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A Non-Foaming Room Temperature Catalyst System For Vinyl Ester Resins

By: David J. Herzog, Paul P. Burrell, Mark D. Teigen



Interplastic Corporation
COMMERCIAL RESINS DIVISION



Interplastic Corporation
COMMERCIAL RESINS DIVISION

Bibliographies

David J. Herzog received a B.A. in chemistry from Carleton College in 1980 and graduated from the University of Minnesota, Duluth with a M.S. in chemistry with emphasis in Analytical. He has been employed by the Commercial Resin Division of Interplastic Corporation since 1983 and is currently the group leader in charge of Vinyl Ester Resins and Analytical Testing.

Paul P. Burrell graduated from the University of Minnesota Institute of Technology with a B.S. in Chemical Engineering. He has been employed by the Commercial Resins Division of Interplastic Corporation since 1971 and is presently the Resin R & D and Special Projects group leader.

Mark D. Teigen graduated from North Dakota State University with a B.S. in Polymers and Coatings. He has been employed by the Commercial Resins Division of Interplastic Corporation since March 1988.

References

1. Recommended MEKP catalyst for use with Vinyl Ester Resins are: L-50 made by Akzo chemie of America, Hipoint 90 made by Witco, DHD-9 made by Lucidol, and MEKP-925 made by Norac.
2. Specific Curing System for Chemical Resistant Unsaturated Polyester Resins, F.R. Willomse, O.K. Strolenberg and M. Storm, (Noury Chemical), 1972.
3. U.S. Patent; 3,980,731.
4. Conventional BPO pastes are: ANS 55 and AFR 500 by Lucidol, Cadox BSP 50 and 55 by Akzo Chemie America, and BZQ 50 and 55 by Witco Chemical.
5. Sprayable BPO-dispersions are: Cadox 40E by Akzo Chemie America, BZQ-40 by Witco Chemical Company, and Abcure S-40-25 by Abco.
6. PPG ADM 1.5 ounce/ft fiberglass mat.
7. Trigonox 21-OP-50 by Akzo Chemie America.
8. Design Ease, Copyrighted, 1987 by Stat-Ease, Inc.
9. "CoRezyn Vinyl Ester Resins", Interplastic Corporation, 1986.

