Available online at www.pelagiaresearchlibrary.com

Pelagia Research Library

Der Chemica Sinica, 2012, 3(2):378-390

ISSN: 0976-8505
CODEN (USA) CSHIA5

Synthesis of one pack hybrid epoxy resin emulsion for coating application

R. N. Patil*, B.V. Sharma and P. A. Mahanwar

Department of Polymer and Surface Engineering, Institute of Chemical Technology (ICT), Mumbai, India

---

ABSTRACT

Hybrid Epoxy resin one pack system was prepared using conventional emulsion polymerization techniques. The effect of increasing the resin percentage of properties of hybrid emulsion was studied. The hybrid polymer coatings were applied on metal surface and were evaluated for physicochemical, physicomechanical and anticorrosive performance under different environmental conditions. Salt spray test and Electrochemical Impedance spectroscopy (EIS) was used to study the anticorrosive behavior of hybrid coatings. The present hybrid epoxy system was found to be stable for a long period of time. It was found that with increase in epoxy resin to acrylate monomer ratio the corrosion resistance of the coating increases but the stability of the emulsion get affected after optimized ratio.

Keywords: Emulsion polymerization, Grafting, EIS, Corrosion resistance, SEM.

INTRODUCTION

The field of polymer chemistry since last few decades is approaching towards new eco-friendly route to develop polymers, in order to minimize or eliminate the utilization of toxic chemicals, particularly organic solvents, which are hazardous to health and the environment [1, 2]. Scientists and technologists trying to innovate green technologies like powder coatings, UV cured coatings, solvent-less coatings, and waterborne coatings. Water-based coatings have become more widely used in the past several decades because they are environmentally friendly and offer easy clean up also their properties and application performance characteristics have been improved.

Epoxy resins have excellent characteristics, such as heat resistance, high strength, good corrosion resistance and good adhesion [3]. Epoxy in combination with different hardener has been used as protective coatings [4, 5]. However; they have a short pot life, poor or low fracture energy, high shrinkage, and show brittle behavior [6]. The solvent based one phase epoxy system to be used in coating applications are reported in the literature [7], but such systems contribute to volatile organic content (VOC) emission. The purpose of this work was to examine the feasibility of polymerizing acrylic monomers in the presence of epoxy resins to determine if this hybrid system could act as one pack system. Hybrid polymer can be defined as the system in which each particle contains at least two distinct polymers [8, 9].

In this article, the polymerization of acrylate in the presence of epoxy resin was carried out via conventional emulsion polymerisation to get the hybrid epoxy-acrylate (Ep-Ac) emulsion. Hybrid Ep-Ac emulsion was synthesized with increasing percentage of epoxy resin. Anticorrosive behaviors of hybrid coatings were evaluated with salt spray test and electrochemical impedance spectroscopy.

MATERIALS AND METHODS

NPEL-128s is one of the diglycidyl ethers of bisphenol A (DGEBA) epoxy resin which was kindly provided by Resin & Plastics (I) Ltd. Mumbai. Butylacrylate (BA) and methylmethacrylate (MMA), Acrylic acid (AA) and 2-hydroxyl ethyl methacrylate (HEMA) were purchased from Indofil chemicals, potassium persulfate (KPS) used as initiator, ethylene diamine (EDA) solution used for neutralization and sodium bicarbonate (SBC) as a buffer was purchased from Sigma Aldrich. Neoigen DK X 405 (HLB 17.8) nonionic surfactant and Daninol 25P anionic surfactant supplied by Dai-Ichi Karkaria, EOPO copolymer (HLB 14-15) nonionic surfactant and H-301 anionic surfactant was supplied by venus ethoxyethers pvt. (I) Ltd, Mumbai. Distilled and Deionized water was used throughout all experiments arranged here. All the other chemicals used in this work were AR grades obtained from a S.D. Fines Chemicals used without further purification.

Preparation of Epoxy-Acrylate organic Phase

The organic phase of epoxy resin and acrylate monomers was prepared by dissolving epoxy resin into acrylate monomers to get a clear and transparent solution. The recipe used in the preparation of organic phase for emulsion polymerization is indicated in Table 1.

Preparation of hybrid emulsion

The synthesis of hybrid Ep-Ac was carried out in a 500 ml four necked reaction vessel equipped with a reflux condenser, nitrogen gas inlet, mechanical stirrer, addition funnels, thermometer placed in a water bath. Typical recipe used for synthesis of hybrid is indicated in Table 1.

Table 1: Typical recipe for Synthesis of hybrid Epoxy emulsion

Components	Concentration (%)
Aqueous Phase	
D.I. water	49.31
Neoigen DK X 405	1.05
Daninol 25P	0.40
SBC (buffer)	0.04
Organic Phase	
Epoxy resin	25.99
BA	9.13
MMA	8.97
HEMA	1.53
AA	1.53
EOPO copolymer	1.62
H-301	0.20
$K_2S_2O_8$	0.2

The deionized water, surfactants mixture and buffer were charged to the flask at room temperature (30°C) with stirring speed of 250 rpm. The temperature of the aqueous phase was raised to 65 °C followed by addition of 33.33% potassium persulfate under nitrogen atmosphere. The polymerization was initiated with the addition 22% of total organic phase. After an initiation period of 0.5 hours remaining organic phase was charged slowly dropwise with constant feed rate simultaneously with the rest of the potassium persulfate solution over a period of 2-2.5 hour at 75 °C. After addition of all the ingredients, the reaction mixture was allowed to stir for additional 1 hour and then the temperature of the vessel was raised to 80°C for 0.5 hours. Neutralization was carried out at 50 °C with 33% EDA solution in deionized water. Finally emulsion was cooled to room temperature and stored in sealed container. The hybrid emulsion was synthesized with increasing amount of epoxy resin into the organic phase indicated in Table 2. The ratio of the aqueous phase to organic phase remains constant throughout all the experiments.

Table 2: Formulations for Epoxy Acrylate emulsions

Formulation	H1	H2	H3	H4	H5	H6	H7
Epoxy: Acrylics [a]	0:100	20:80	30:70	40:60	50:50	60:40	70:30
Epoxy: Acrylics [b]	0:100	8.3:91.7	12.4:87.6	16.4:83.6	20.5:79.5	24.6:75.4	28.8:71.2

a: weight ratio, b: mole ratio

CHARACTERIZATION

FT-IR spectroscopic analysis

Structural characterization of the hybrid polymer was performed using FT-IR on *Perkin Elmer FT-IR system spectrum BX.*

FT-IR ATR was performed on Magna-IR 550 FTIR spectrometer (Nicolet Instruments, Madison, WI). The scanning was repeated at least 200 times before the spectra were recorded at a resolution of 2 cm^{-1}. The hybrid emulsion was cast on clean glass and dried to prepare the films for analysis.

