2018 Electrical Insulation Conference (EIC), San Antonio, TX, USA, 17-20 June 2018

UP Emulsion: A novel electrical insulating material

Bharathi Balagam
Research and Development
ELANTAS PDG Inc
St, Louis, USA
Bharathi.Balagam@Altana.com

Cynthia Chapple
Research and Development
ELANTAS PDG Inc
St. Louis, USA
Cynthia.Chapple@Altana.com

Thomas Murray
Research and Development
ELANTAS PDG Inc.
St.Louis,USA
Thomas.Murray@Altana.com

Abstract— **Unsaturated polyester (UP) resins are used extensively in electrical impregnation applications. The major disadvantage of UP resins is that reactive diluents such as styrene, vinyl toluene and diallyphthalate must be used to maintain low viscosity for application. Approximately 30-75% of the reactive diluent is lost during the curing cycle as a volatile organic compound (VOC). The use of waterborne polyester resins is a competing technology. However even waterborne polyesters typically contain a co-solvent which contributes to VOC emissions. The presence of a co-solvent can also lead to low flashpoints and safety concerns. Epoxy resins on the other hand do not contain VOC's but are significantly more expensive than UP resins and are high viscosity for application on electrical devices. The current invention describes the utilization of UP Emulsion along with crosslinking agents for a high performance impregnation material. The emulsion particle size is less than one micron for long-term shelf life and has an application viscosity of only 300-600 cP at greater than 60% solids content. This UP emulsion product offers properties such as superior coating quality, high bond and dielectric strengths, and excellent corrosion / moisture resistance. The other advantages of emulsion products are that they are easy to use and cleanup, low VOC, no HAPS, no odor and low viscosity**.

Keywords— Unsaturated polyester resins, emulsion, polymerization, viscosity, VOC, emulsifier, aqueous, impregnation

I. Introduction

Organic resin compositions are used as coatings for the mechanical, electrical, and environmental-resistance they impart to electromagnetic devices. The coatings provide mechanical strength, electrical insulation, and environmental protection for improved long-term durability of the devices, as well as increasing performance of the final product. Suitable chemistries for the coating resin include, but are not limited to, unsaturated polyesters, epoxides, waterborne polyesters,[1,2,3] epoxy emulsions,[4] polyurethane dispersions,[5,6] silicones[7], organic solvent borne alkyds, acrylated and methacrylated urethanes, acrylated and methacrylated epoxides, acrylated and methacrylated polyols, and acrylated and methacrylated vegetable oils.

Many of the chemistries including unsaturated polyester resins (UP) contain volatile reactive monomers such as styrene, vinyl toluene (VT), acrylates,[8] and diallylphthalate (DAP). Each of these monomers have significant drawbacks in use as electrical insulating varnishes. Styrene and VT have high vapor pressure and low flashpoints leading to environmental and safety concerns. Acrylates carry an unpleasant odor in addition to being expensive and having poor viscosity reduction of the unsaturated polyester resin. DAP requires very high concentrations to achieve suitable viscosity for impregnation of electromechanical device such as a rotor or stator in an electric motor. Even with a low vapor pressure monomer such as DAP, volatile organic content (VOC) emissions of 1.3 lbs/gallon are observed. UP resins also have stability issues with only 6 months of shelf life before increases in viscosity are observed.

A. Alternative Approach- Waterborne resin systems

Waterborne resins are one option for a more environmentally friendly material.[9,10] However they typically contain a co-solvent that adds to VOC emissions of the system and longer cure times. Waterborne resins can be cured with melamine resins, which emits hazardous air pollutants (HAPS) such as formaldehyde.[11] Aqueous epoxy emulsions are VOC and HAPS free but are very expensive compared to the other chemistries. What is desired is an aqueous coating that is cost effective like an unsaturated polyester but without the VOC and HAPS issues present with current technologies.

It would be advantageous to be able to provide compositions, especially for electrical insulation, that offer a wide variety of properties. Specifically, new resin technologies should have very good storage stability with shelf-life of one year or more. The resin should be cost effective and similar in both preparation and handling to unsaturated polyesters. The resin could be an aqueous compositions with no VOC or HAPS issues at desired low viscosities. The composition should contain no volatile reactive diluents yet allow for easy application. Finally, they should exhibit chemical and mechanical properties that equal or surpass those of previous compositions.