FIGURE 10

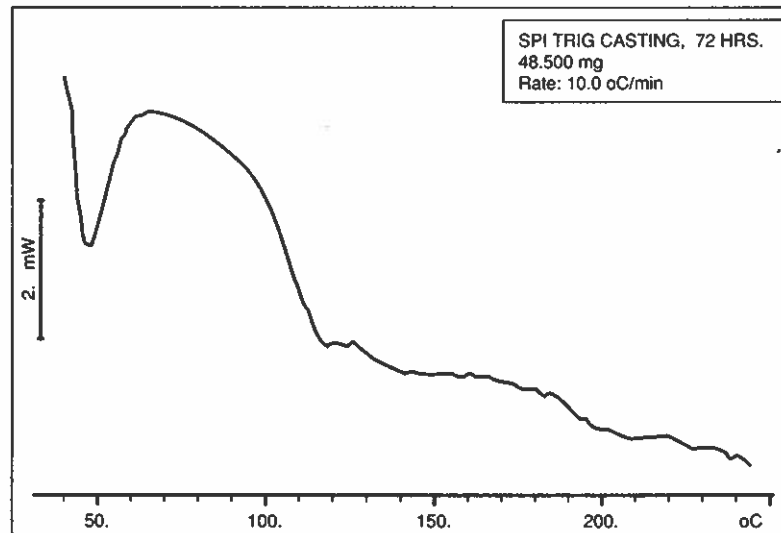


FIGURE 11

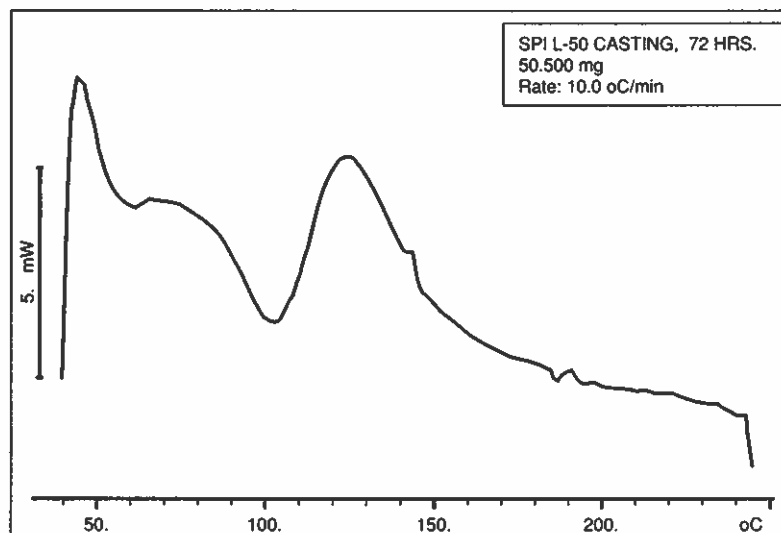
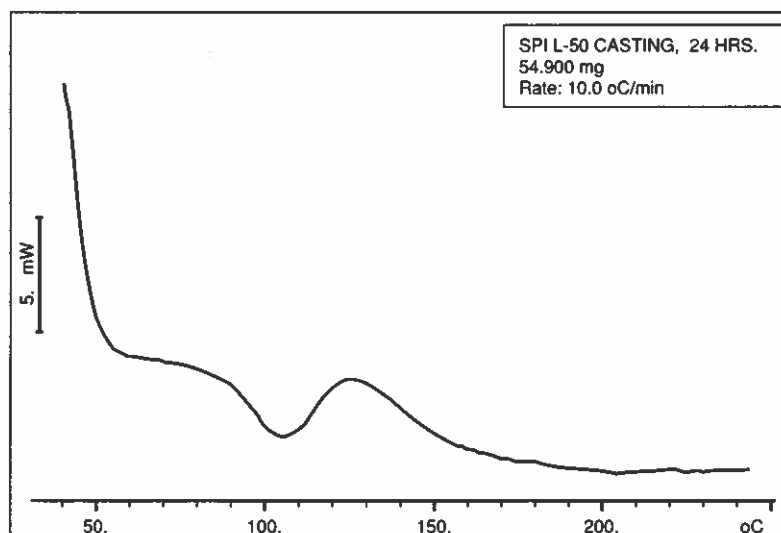


FIGURE 12



A Non-foaming Room Temperature Catalyst System for Vinyl Ester Resins

Abstract

Gassing of vinyl ester resins promoted with cobalt and catalyzed with methyl ethyl ketone peroxides has plagued vinyl ester resin users for many years. The gassing phenomena increases the risk of bubble entrapment in the laminate. The incorporation of voids in the composite can be detrimental to the physical properties and performance characteristics of the FRP composite.

The new "Non-Foaming Room Temperature Catalyst System for Vinyl Ester Resins" is introduced. The attributes of this system are: it promotes excellent cure in laminates and castings, utilizes the same promoters as the Methyl Ethyl Ketone Peroxide system, does not gas when catalyzed, and the catalyst is a sprayable liquid. The effects of the promoters and catalyst were evaluated by designed experiments. The physical properties of castings and laminates catalyzed with tertiary butyl peroxide and methyl ethyl ketone peroxide solutions are compared. Differential scanning calorimetry and hardness development were used to monitor the degree of cure during the room temperature cure of similar castings and laminates. A comparison of the physical properties, differential scanning calorimetry, and hardness development were made to determine if these three tests could be related.

Introduction

Vinyl ester resins promoted with cobalt naphthenate and/or cobalt octoate foam when catalyzed with the recommended methyl ethyl ketone peroxides (MEKP's) [1]. Hydrogen peroxide rapidly decomposes in the presence of a non-shielded cobaltous complex. Molecular oxygen (O_2) evolves during this reaction [2] and forms the bubbles in the resin for a period of 3 to 5 minutes. Low foaming vinyl ester resins have been developed [3] and the gassing is decreased but not totally eliminated.

