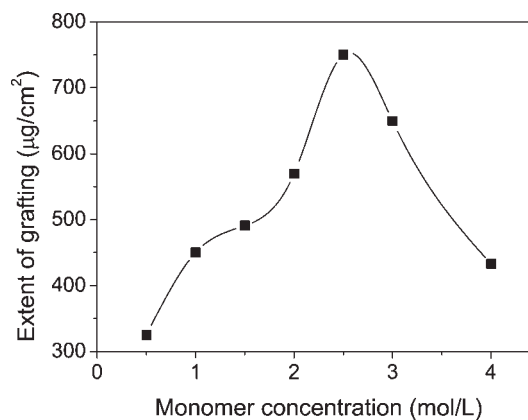


Figure 3 The effect of monomer concentration on grafting. Irradiation time: 5 min; monomer: MAA, polymer substrate: HDPE; mixed solvent: 4% formaldehyde aqueous solution.

as shown in Figure 4(b), the grafting of MAA performed in 20% formaldehyde aqueous solution led to the highest extent of grafting. The extent of grafting of LDPE sample grafted in the 20% formaldehyde aqueous solution reached about 2500 µg/cm².

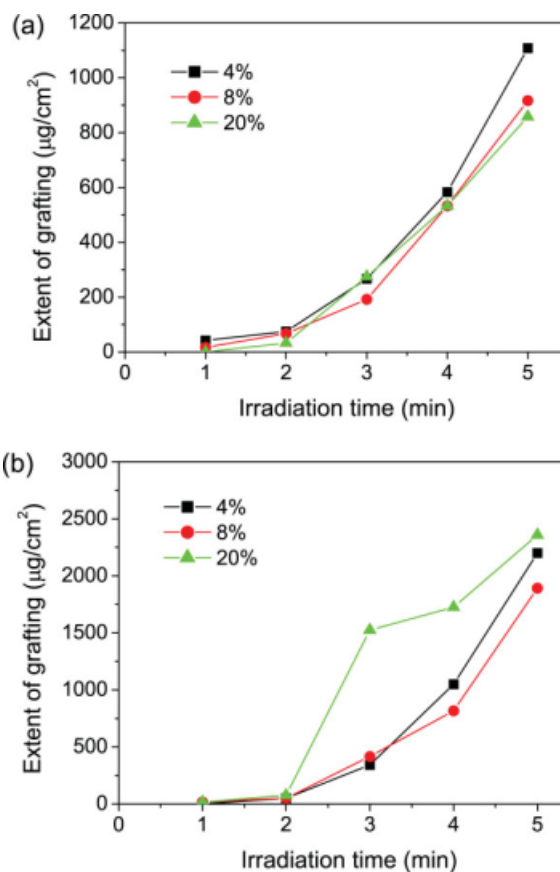


Figure 4 The grafting of AA and MAA onto LDPE surface performed in different formaldehyde solutions. (a) AA, 2 mol/L; (b) MAA, 2 mol/L. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

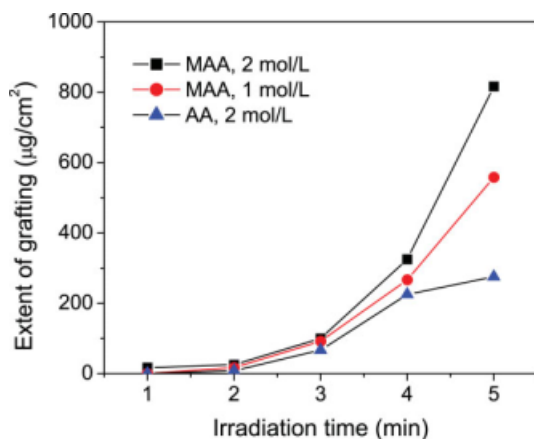


Figure 5 The grafting of AA and MAA onto PP surface performed in 8% formaldehyde aqueous solution. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

The highest extent of grafting for LDPE sample grafted with MAA [Fig. 4(b)] was also more than twice that of LDPE sample grafted with AA [Fig. 4(a)], same as the situation of grafting onto HDPE.