^{13}C-NMR spectroscopic analysis

^{13}C NMR Spectrum was obtained by *Bruker/advance AV 500WB spectrophotometer (Bruker Biospin, Switzerland)* operating at 500-MHz solid state NMR Spectroscopy. De-emulsified emulsion sample was dried at 50 ºC for 24 hrs and then ground to get fine powder for the analysis.

Thermal analysis

Thermal analysis was carried out using *DSC Q100, TA* Instruments, polymer latexes were de-emulsified washed, dried and then used for analysis. About 5 mg of sample was used for the analysis. The DSC scanning was performed from 100 to -50°C at a heating rate of 10°C/min under a nitrogen atmosphere.

Physicochemical characterization of Emulsion

The progress of the reaction was determined gravimetrically. For each experiment, three parallel samples were dried and solid content was determined as an average value of the three samples according to ASTM D 2834. The pH values of the hybrid emulsions were measured by means of a digital pH meter (Mettler Toledo). The viscosity of the emulsion was recorded using (ASTM D2196) Brookfield Viscometer using spindle no. 3 at 30 °C.

Hydrophobicity of Polymer Films

The hydroscopicity of copolymer’s film was tested according to ASTM D 570-8. The weighted films were dipped in distilled water at 25°C for 48 hours. Then, the free water on surface of films was cleared by filter paper, and the film was weighted again. The water absorption ratio of films was calculated by following equation:

$$\text{Water Absorption Ratio (Wt \%)} = \frac{(W1 - W0)}{W0} \times 100$$

Where W_0 is the weight of dry film, and W_1 is the weight of the film absorbing water, respectively.

Emulsion stability

The shelf-life of waterborne dispersions is a very important characteristic, which determines their safe storage period. The shelf life of the emulsion was analyzed by storage of emulsion under room temperature (30°C) for six months and accelerated storage stability test was performed by visually evaluating the stability of the sample after storage at 50°C in oven for a period of 7 days. Any kind of phase separation was noticed.

Electrolytic stability of emulsion was tested using 5% alum solution prepared in D.I. water. The amount of electrolyte required for coagulation to take place was taken as a measure of electrolytic stability.

Freeze thaw stability was measured according to ASTM D 2243-95 by subjecting samples to cycles of the frozen environment followed by ambient one. Capped vials containing samples were put in the freezer at -17ºC for 12 hours and then put on the shelf (30 ºC) for the same time. This cycle was repeated until coagulation or separation occurred.

Morphology of hybrid

The morphology of these emulsions was observed with a ZEISS SUPRA 40 Scanning electron microscope (SEM). Particle size and distribution of emulsion were measured by dynamic light scattering Malvern mastersizer. Samples were diluted to low concentrations (5mL/1000mL) with deionized water and then subjected for the particle size and particle size distribution analysis.

Determination of molecular Weight

The hybrid epoxy-acrylate emulsion was de-emulsified with methanol, washed 5 times with deionized water, followed by drying at 50°C under a vacuum oven for 24 hours to obtain the hybrid copolymers. GPC were used for determination of molecular weight and molecular weight distribution. The sample was prepared with 0.8 wt % polymers in THF and run through a Waters Liquid chromatograph at 30°C. This system consisted of a waters 150 pump, refractive index (RI) detector, and two ultrastyragel columns with THF as eluent phase. The elution volumes were converted to apparent molecular weights using narrow distribution polystyrene standards.

Degree of Grafting

Solvent extraction is an effective method used by many researchers for determination of degree of grafting [10, 11]. Solvent Extraction was performed in a soxhlet extractor, using diethyl ether and ethyl acetate as the solvent for the measurement of degree of grafting; then tetra hydro furans (THF) was used as solvents for the measurement of possible crosslinking. The extraction procedure involved about 1 gm of dried emulsion polymer wrapped with filter paper and placed into the extractor. After extraction with diethyl ether for 24 hr, unreacted free epoxy resin present in sample was extracted with ethyl acetate for a period of 12 hr. The sample was dried and weighed for grafting determination. Grafted and ungrafted epoxy resin where extracted with the diethyl ether, while ungrafted epoxy was extracted with ethyl acetate. After extraction with diethyl ether residual part were pure polyacrylate, crosslinked material or both while the final residual sample after extraction ethyl acetate will compose of grafted epoxy-acrylate. For the measurement of crosslinking percentage, the weighed sample was extracted with THF for 12 hours and then dried and weighed again. After extraction with solvents, the remaining material was assumed to be the crosslinked polymer.

Preparation and characterization of waterborne coatings

The hybrid coatings of the prepared emulsion were applied on commercially available mild steel strips of 1000 × 700 × 0.5 mm size for physicomechanical properties. Dry film thickness of coatings was measured according to ASTM D 1005. Gloss at 60° was measured as per the ASTM standard D523-89 on a multiangle glossometer.

Corrosion resistance

Salt spray test (ASTM D 1654) was performed to study the corrosion resistance of hybrid coatings. 5% NaCl salt water solution was used as corrosive environment; test was performed in a period of 500 hours. Coated panels were examined periodically after 100 hours for blistering or sign of corrosion.