Benzoyl Peroxide (BPO) has been recommended by Vinyl Ester Resin Manufacturers as an alternate to MEKP but is difficult to use in spray-up applications. This system utilizes N, N-Dimethyl Aniline (DMA) as the promoter. One of the difficulties with this system is dispersing the BPO uniformly in the resin. A majority of BPO is sold as a paste [4], which can be very difficult to mix into the resin. Sprayable BPO's are available [5]. The carriers used in these catalysts are plasticizers and water. These catalysts are 40% dilutions of BPO and when 1.0% active BPO is used, 2.5% catalyst is required. This means 1.5 grams phr, of diluents are added to the resin. Inhibition of the cure and/or plasticizing of the composite is a matter of concern due to the high levels of nonreactive components. The corrosion resistance of resins can also be degraded by the incorporation of these constituents.

The incorporation of voids in the laminate presents a serious problem to fabricators. When vinyl ester resins are catalyzed with MEKP's in a container, the laminator runs the risk of encapsulating bubbles in the composite. Ideally, the applicator should wait 5 to 10 minutes after catalyzation to significantly lower this risk. During this short period of time, the gassing stops and the bubbles dissipate. Even the most careful of lamination techniques risk encapsulating the bubbles if this delay is not used.

The ultimate strength, corrosion resistance, fatigue resistance, as well as over-all physical properties of the composite can be lowered because of the entrapped bubbles. When the resin is

replaced by bubbles the strength of the part is diminished, possibly severely, depending on the amount of voids in the composite. The military has acted on this by setting up specifications in Mil-P-17549C for the void content in various grades of laminates. These specifications range from a maximum of 5% voids for Grade 5 to a maximum 1.5% voids for Grade 1 in FRP laminates. If care is not taken during manufacturing, the void content in a laminate can easily reach 15%.

The hydrogen peroxide comes from MEKP's. In all commercial MEKP's a small amount of hydrogen peroxide remains as a reaction residual. In some formulations hydrogen peroxide is added to give a faster gel. The cobalt is added to the resin as the primary promoter. Removal of the hydrogen peroxide or shielding the cobalt by forming a complex similar to the one formed with unsaturated polyester resin acid end groups will minimize the gassing. The approach used with this new system to totally prevent the gassing was to search for another ambient temperature initiator which does not contain hydrogen peroxide.

Experimental

The catalysts in Table 1 were screened. The parameters used for the evaluation were:

1. Gel time at 25°C in a 100 gram mass.
2. Gel to peak exotherm at 25°C in a 100 gram mass.
3. Peak exotherm at 25°C in a 100 gram mass.
4. Laminate hardness development at 25°C in a laminate constructed with 4 plies of 1.5 ounce fiberglass mat [6].
5. Gassing in a 100 gram mass catalyzed at 25°C with 1.0% catalyst.
6. Suitability for use with currently used spray equipment.
7. Ease of dispersion into vinyl ester resin.
8. Non-refrigerated shipment desired.

The above criteria were used in the selection of a catalyst. A 50% dilution of Tertiary-Butyl Peroctoate (TBPO) was the only catalyst to fit all of the parameters and will be used exclusively as the catalyst of choice in the remainder of the experiments.

We evaluated the effects of various levels of 12% Cobalt, DMA, and a 50% TBPO [7] catalyst solution by Designed Experiment [8] on CoRezyn VE8320. CoRezyn VE8320 is a non-promoted vinyl ester resin designed to work with this new catalyst system. This resin is a standard Bisphenol-A Epichlorohydrin based vinyl ester with the same molecular structure and corrosion resistance as CoRezyn VE8300 [9]. Two designed experiments were run with gel time, gel to peak internal, and peak exotherm as the response parameters. A three variable by two level experiment shown in Table 2 was used to evaluate the effects at low concentrations of promoters. The second designed experiment, contained in Table 4, was 3 by 2 and incorporated three center points to evaluate the linearity of the effects at higher levels of promoters and catalyst.

Table 6 contains a compilation of the cure development for laminates and castings at 25°F, catalyzed with MEKP as well as a 50% dilution of TBPO. The evaluation was run on 2 and 4 ply laminates constructed of 9 by 9 inch pieces of 1.5 ounce fiberglass

mat as well as 100 gram castings made in gallon lids. The catalyst level used for the 2 ply laminates was 2.0cc phr. The 4 ply laminates and 100 gram gallon lid castings were catalyzed at 1.20 phr respectively. The hardness development was checked with the Barber Coleman GYZJ 934-1 Impressor Gauge at 15 minute intervals starting at 45 minutes.