II. Experimental

It is well known how unsaturated polyester resins can be synthesized. Glycols are added along with unsaturated diacids that include maleic anhydride and the mixture is heated to 355-430°F with agitation. Dicyclopentadiene can also be added with cracking, using Diels-Alder chemistry, or under hydrolysis conditions, to add to the polymer. Volatiles are removed, preferably by distillation, and the acid value and viscosity of the mixture are monitored until the desired end-point is reached. The reaction mixture is cooled and monomer is added to give the desired UP resins. Inhibitors can be added to the monomer for extending storage stability of the resin.

Unsaturated Polyester resins are typically used in combination with an initiating system. Common initiators include peroxide, azo compounds, and UV agents. The most common initiator used in electrical insulating system are peroxides such as dicumyl peroxide and t-butylbenzoyl peroxide. Typical loading levels are 0.5 to 4% based on unsaturated polyester-reactive monomer weights. The surfactant used in this present system preferably are ethoxylated-polyether and/or ethylene or propylene oxide surfactants. Additives that affect pH, surface smoothness, flash rusting, and defoaming for example can also be added to the system prior to emulsification or after the emulsion has been formed.

The unsaturated polyester resin, reactive diluent, additives, and initiator are mixed to form a homogeneous mixture prior to emulsification. The mixture can be heated to reduce viscosity if needed. In a separate vessel, the surfactant is added to the water and mixed until homogeneous. The unsaturated polyester resin mixture is slowly added to the water/surfactant mixture under high shear mixing. Typically, a cowles blade is used, but other forms of high shear mixing will work as well. Emulsification can be created by using medium or high-pressure homogenization techniques, until the desired particle size is obtained.

The particle size was measured by Malvern, Mastersizer 3000. Viscosity was measured at 25°C by Brookfield viscometer. Magnet wire (MW35) was formed into tight helical or twisted coils, dipped into the resin solution, and cured in an oven for 2 hours at 150°C. The bond strength was measured on an Instron using the 3-point break method at 25°C using ASTM D2519. The Dielectric strength was measured on coated metal panels using ASTM D149, by increasing the voltage at 500 volts per second, until breakdown occurs. The glass transition temperature (Tg) was measured using Modulated Differentiatial Scanning Calorimetry (MDSC), modulating 1°C per minute from -25°C to 250°C while ramping 3°C per minute.

III. Results and Discussion

The present invention's resin compositions are very well suited for electrical insulation and offer a wide variety of properties all in conjunction. They have very good storage stability/shelf-life of more than a year. They are very cost effective similar to unsaturated polyesters in both preparation and handling. They have viscosities that allow for good application, especially when impregnating electrical or electromechanical devices such as, motors and stators due to good diffusion into motor windings. This technology allows for coating without the necessity to add reactive diluents (water can be added if deemed necessary). They have chemical and mechanical properties that equal or surpass those of previous compositions. A motor stator cured by dip and bake method (150°C, 2hours) is illustrated in Fig. 1.

Fig. 1 Motor stator coating by dip and bake method

The physical, mechanical, and electrical properties of these unsaturated polyester emulsion materials are presented in Tables I and II. Excellent bond strengths of 40 lb. (18.2 kg) and dielectric strengths of 4000-5000 volts per mil were observed by using these formulations. The bond strengths of coated magnet wire, cured under various conditions are summarized in table III.

TABLE I. PHYSICAL AND THERMAL PROPERTIES

Formulations	*Viscosity (cP)*	*Solids (%)*	*Particle Size (μ)*	*Tg (°C)*
Intiator 1-Batch 1	404	61.0	0.2	123
Batch 2	440	61.0	0.3	118
Intiator 2-Batch 1	656	60.4	0.4	120
Batch 2	649	61.0	0.2	122

TABLE II. ELECTROMECHANICAL PROPERTIES

Formulations	*Bond Strength (lbs)* *25°C	* 150°C	*Dielectric Strength* *Mils*	*Volts per Mil*
Intiator 1				
Standard UP waterborne	21.0	5.3	1.5 **1.5	3000 2200
UP Emulsion Batch 1	43.3	22.5	1.0 ** 0.9	4146 4606
UP Emulsion Batch 2	44.7	23.1	1.0 ** 0.8	4442 4058
Intiator 2				
UP Emulsion Batch 1	43.6	21.1	1.7 ** 1.8	4061 4317
UP Emulsion Batch 2	43.8	23.5	1.4 ** 1.4	3879 3486

represents the testing temperature;results after 24 hours exposure in water*

TABLE III. VARIATION OF PROPERTIES WITH CURE

Formulation Initiator 1	*Curing Condition*	*Helical Coil Bond Strength (lb)* *25°C	* 150°C	*Twisted Coil Bond Strength (lb)* *25°C	*150°C
	135°C, 60 min	38.5	9.5	49.4	13.5
	140°C. 45 min	24.8	8.4	59.1	13.2
	145°C, 30 min	35.8	9.5	64.2	21.7
	150°C, 30 min	36.2	11.1	67.7	21.1
	150°C, 120 min	40.6	19.9	91.0	33.8