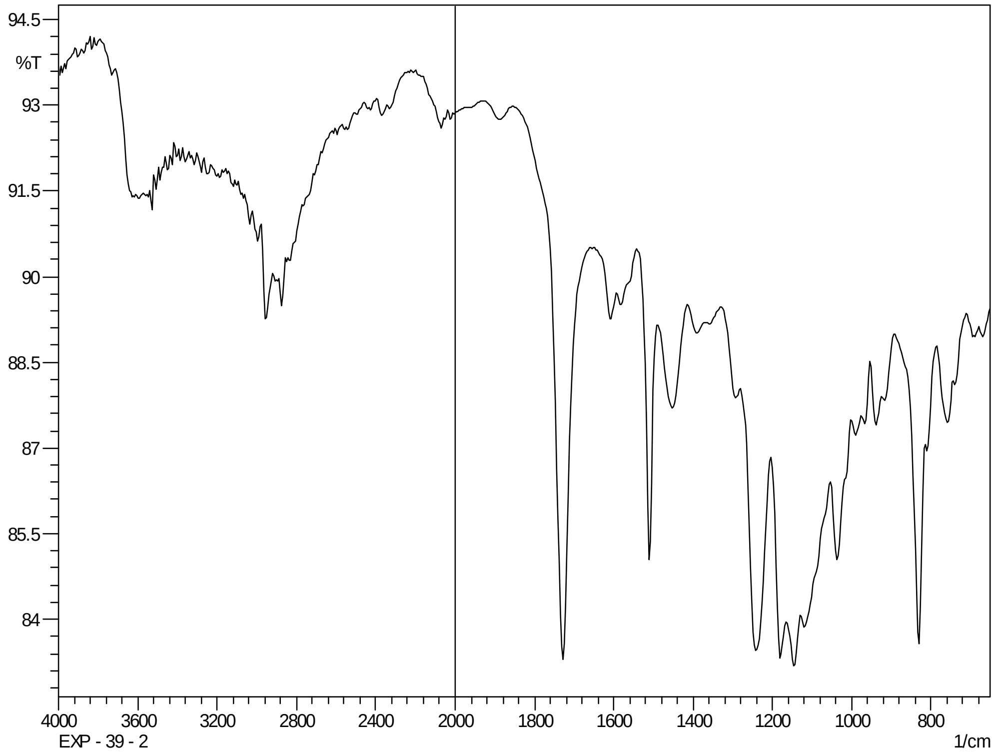
The use of EIS for measurement for corrosion resistance study are reported in the literature [12]. The anticorrosive performance of the coated specimens was monitored using electrochemical impedance spectroscopy. DC polarization study was performed in 3% Nacl solution at scan rate of 1.66 mV/s. A saturated calomel electrode (SCE) was used as the reference electrode. It was coupled capacitively to a Pt wire to reduce the phase shift at high frequencies (Princeton applied research, VersaSTAT 3). The corrosion rate of coatings was obtained as millimeter per year (mmpy).

RESULTS AND DISCUSSION

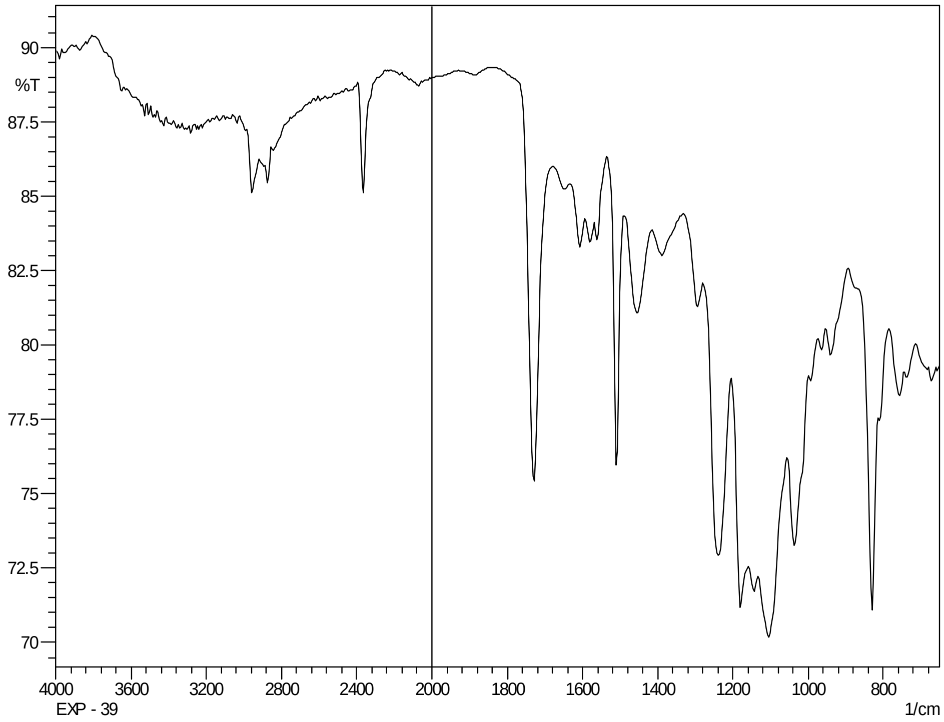
Hybrid Epoxy- Acrylate (H6) (FTIR-ATR, cm^{-1})

The peak at 3438 cm^{-1} was due to –OH stretching, peak at 2922 cm^{-1} indicates $-CH_2$, symmetrical stretch vibration. The carbonyl group (>C=O) peak at 1729.28 cm^{-1} confirms presence of acrylate polymer. The peak at 1038.79 cm^{-1} was due to aryl alkyl ether, symmetrical stretch present in epoxy resin [Figure 1 I]. Secondary hydroxyl groups present in the epoxy backbone shows medium intensity band at 1171 cm^{-1}. The comparison of the two spectra shows that the intensity of the peak at 917cm^{-1} due to the oxirane ring of the epoxy resin was decreased after addition of EDA. The lowering of the oxirane ring peak intensity was expected due to the ring opening and crosslinking between oxirane of epoxy resin and $-NH_2$ group of the EDA. The absence of two sharp N–H stretching bands near 3335 $cm^{-1}$and broadening of 2922 cm^{-1}peak intensity due to tertiary amine N-CH_2 stretching shows that the four hydrogen atoms present in the EDA has reacted with four oxirane ring to give tertiary amine in crosslinked structure.

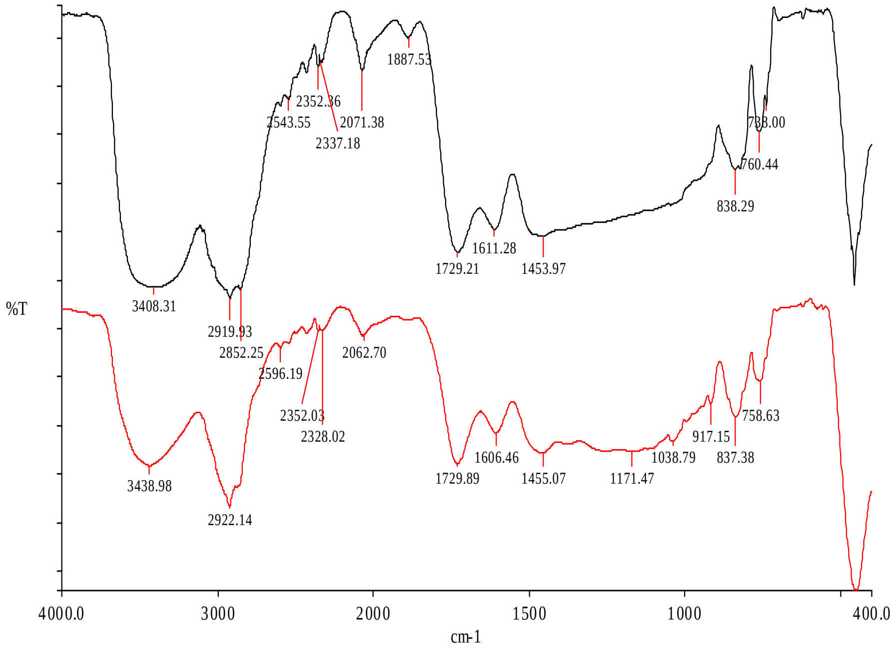
Figures 1 (a)) FTIR-ATR spectra H6 air facing, (b) FTIR-ATR spectra H6 metal facing (c) FTIR Spectra of H6 before and after curing