Differential Scanning Calorimetry (DSC) compiled in Table 7 was run on these laminates and castings at 24 and 72 hours after the catalyzed using a Mettler DSC 20 and the TA10 data processing station. The samples of the laminates and castings were taken by cutting out a section at the completion of each time period and tested immediately. The specimens used for DSC were cut out the composite a minimum of 2 inches from any edge. The DSC samples for the 4 ply laminates were 40±3 milligrams. The DSC sample weights for the 2 ply laminates and castings were 50±4 milligrams. An empty crucible was used as the reference for the casting samples. The reference for the laminates were samples of the respective laminates cured up by ramping a specimen from 40°C to 250°C and then rescanning over the same temperature range to insure no detectable energy remained. The standard was in the same weight range that was used for the samples. Each scan was started at 40°C and ramped at a rate of 10°C/minute to 250°C. The samples were scanned a second time, using the same test conditions, after they cooled down to 40°C to determine if any residual energy remained in the samples after the first scan.

The physical properties of castings were evaluated to determine the effect of the catalyst systems and compiled in Table 8. A Tinius Olsen Universal Tester was used to evaluate the static physical properties (ASTM D790, ASTM D638, ASTM D648, ASTM D792, and ASTM D2583). The impact strength was run using a model 8200 Drop Weight Impact Test Machine manufactured by Dynotup (ASTM 3763). The castings were 1/8 inch thick, gelled and cured at room temperature. Twenty four hours after making the clear casting they were postcured. During postcure, the casting is ramped from 25°C to 121°C over a period of 3 hours then held at 121°C for 2 additional hours. The casting is then conditioned at 25°C for a minimum of 24 hours before testing.

Due to the excellent cure development of the laminates with this new system, the ability to bond to the vinyl ester with the vinyl ester, orthophthalic, or isophthalic resin were questioned. An orthophthalic laminating resin was chosen for its relatively poor adhesion properties when compared to the vinyl ester family. The adhesion of an orthophthalic laminating resin to the cured vinyl ester panel catalyzed with 50% TBPO and MEKP respectively, was evaluated at 2 hours and 72 hours after catalyzed and evaluated according to ASTM D3846. The general construction of the panels used for this test is as follows:

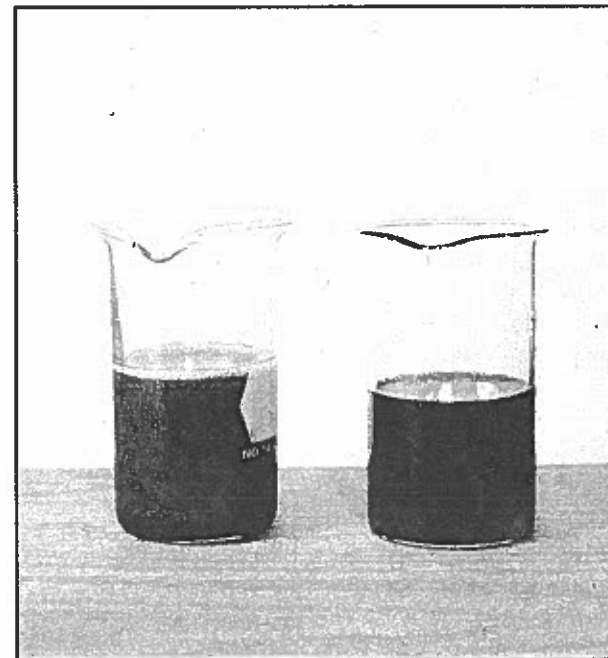
1. 4 plies of 1.5 ounce fiberglass mat. Vinyl Ester Resins VE8320 promoted with 0.20% of 12% Cobalt and 0.25% DMA or VE8300 promoted with 0.20% 12% Cobalt and 0.05% DMA then catalyzed with 1.7 phr catalyst, a 50% dilution of TBPO and MEKP respectively. The resin to glass ratio was 2:1.
2. 4 plies of 1.5 ounce fiberglass mat. Orthophthalic laminating resin (CoRezyn 65-AA-015) catalyzed with 1.0% MEKP, M-50 made by Akzo Chemie of America. The resin to glass ratio was 2:1. A small amount of dye was put into this resin so the interface between the laminate could be seen.