**represents the testing temperature;*

A. Evaluation of cured films by various coating tests

Formulations 1-2 were coated on thin steel test panels by dip and bake method (baked in an oven at 150 °C, 2 hours). The dry film thickness of the coatings films was roughly 1.0 mil. Several coating properties were evaluated including adhesion (ASTM D3359), water resistance, and MEK rub test. All test results are summarized in Table IV. The glass transition temperatures on these cured materials fall in between 115 °C-125 °C. The thermal endurance testing with MW35 magnet wire is underway. Testing per ASTM D 3251 indicates a thermal class of Class 155, minimum. Testing per ASTM D 3145 indicates a thermal class of Class 180, minimum.

TABLE IV. CURED FILM COATING TESTING

Test Method	*Formulations*	
*	1	2
Pencil Hardness	6H	6H
Crosshatch Adhesion	5B	5B
MEK Rubs	500+	500+
Water resistance 168 h, 100%RH ; 25°C 85% RH; 85°C	No effect No effect	No effect No effect

**represents differences in initiator choice*

IV. CONCLUSION

In this study, we presented the insulating application of a novel resin chemistry utilizing an aqueous unsaturated polyester resin emulsion. This formulation utilizes an unsaturated polyester resin with either no monomer or low monomer content. Use of a surfactant with a suitable HLB value gives a stable aqueous emulsion for a VOC/HAPS free coating system. The emulsion particle size is less than one micron for long-term shelf life and has an application viscosity of only 300-600 cP at greater than 60% solids content. This UP emulsion product offers properties such as superior coating quality, high bond and dielectric strengths, and excellent corrosion and moisture resistance. The emulsion is also stable with over one year of shelf life with no loss in reactivity, hard settling, or viscosity increase.

ACKNOWLEDGMENT

The authors would like to acknowledge the Research and Development department and business of ELANTAS PDG, for the support of the research project.

REFERENCES

[1] Y. Yu. W. Funke. “Reactive microgels by emulsion polyermization of unsaturated polyesters.” W. Angew Macromol. Chem, 103, pp.187-202 , March 1982.

[2] L. Liang, W. Funke, “Crosslinking self-emulsifying copolymerization of an unsaturated polyester and styrene.” Marcromolecules, 29(27), pp. 8650-8655, December 1996

[3] H. Baumann, B. Joos.; W. Funke, “Emulsifying properties of unsaturated polyester resins.” Agnew Macromol. Chem., 187, pp. 2933, 1986.

[4] J. T. K. Woo, A. Toman, “Water based epoxy-acrylic grafted co-polymers” Pro. In Org. Coatings., 21(4). pp.371-385, March 1993.

[5] D. Dieter, polyurethane coatings for aqueous dispersions, Advances in organic coatings Science and technology, 1, pp.55-76, 1979,

[6] R.L. Scriven, W-H Chang, “Water-reduced urethane coating compositions” US 4,147,679, PPG Industries, 1979

[7] R.D. Johnson. J. C. Saam., C. M. Schmidt. Silicon Emulsion which provides an elastomeric product and methods for preparation.” US. Pat. 4221688A. Dow Corning Corporation. 1980.

[8] J. C. Hewitt., J. E. McAlvin., P. Taylor Hutson., A. E Craig., M. Kratz., D. K. Rivers., “Styrene –free unsaturated polyester resin compositions.” US Pat. 7396882B2. AOC. LLC. 2004.

[09] A. Bouvy, B.S.A. Dehuvyne, “Alkyd Resin Emulsions.” US Pat. 6,780,910 B2. Imperial Chemical Industries, 2004.

[10] H. Mijuhata, N. Kamiyoshi., S.Sata, "Methods for producing Resin Emulsions." US Pat. 20010/0316947A1. KAO Corporation, 2010.
[11] J.S. Dziczkowski., K.D. Chaffin., "Thermosetting coating compositions." US Pat. 2017/0240768A1. Eastman Chemical Company. 2017.