(a)

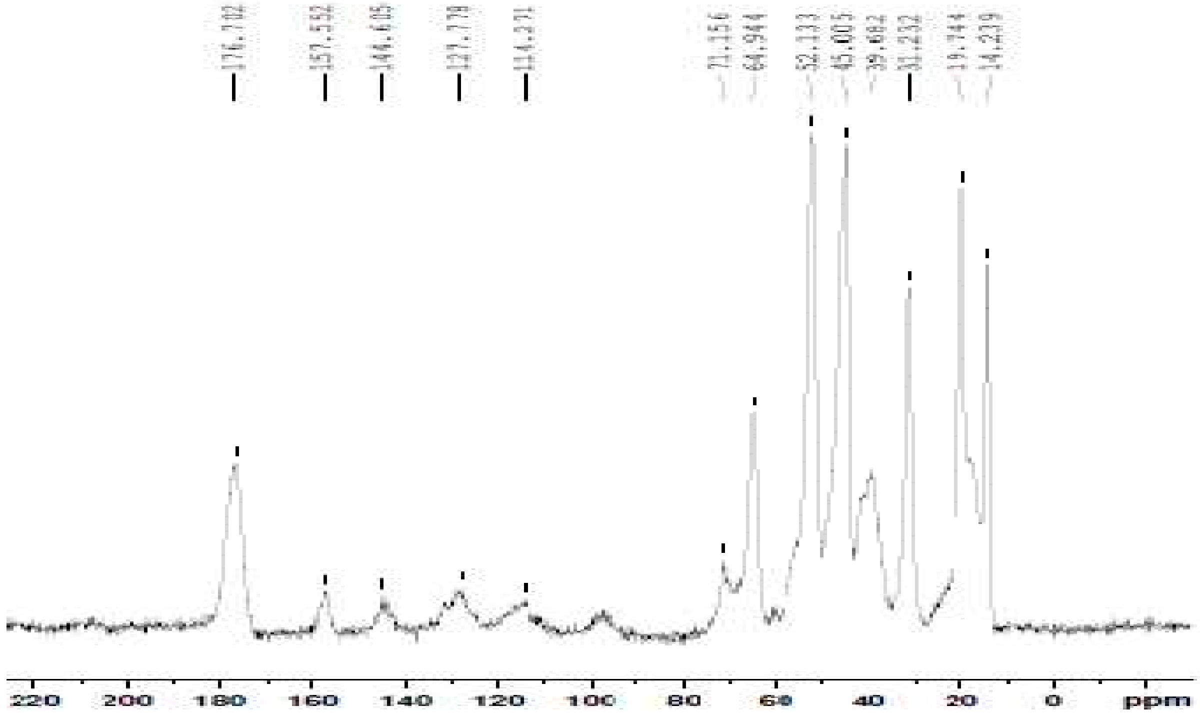


(b)



(c)

Figure 2 Solid state ^{13}C NMR of hybrid H6



Structural confirmation by ^{13}C NMR spectrum

Structural confirmation of hybrid Ep-Ac polymer was performed with ^{13}C NMR analysis. The signal at 14.18 ppm and 19.71 ppm represents $-\underline{C}H_3$ and $-\underline{C}H_2$ carbon of acrylate polymer. The quaternary carbon of acrylates shows signal at 39.52 ppm. The methylmethacrylate used in recipe give signal at 52.1 ppm for $-O\underline{C}H_3$ group. The $-\underline{C}H_2$-OH carbon of HEMA shows signal at 64.9 ppm. The carbonyl carbon of acrylates gives signal at 176.7 ppm, the presence of signals for acrylate confirms their presence in hybrid polymer. Signal for $-\underline{C}H_3$ group of epoxy resin appears at 31.29 while for $-\underline{C}\,(CH_3)_2$ at 45 ppm. The quaternary $\underline{C}$–OH of epoxy resin after grafting shows peak at 71.15 ppm. Signals at 114.2 ppm, 127.7 ppm, 144.6 ppm and 157.5 ppm are due to aromatic ring carbons of epoxy resin.

Structural orientation by FT-IR ATR

The hybrid latex with different levels of epoxy resin were cast on clean glass and dried to prepare the films for FTIR-ATR analyses. Figure 1 (a) demonstrates the representative FTIR spectra for the air-facing side and Figure 1 (b) metal-facing side of the hybrid H6 containing 60 wt % epoxy resin. Both spectra display similar absorbing bands at the same wavelength, suggesting that they are analogous in structure. If the peak at 1508 cm^{-1} for stretching of *para*-phenyl could be indicated as the concentration for the epoxy resin and the peak at 1729 cm^{-1} for the absorption of carbonyl used as an index for the concentration of the acrylic-copolymer, then the relative concentration of the epoxy distributed in the film can be judged by the absorbance intensity ratio of the peak at 1508 cm^{-1} to the peak at 1729 cm^{-1}, as shown in Figures 1(a) & 1(b). Absorbance intensity of 1508 cm^{-1} peak at the metal facing side is higher than those at air-facing side, suggesting that the epoxy resin part in emulsion tends to move to the metal facing side. The driving force for this movement could be attributed to the difference in the surface free energy between the epoxy resin and the acrylic copolymer. The critical surface tensions of poly butyl acrylate, polyacrylic acid, poly methylmethacrylate and poly 2-hydoxyl ethyl methacrylate are around 31, 11.1, 39 and 37 mN/m, respectively [13], so the critical surface tension of the acrylic copolymer should be between 11 and 39 mN/m, which is lower than that of the epoxy resin, which is around 44 mN/m.

Thus, during the process of casting and drying the hybrid films, the acrylic-copolymer segments tried to aggregate near the air-facing layer and the epoxy segments moved to the mold-facing side to minimize the surface energy. This migration is very beneficial in the application of coatings, because epoxy resins have excellent corrosion resistance while acrylic copolymers remaining on the air-facing side have very good weatherability and appearance.