A duplicate set of laminates were constructed and tested. The first

set of vinyl ester laminates were allowed to sit for 2 hours after catalyzed before the orthophthalic laminates were laid down on top of them. The second set of laminates were allowed to sit for 72 hours after catalyzed before the second laminates were laid down on top of it. These panels were stored at room temperature for 7 days after the 72 hour set of laminates were laminated over before testing.

Results

The preliminary scan of the catalysts in Table 1 revealed that the Peroxyester was the only type that met the gassing, suitability for spraying, and ease of mixing criterion. It was discovered that the lower the 10 hour half life temperature the faster the gel time in the same resin. This helped to narrow down the selection process by ruling out certain catalysts with minimal work based solely on gel time. The catalyst selected for this work was a 50% Dilution of TBPO. It was found to yield gel times ranging from 15 to 120 minutes by adjusting the levels of promoters and catalyst. A comparison of the new system (TBPO) to the old system (MEKP) one minute after catalyzed is shown in Picture 1 to illustrate the non-gassing characteristics. The resin on the right, catalyzed with TBPO, showed no sign of bubbles, while the resin on the left catalyzed with MEKP is saturated with bubbles. The 50% solution of TBPO, Trigonox 21-OP50, does not require refrigerated storage and shipment like 100% TBPO.



The effects of promoters and catalyst on the gel time, gel to peak interval, and peak exotherm were evaluated by Designed Experimentation using CoRezyn VE8320. CoRezyn VE8320 is a non-promoted, Bisphenol A-Epichlorohydrin based vinyl ester resin specifically developed to work with this new catalyst system. The data is compiled in Tables 2 and 4. The evaluation of the designed experiments in Tables 3 and 5 show the effects of the three components. None of the effects were linear over the whole range and two 2 factor interactions were seen. The regression coefficients for the models gave us quite high confidence levels in the models. Large changes in gel time, gel to peak interval, and peak exotherm were seen at low levels of Cobalt as seen in Table 3. One 2 factor interaction was seen between Cobalt and DMA on