Grafting on PP

The grafting of AA and MAA onto PP surface initiated by formaldehyde was also studied. The grafting reactions were performed in an 8% formaldehyde aqueous solution. As shown in Figure 5, at the same irradiation time, the extents of grafting of PP samples grafted with MAA were higher than those grafted with AA. Monomer concentration also affected the grafting of MAA onto PP. Higher concentration lead to higher extent of grafting.

FTIR characterization

The FTIR spectra of the LDPE and PP samples grafted with AA and MAA, respectively, were obtained and shown in Figure 6.

Because of the oxidation of PP in thermal processing and storage, the FTIR spectrum of pristine PP has a weak absorption peak near 1691 cm^{-1} , which is the characteristic absorption peak of the carbonyl group ($\text{C}=\text{O}$). LDPE is a polymeric material more stable to oxidation than PP because of the lack of tertiary hydrogen atom in its chemical structure, which is sensitive to oxygen attack, so only very weak peak of carbonyl group can be found in the FTIR spectrum of pristine LDPE.

The grafting reactions of AA and MAA onto LDPE and PP were confirmed by FTIR spectroscopy. In the FTIR spectra of the grafted samples, strong absorption peaks occurring at about 1705 cm^{-1} (for samples grafted with MAA) and 1713 cm^{-1} (for

samples grafted with AA) appears. And the absorbance increases with an increase of grafting time. For the grafted LDPE samples, especially those grafted with MAA, when the irradiation is long, the absorption band become too intense, and thus the absorbance cannot be obtained.

The calculated CIs of the grafted samples are shown in Figure 7.

The CI of the grafted samples increased with irradiation time, and the tendency is very similar to the change of the extent of grafting with irradiation time (Figs. 4 and 5). For the grafted LDPE, the CI values are very low when the grafting time is less than 2 min, but after then increases quickly. The $A_{\text{C-H}}$ of grafted PP samples is usually only about one fifth of the $A_{\text{C-H}}$ of grafted LDPE samples. Thus, although the amounts of grafted materials on PP are much lower than that on LDPE, the CI values are very close. The CI value of PP samples grafted for only 1 min is about 5, it is mainly due to the oxidation of PP rather than the grafting.

For both grafted LDPE and PP samples, at the same irradiation time, the CI of the samples grafted with MAA is higher than that grafted with AA. These results are in accord with the results obtained by gravimetric method (Figs. 4 and 5). The difference between the CI values is more significant than that between the extents of grafting at the same irradiation time. It suggests that FTIR spectroscopic method is more sensitive to indicate the occurrence of grafting than gravimetric method. The FTIR spectroscopic method was used as a semi-quantitative method here, however, when it is correlated with gravimetric method, it can be used as a quantitative method in some cases. Of course, the FTIR spectroscopic method can only be used when the amount of grafted material is not too much and the absorbance is not too high.

The water absorbency of grafted samples

The grafted samples were immersed in 50°C water for 48 h to obtain equilibrium swelling. The water absorbency of the grafted samples was plotted as a function of the extent of grafting (Fig. 8).

Figure 8(a) shows the water absorbency of HDPE samples grafted with MAA, the grafting reactions were performed in 4% and 20% formaldehyde aqueous solutions, respectively. For both series of grafted HDPE films, the water absorbency increased almost linearly with the extent of grafting. The water absorbency of the sample grafted in the 20% formaldehyde aqueous solution was a little lower than that of the sample grafted in the 4% formaldehyde aqueous solution at the same extent of grafting.

Figure 8(b) shows the water absorbency of LDPE samples grafted with MAA or AA, the grafting