Figure 3 DSC for H6

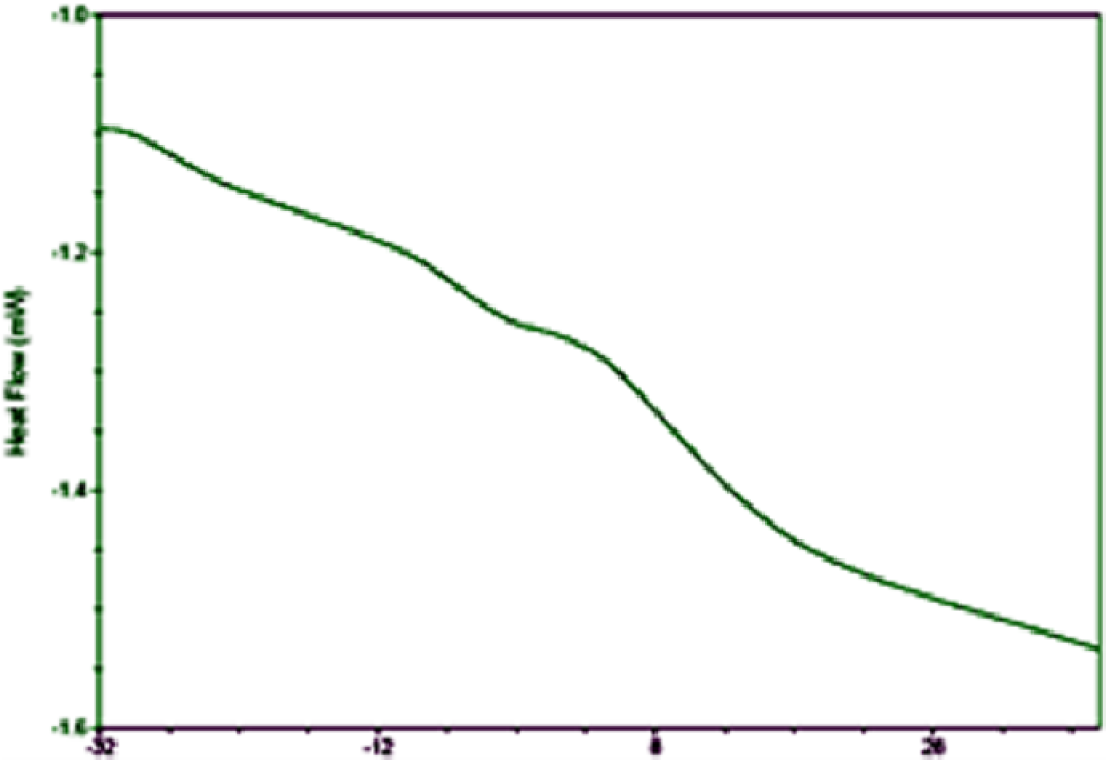


Table 3: Particle size and Tg with different Epoxy/acrylate percentage

Epoxy/ acrylics	Particle size µm	Tg Tested °C		
		I	II	III
H1	0.122	N/A	N/A	20.32
H2	0.168	-28.88	-3.82	21.35
H3	0.176	-25.98	-8.10	19.85
H4	0.187	-25.43	-7.98	18.56
H5	0.176	-30.12	-9.03	22.17
H6	1.20	-28.93	-7.07	19.25
H7	3.33	-27.76	-8.45	18.39

Glass-Transition Temperature and degree of grafting

For the hybrid polymerization system, a graft copolymer of epoxy and acrylates was expected. To confirm this, the polymer samples were analyzed by DSC. Figure 3 shows a typical heat flowchart for Sample H6. From the chart, three glass-transition temperatures (*Tg*) can be identified, indicating three distinct types of polymer. The first *Tg* is at about -30 to -25°C. This is thought to be ungrafted epoxy .The second *Tg* is at -5 to -9°C. This peak corresponds to poly (acrylate-graft-epoxy). The third *Tg* is at 0 to 10 °C and results from polyacrylate copolymer.

The measured glass-transition temperatures for all samples are given in Table 3. The higher *Tg*s correlate with the *Tg*s of polyacrylate copolymer and poly (acrylate-graft-epoxy) copolymer. Therefore, the polymer resulting from emulsion polymerization appears to be of two types: polyacrylates and poly (acrylate-graft-epoxy). The presence of poly (acrylate-graft-epoxy) serves to compatibilize free epoxy and polyacrylate during film formation.

The relative proportions of grafted and pure polyacrylates were determined by extraction. Poly (acrylate-graft-epoxy) and free epoxy are known to be soluble in THF and ethyl ether; polyacrylates are not soluble in ethyl ether but do dissolve in THF. Highly crosslinked polymer does not dissolve in any solvent. All of the samples analyzed here dissolved in THF. This indicates feebly crosslinked polymer existed in the samples. After extraction with diethyl ether, only a small amount of polymer remained. This was assumed to be polyacrylate, whereas the extracted polymer was considered to be poly (acrylate-graft-epoxy) and free epoxy. The ungrafted epoxy was extracted with ethyl acetate.

The fraction of polyacrylate in the form of polyacrylate-graft-epoxy was calculated as:

$$\text{Degree of Grafting} = \frac{\text{Weight of polyacrylate grafted to epoxy}}{\text{Weight of total acrylate monomer}} \times 100$$

Table 4 Degree of Grafting with different Epoxy Resin to monomer ratio

Sample	Sample weight(g)	Residual weight after extraction	Degree of grafting
H1	N/A	N/A	N/A
H2	1.271	0.412	0.902
H3	1.424	0.658	2.24
H4	1.315	0.689	4.10
H5	1.708	0.728	4.87
H6	1.101	0.376	6.87
H7	1.400	0.432	10.93

Molecular Weight

Figures 4 is a typical representative of the GPC measurements for the hybrid H6 emulsion using the RI detector. In the RI curve the first peak corresponds to a molecular weight of more than 700,000, which can be taken as the GPC chromatogram of the copolymer, including the epoxy-acrylic graft copolymer and the engrafted acrylic copolymer. The second one corresponds to a molecular weight of less than 1000, which is obviously the GPC chromatogram of the ungrafted epoxy resin.

Table 5 summarizes the GPC results for all hybrid polymers. The increase in the epoxy resin concentration corresponds to the decrease in the acrylic monomer concentration, so the weight-average molecular weight decreases. The increase in the epoxy resin concentration causes an increase in the numbers of active hydrogen atoms, but the increase in the epoxy resin concentration decreases the concentration of acrylic monomers concurrently because the total solid content was maintained constant in our experiments.