FIGURE 7

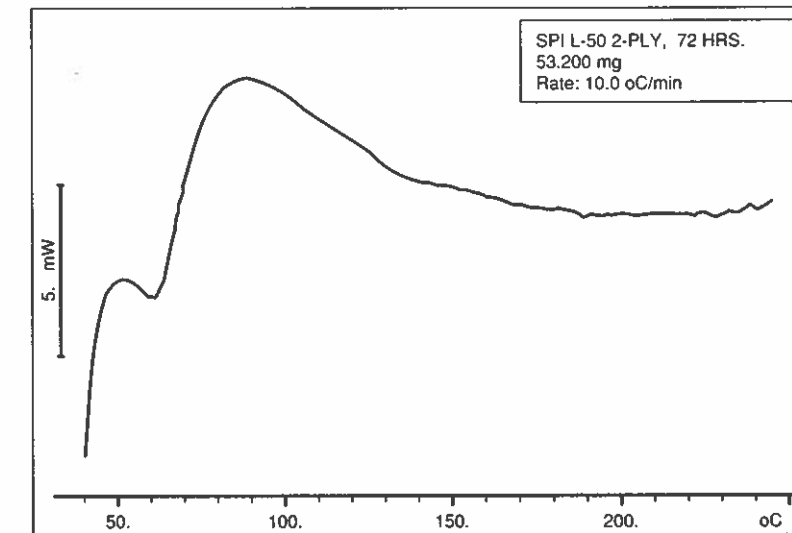


FIGURE 8

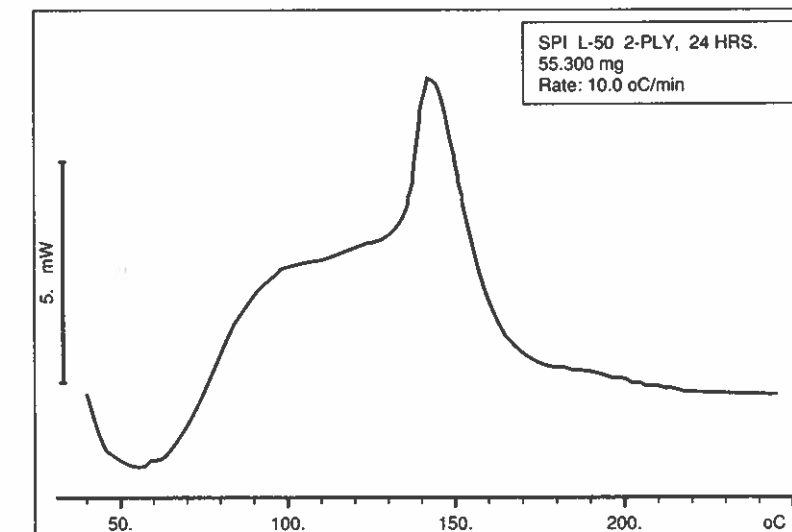


FIGURE 9

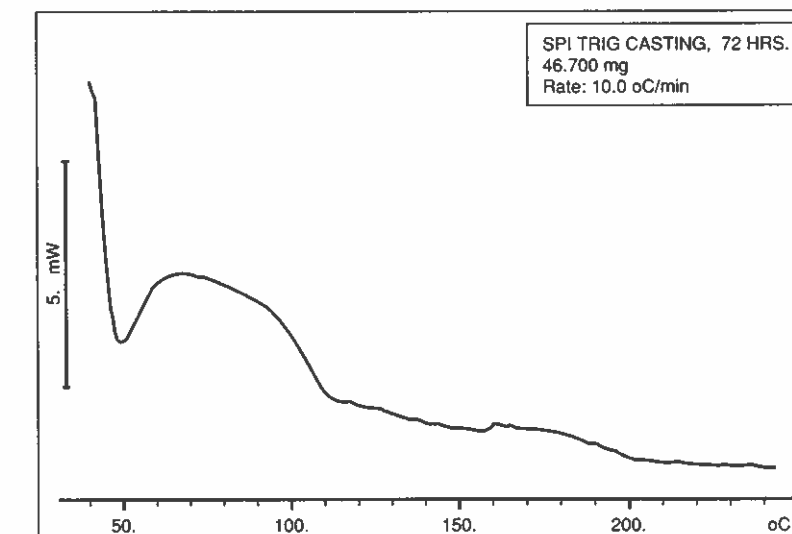


FIGURE 4

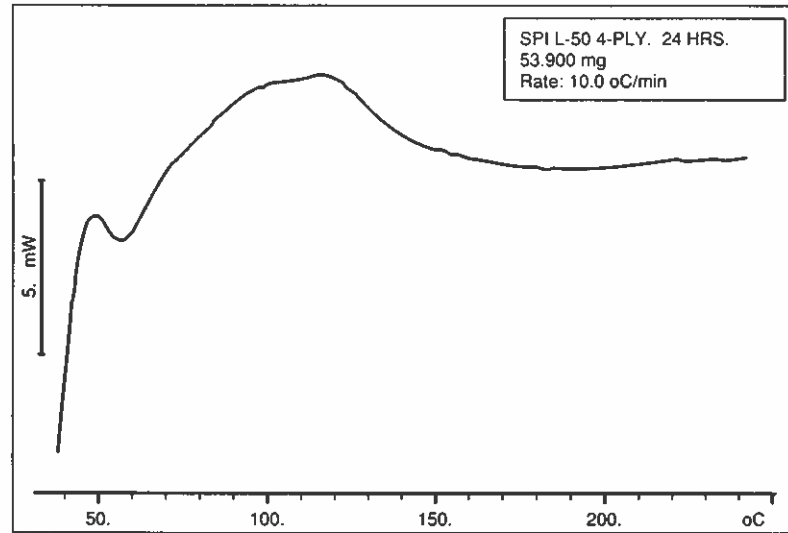


FIGURE 5

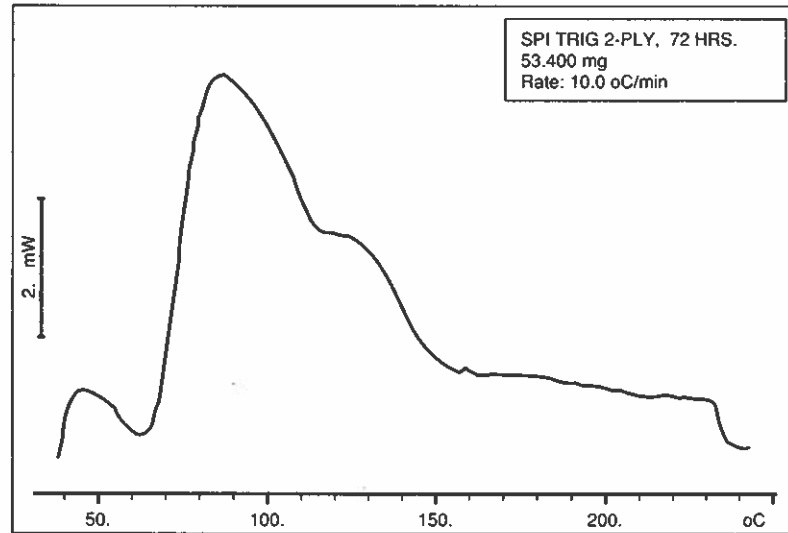
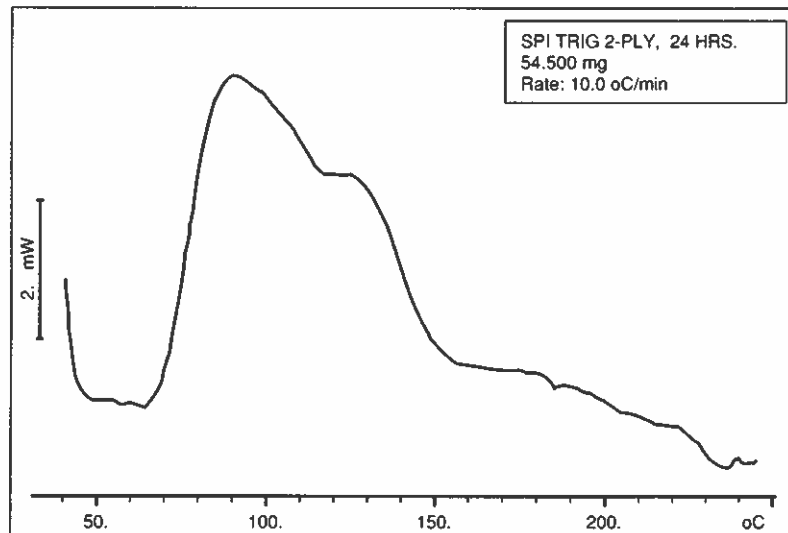


FIGURE 6



the interval. DMA had a much greater effect on the interval when the Cobalt level was low. The catalyst level slightly affected the gel time and interval, but significantly increased (15°C) the peak exotherm when increased.

The analysis of Experiment 2 in Table 5 showed smaller variations in the gel time, interval, and peak exotherm. The gel time seemed to be affected the most with decreases of 6 to 7 minutes as the level of each increased. A 2 factor interaction was also found during the analysis. When DMA was at its low level (0.20%), Cobalt had very little effect on the exotherm. However, at the high level of DMA (0.40%) the increase in Cobalt increased the peak 4°C.

The overall analysis of the two designed experiments show the effects of all three components were not linear. The lower the level of cobalt the more effect each of the components had on the three responses.