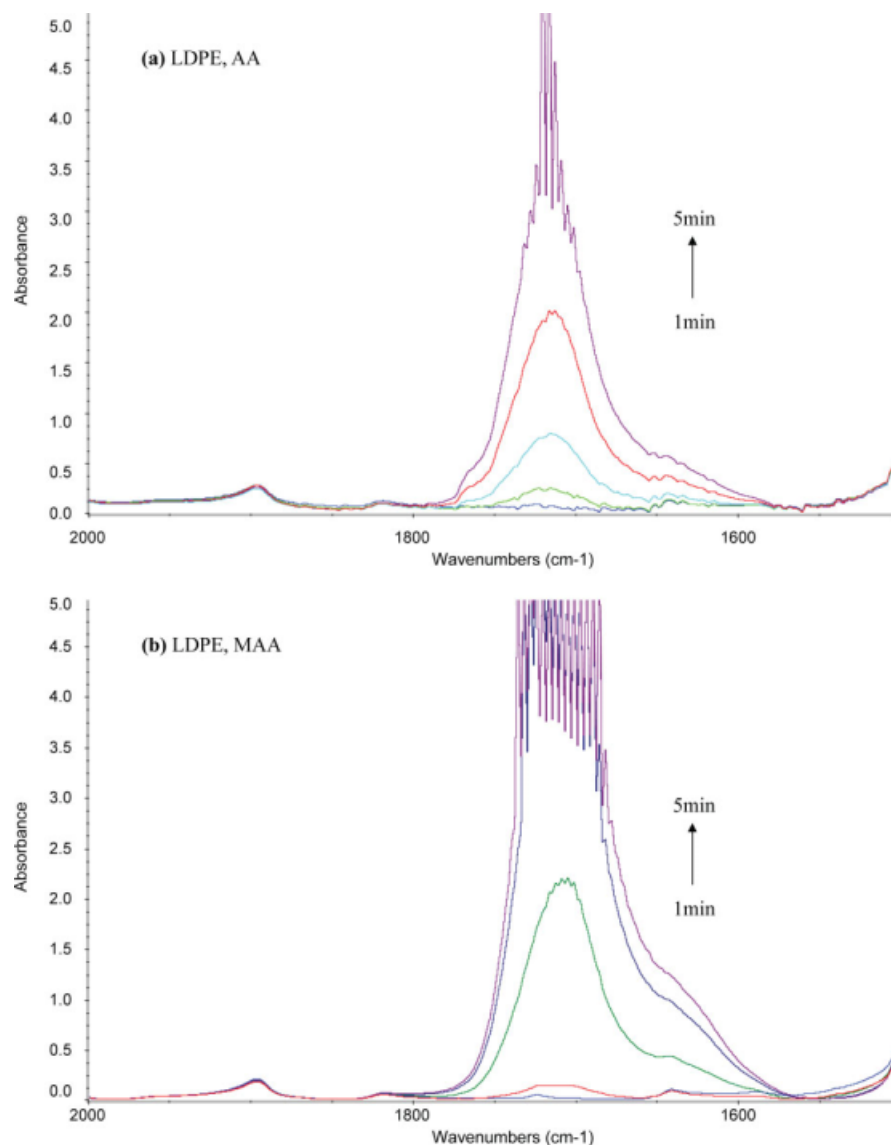


Figure 6 FTIR spectra of the grafted LDPE (a, b) and PP (c, d) samples. Grafting was performed in 8% formaldehyde aqueous solution, monomer concentration was 2 mol/L. The lines from bottom to top are the samples grafted for increasing time, respectively. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

reactions were performed in 4% and 20% formaldehyde aqueous solutions, respectively. For the LDPE samples grafted with MAA, similar to the situation of grafted HDPE samples, the water absorbency of the LDPE sample grafted in the 20% formaldehyde aqueous solution was also a little lower than that of the sample grafted in the 4% formaldehyde aqueous solution at the same extent of grafting. For the LDPE samples grafted with AA, however, the water absorbency of the samples grafted in the 4% and 20% formaldehyde aqueous solutions were almost the same at the same extent of grafting.

Figure 8(b) also shows the water absorbency of LDPE sample grafted with AA was higher than that of LDPE sample grafted with MAA at the same extent of grafting. The HDPE and LDPE samples

grafted with MAA adsorbed approximately 25–35 wt % water per MAA. The amount of water absorbed is similar to that reported for p-MAA layers grafted in water,¹³ acetone/water,¹⁴ and butanone/water/ethanol.¹¹ However, the LDPE samples grafted with AA adsorbed approximately 65 wt % water per AA. The obvious reason for the higher water absorbency of the grafted AA than the grafted MAA is that there are more hydrophilic $-\text{COOH}$ groups on the same amount of grafted AA than on grafted MAA.