Figure 4 GPC chromatograms for H6

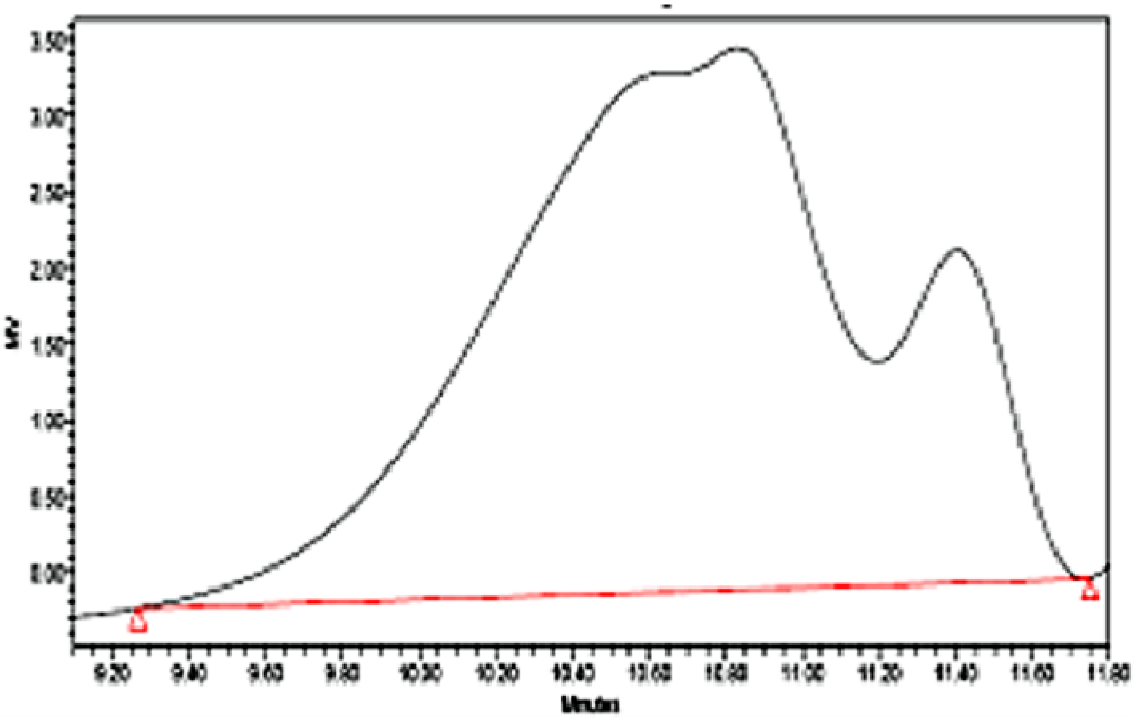
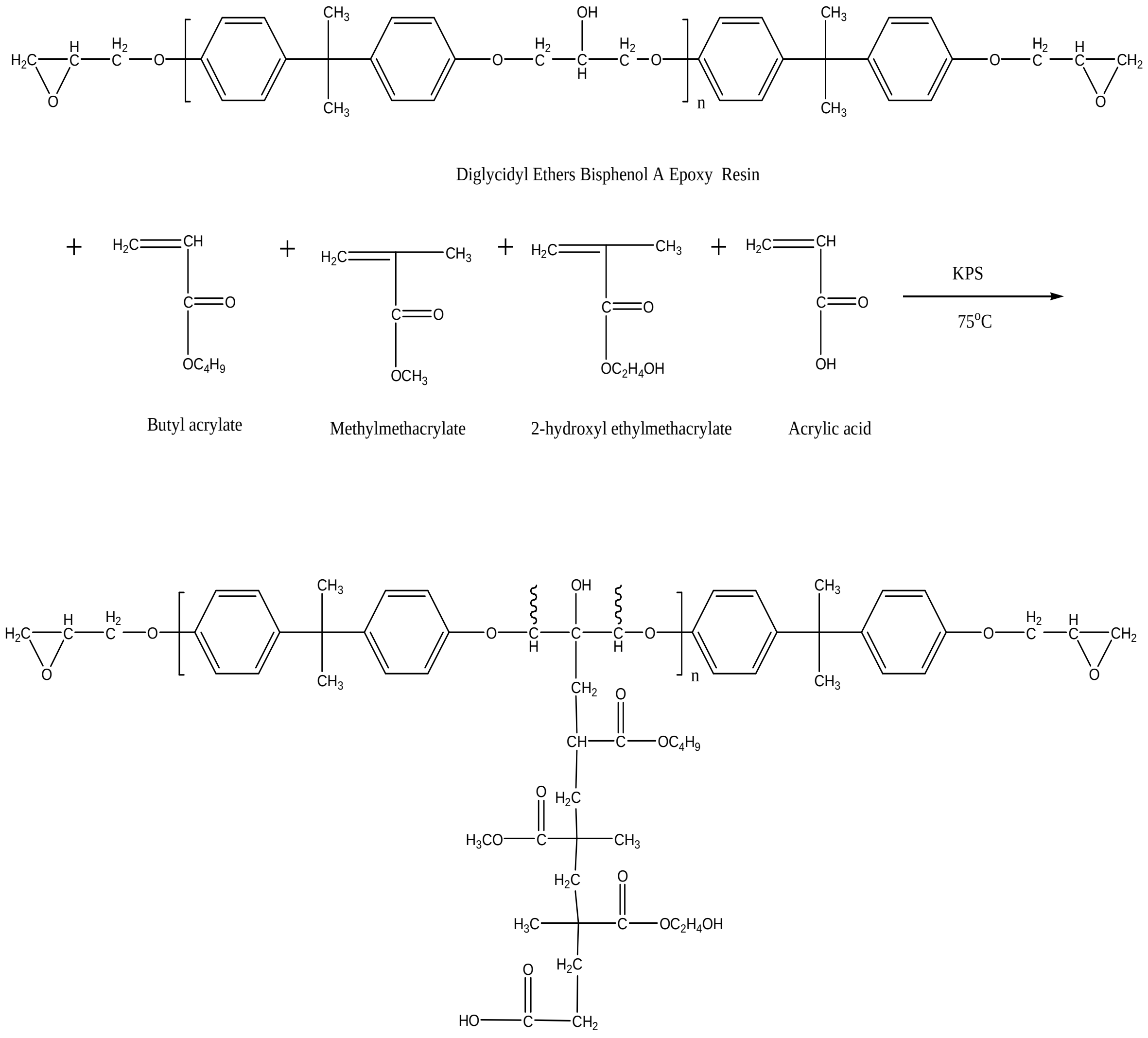


Table 5: GPC results for hybrid Ep-Ac polymer

Epoxy/ acrylics	Molecular weight		Polydispersity
	Mw	Mn	
H1	928021	905437	1.009
H2	796574	778620	1.013
H3	766417	748721	1.025
H4	630491	615632	1.024
H5	680538	679854	1.0314
H6	789793	776543	1.196
H7	697865	689641	1.212

Analysis of hybrid polymer with ^{13}C-NMR, FTIR, DSC and GPC indicates that acrylic monomers had grafted onto the epoxy resin. Graft reaction and reaction mechanism between epoxy resin and acrylate was proved by woo and ting showed that the most probable grafting locations on epoxy resin molecular chains were tertiary carbon and adjacent secondary carbon [14]. Grafting site on epoxy backbone was also been studied on the basis of gibbs free energy criterion [15]. The reaction between epoxy and acrylate can be represented as follows.