Discussions of the grafting

In our previous work, aliphatic ketone/water/alcohol mixed solvents have been used as new and high

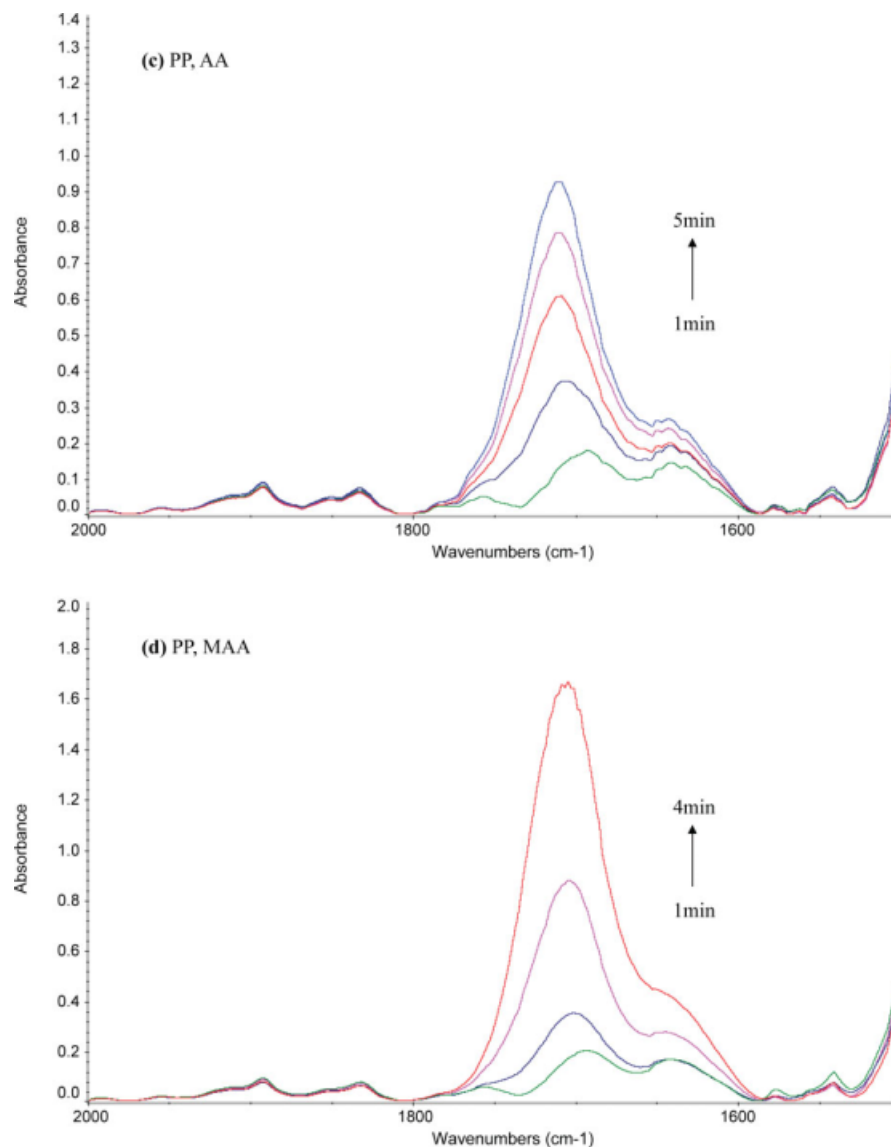


Figure 6 (Continued from the previous page)

efficient photoinitiating systems for the photografting of MAA onto HDPE.^{10,11} This work proves that the aliphatic aldehyde–formaldehyde can also be used as a photoinitiator for photografting when it was dissolved in water to form an aqueous solution with a proper content range.

With comparison to the previous work done with aliphatic ketone/water/alcohol mixed solvents,^{10,11} formaldehyde aqueous solution has a lower initiation efficiency when the aliphatic ketone or formaldehyde content is the same. This probably can be explained as follows: the two alkyl groups attached to the carbonyl group in aliphatic ketones are electron-rich groups, which have higher electron-repelling effect than the hydrogen atoms connected to carbonyl group in formaldehyde, and hence the electron density on the oxygen atom of carbonyl group in aliphatic ketone is bigger than that in formalde-

hyde. Therefore, the oxygen atom of carbonyl group in aliphatic ketone is easier to form stronger hydrogen bonding with water than that in formaldehyde. Under UV irradiation, the excited state of the carbonyl group of aliphatic ketone has a higher energy, which makes the initiation reaction easier to occur.

The discussion is based on the assumption that formaldehyde molecule itself acts as the photoinitiator. However, the fact is that formaldehyde is predominantly chemically bound when dissolved in water.¹⁵ The reason is that, in aqueous solutions, formaldehyde (CH₂O) reacts with water to form methylene glycol (HOCH₂OH, MG) and higher poly (oxymethylene) glycols (H(OCH₂)_nOH, MG_n, *n* > 1) via a series of reversible reactions. The good apparent solubility of formaldehyde in water is actually the good solubility of MG, and the capacity of the solution to accommodate MG_n.¹⁶

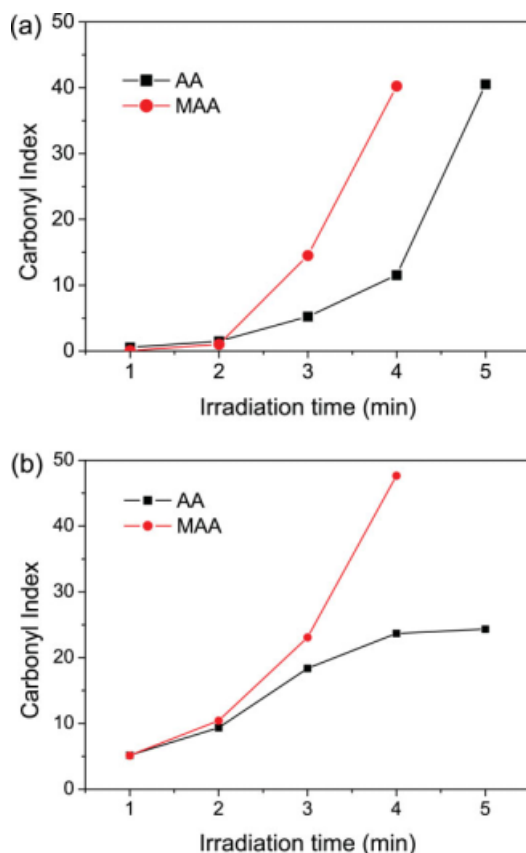


Figure 7 Carbonyl index (CI) of the grafted LDPE samples (a) and PP samples (b) as a function of irradiation time. Grafting reactions were performed in 8% formaldehyde aqueous solution, monomer concentration was 2 mol/L. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Therefore, the true molecules that act as photoinitiator should be the MG and MG_n formed in the aqueous solution. We do not know how they function as photoinitiators for the photografting reactions yet, theoretical calculations the photoinitiation mechanism of the molecules will be performed later.

The grafting reactions of AA and MAA onto HDPE, LDPE, and PP showed similar tendency: there was almost no grafting in the first 1 min; the extent of grafting increased very slowly in 1–3 min; and then in 3–5 min, the extent of grafting increased quicker and almost linearly.

Because the grafting reactions were performed in atmospheric conditions, the grafting solutions dissolved some molecular oxygen, which is a radical scavenger. The oxygen molecules can react with the macromolecular radicals formed on the surface of polymeric substrate or growing grafting chains to form peroxy radicals with low reactivity, hence decrease the grafting degree or even completely inhibit the grafting reaction. Only after the consumption of dissolved oxygen in grafting solution, the grafting reaction can proceed as usual.

The formaldehyde aqueous solution is a polar solvent, which cannot swell the nonpolar polyolefins, therefore, the initiation reaction is difficult to occur on polyolefin surface. This is possibly the reason for the slow increase in the extent of grafting in 1–3 min. However, once there are grafted chains formed, the excited formaldehyde molecule can abstract hydrogen atom from the grafted chains to initiate grafting, i.e., branching. Because the grafted p-AA or p-MAA chains also have secondary or tertiary hydrogen atoms and the grafted hydrophilic chains are soluble in the formaldehyde aqueous solution, the branching is much easier to occur. This is possibly the reason for the faster increase in the extent of grafting in 3–5 min.