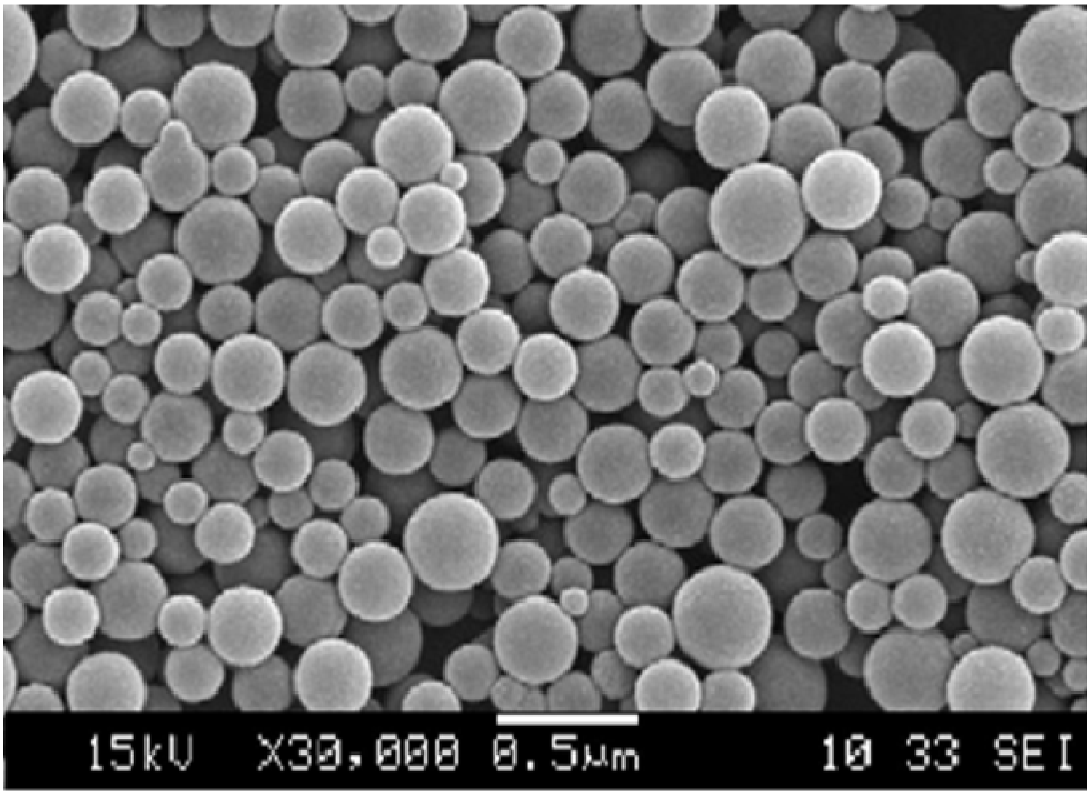
Figure 5: Reaction between epoxy and acrylate



Morphology of hybrid polymer

The SEM micrographs of H6 hybrid emulsion particles are presented in Figures 6. Indicate that the shape of the emulsion particles is uniformly spherical. The particle size in the hybrid Ep-Ac emulsion system increases with increasing resin to acrylate monomer ratio (Table 3). The narrow particle size distribution was observed by particle size analyzer.

Figure 6: SEM monograph of H6



Storage stability

Stable emulsions are essential in order to achieve successful emulsion products. An accelerated storage stability test was carried out for the hybrid products. The samples were kept in an oven at 50ºC for 12 hours. Stable behavior was confirmed with all samples. The properties of hybrid emulsion with increasing resin content are represented in table 7. The effect of storage time on the pH of the hybrids was examined (Table 6). PH of the hybrids was measured within 24 hours after preparation (fresh) and after approximately 6 months of storage at ambient temperature. The insignificant decrease in pH value was expected and also observed.

Table 6: pH of the emulsions after storage

	Fresh	pH after 24 hr	pH after 6 months
H6	10.5	10.4	9.8
H1	10.4	10.3	9.0

Table 7: Physicochemical and Physicomechanical characteristics of hybrid emulsion

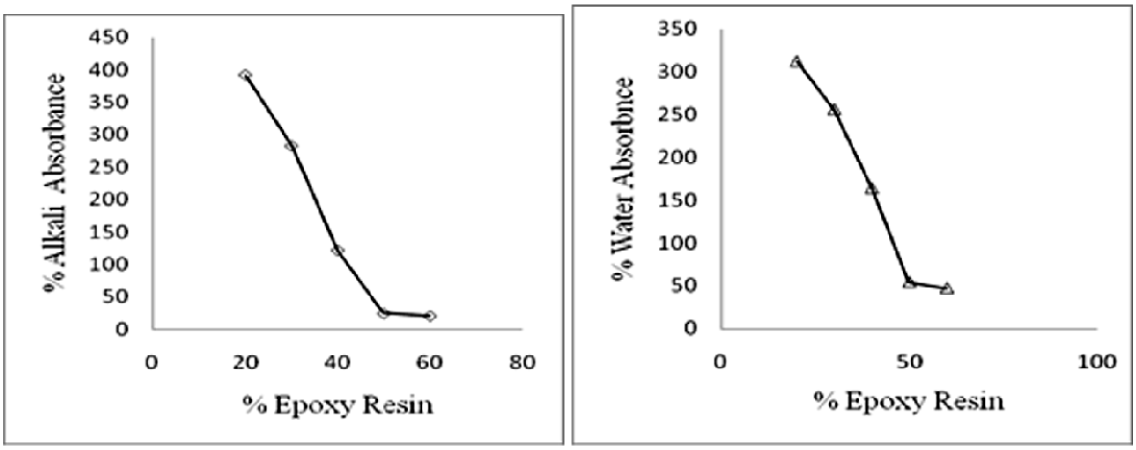
Formulation	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**
Viscosity cps	45	40	45	40	45	45	40
Electrolytic stability[a]	60	32	25	41	46	47	12
Freeze-thaw cycles	4	5	4	3	4	3	1
Shelf stability month	>6	>6	>6	>6	>6	>6	<48 hr
Accelerated Stability Day	>7	>7	>7	>7	>7	>7	<1
DFT (µm)	73	75	70	75	76	78	68
Gloss 60^0	85	82	83	81	80	82	65
Salt spray rating	1	2	3.	3	5	6	3

a: 5 % alum soln ml/100 gm of emulsion,

Water and alkali resistance

Both the water and salt-water resistance of the hybrid Ep-Ac by immersion test was quite satisfactory. The results in figure 7 reveal a somewhat poor performance of the H1 emulsions, which can be attributed to the hydrophilic nature of the acrylate copolymers; it forms the active centre on the surface of the film through which the attack by the polar moieties, such as water, salt water or other corrosive materials, is facilitated. Both the water and alkali absorption shows the same trend as the percentage of resin increases the value of absorption decreases.