The photografting polymerization reactivity of various monomers was examined with BP as the photoinitiator and LDPE film as the substrate by Yang and Ranby.¹⁷ Their results show that acrylate monomers have the highest photopolymerization and photografting reactivities, whereas methacrylate monomers have low reactivities because of the

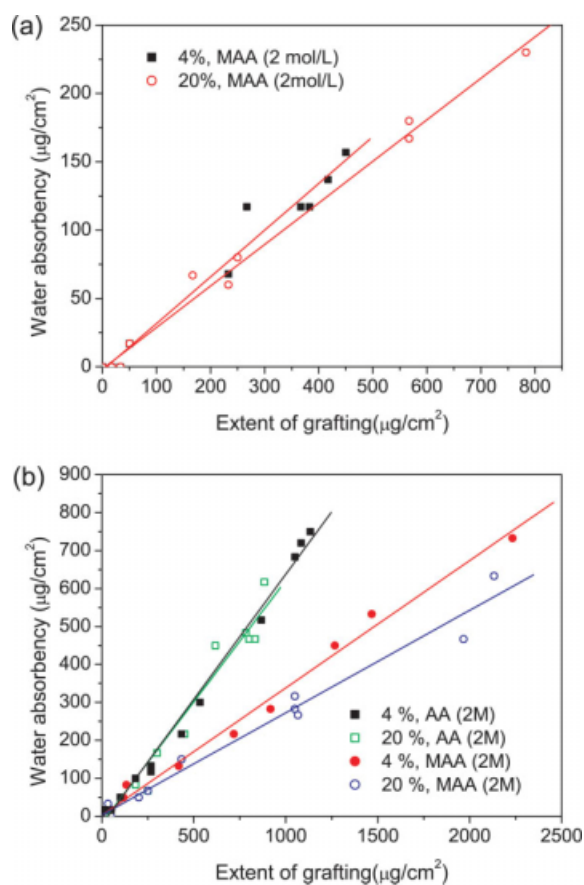


Figure 8 Water absorbency of HDPE (a) and LDPE (b) samples grafted in different MAA and AA formaldehyde aqueous solutions as a function of the extent of grafting (48 h immersion in 50°C water to obtain swelling equilibrium). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

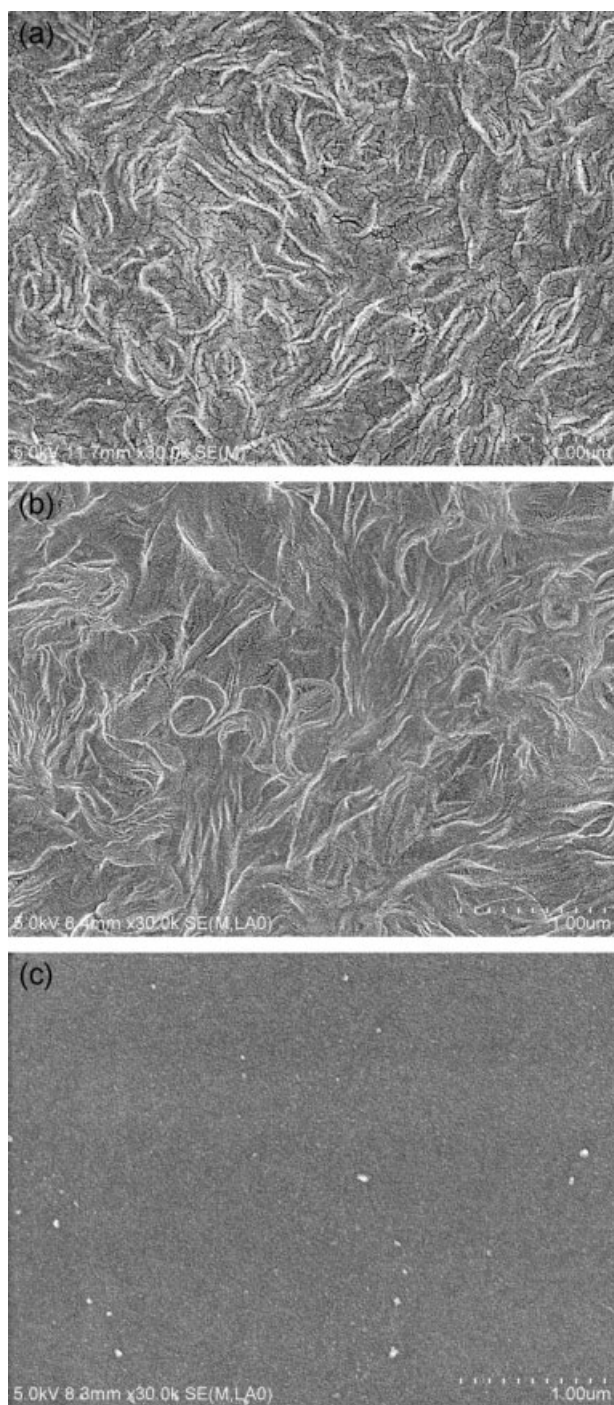


Figure 9 SEM micrograms of pristine HDPE (a), LDPE (b), and PP (c).

allylic hydrogen atoms in the monomer and no tertiary hydrogens on the polymer formed. However, in this study, MAA was easier to be grafted onto the three polyolefins than AA. One possible reason is that formaldehyde can produce more free radicals under UV irradiation than BP, and then AA is easier to be photopolymerized to form homopolymers than MAA because of the higher photopolymerization reactivity of AA. The more consumption of monomer

for photopolymerization, the less for photografting. More homopolymers formed lead to the higher viscosity of the solution, which retards the diffusion of monomer to the active sides on polymer substrate. The two factors lead to the lower grafting rate.

The polymer substrate significantly affected the grafting rate. The easiness of grafting occurring on the polyolefins was in a decreasing order of LDPE > HDPE > PP in this study. For PE samples, the differences in the grafting rate as a function of irradiation time can be attributed to the differences in crystallinity of the polymers.¹⁸ Grafting is easier to occur in the amorphous regions of the polymer because high crystallinity prevents penetration of the reaction solution into the base polymer. The grafting rate for HDPE is slower than that of the LDPE because of the higher crystallinity of the former polymer.

Yang and Ranby evaluated the photografting reactivity of polymer substrates by using AA and BP as the monomer and photoinitiator, respectively.¹⁷ Their results show a sequence of decreasing photografting reactivity in the order PP > LDPE > HDPE. They interpreted the sequence in terms of difference in surface hydrogen atoms. PP has tertiary hydrogen atoms, which requires lower energy to be abstracted by the excited state of photoinitiator, in its chemical structure. It is reasonable to assume that PP should have higher photografting reactivity than PE. However, PP showed the lowest photografting reactivity in this study. This is possibly due to the PP substrates used were different. The PP substrate used in this study was much smoother than the HDPE and LDPE substrates at a sub-micrometer scale (Fig. 9). The former has a smaller surface area for grafting reactions to occur and hence leads to the low extent of grafting.

CONCLUSIONS

On the basis of this work devoted to the surface photografting of AA and MAA onto HDPE, LDPE, and PP, respectively, performed in formaldehyde aqueous solutions in the absence of any other photoinitiators, the following conclusions can be drawn:

1. Formaldehyde can act as an effective photoinitiator for water-borne photografting when it is dissolved in water with a proper content.
2. The grafting reaction initiated by formaldehyde aqueous solution is affected by several factors: the content of formaldehyde in the solution, monomer type, monomer concentration, and polymer substrate. And their effects on grafting vary with different grafting systems.

This study had broadened the water-soluble photoinitiating system from aliphatic ketone/water/alcohol to aliphatic aldehyde–formaldehyde aqueous

solution. Possibly, some other aliphatic aldehydes can also be used as photoinitiators for photografting when they are dissolved in water. Of course, similar to the aliphatic ketones, the aldehydes with longer carbon chains can only be dissolved in water with the assistance of a cosolvent, such as alcohol.

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