Figure 7 Water and alkali absorption of hybrid Ep-Ac (H6)



Corrosion Resistance

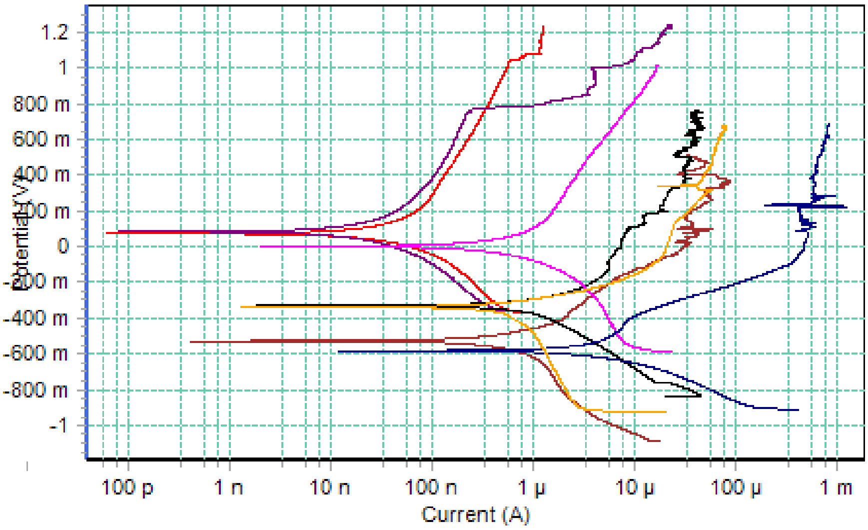
The corrosion resistance of the hybrid Ep-Ac coating was tested with salt spray (ASTM-117) method for 500hr. Analysis reveals that with increasing percentage of epoxy resin the corrosion resistance of the coating improves. The improvement in the corrosion resistance of the hybrid coating with the content of the epoxy resin was attributed to the hydrophobic nature of resin. There is increasing trend in corrosion resistance properties up to H6 but for H7 formulation the corrosion resistance is not satisfactory. The poor corrosion resistance of H7 is attributed to larger particle size (3.33 µm) of the emulsion which will affect the uniform distribution of polymer coating on metal surface.

EIS studies were performed to study the corrosion behavior of hybrid coatings with increasing percentage of epoxy resin. Table 8 shows the electrical parameters for hybrid coatings. The E_{corr} values for hybrid coating moves towards more negative, while I_{corr} and corrosion rate decreases with increasing resin content however the parameters for hybrid with more than 60% resin content does not follow the trend. Figure 8 represents tafel overlay of hybrid coatings which shows that the corrosion resistance of coatings improves with resin content. Results obtained with EIS studied are in good argument with salt spray results.

Table 8: Corrosion rate for hybrid coatings.

Specimen	E_{corr} mV	I_{corr} µ A/cm^2	C.R. mmpy
H1	-61.33	3.169	0.0526
H2	-159.73	1.273	0.00185
H3	-161.84	0.721	0.00018
H4	-373.14	0.191	0.00119
H5	-599.13	0.113	0.00031
H6	-951.37	0.009	0.000016
H7	-275.24	0.219	0.00211

Figure 8 Overlay of tafel graph with increasing ratio of epoxy resin



CONCLUSION

Hybrid epoxy resin one pack system was synthesized using a conventional emulsion polymerization technique which is stable for more than six months. Analysis of hybrid polymer with GPC and DSC indicates presence of Poly (acrylate-graft-epoxy) and Polyacrylate polymer. FTIR-ATR study shows that the grafted epoxy segments tend to move towards metal facing side while polyacrylate polymer moves toward air facing side of the coating. Because of this movement epoxy resin gives corrosion resistance while acrylic copolymers on the air-facing side give very good weatherability and appearance to coating. Salt spray analysis and EIS studies confirms the improvement in corrosion resistance of hybrid coatings with increasing resin content.

REFERENCES

[1] M. Kidwai, R. Thakur, *J. Ind. Chem. Soc.*, **2005**, 82, 1103
[2] Y. Chimankar, S. Patel, R. Jagtap, *Der Chemica Sinica*, **2010**, 1 (3), 91
[3] A. Clayton, Epoxy Resin: Chemistry and Technology, 2nd Edition, Marcel Dekker, Wiley–Interscience, New York, **1988**.
[4] Z. Ranjbar, S. Montazeri, M. Jalili, Prog. In Color Colorants Coat., **2009**, 2, 23
[5] H. Patel and A. Naji, *Der Chemica Sinica*, **2011**, 2 (2), 98
[6] P. Xingshou, C. Guoxiang, L. Shulai, *J. Appl. Poly. Sci.*, **2004**, 92, 2675
[7] D. Patel, K. Nimavatb and K. Vyasc, *Adv. Appl. Sci. Res.*, **2011**, 2 (3), 558
[8] A. Guyot, K. Landfester, F. Joseph, C. Wang, *Prog. In Poly. Sci.*, **2007**, 32, 1439
[9] R. Patil, B. Sharma, P. Mahanwar, *Paint India*, **2010,** 60, 59.
[10] S. Banyal, B. Kaith, R. Sharma, *Adv. Appl. Sci. Res.*, **2011**, 2 (1), 193
[11] A. Dholakia1, J. Jivani, K. Patel, and H. Trivedi, *Der Chemica Sinica*, **2011**, 2 (6), 80
[12] B.S. Shylesha, T.V. Venkatesha and B. M. Praveen, *Adv. Appl. Sci. Res.*, **2011**, 2 (2), 333
[13] J. Brandrup, 2nd Ed, Polymer Handbook, Immergut, E. H., Eds.; Wiley–Interscience, New York., **1975**
[14] J. Woo; V. Ting; J. Evans; C. Ortiz, *J. Coat. Tech.*, **1982**, 54, 41
[15] C. Song and L. Xiao-Yu, *Chin. J. Poly. Sci.*, **2009,** 27, 517