The gelation of the resin in 1/16 and 1/8 inch thick laminates and 100 gram gallon lid casting appeared to be quite different when catalyzed with 50% TBPO compared to the MEKP. The gel time of the resin in laminates and casting were virtually the same as the 100 gram cup gel time when the 50% dilution of TBPO was used at 25°C. However, when the resin was catalyzed with MEKP, the laminates and castings gel a minimum of 10 minutes longer than the cup gel time at 25°C.

Table 6 contains the hardness development comparison to 2 and 4 ply laminates as well as 100 gram gallon lid castings made with both catalyst systems. Hardness development of the 1/16 to 1/8 inch thick laminates and 100 gram one gallon lid castings with the new system can be roughly approximated by the cure time in a 100 gram mass. A 1/16 inch thick laminate was constructed of two layers 1.5 ounce fiberglass mat and catalyzed with 2.0cc phr of the 50% dilution of TBPO. It cured to 20 to 30 on the 934-1 gauge a minimum of 30 minutes after the 100 gram cup reaches its peak exotherm. An identical laminate construction using VE 8301 and catalyzed with 2.0cc phr MEKP only cured to 1 to 10 on the 934-1 approximately 90 minutes after the 100 gram cup reached its peak exotherm. The improvement in the hardness development and the higher ultimate hardness readings at 72 hours in the laminates and castings was quite significant. The new system is superior to a conventional MEKP system.

The DSC results compiled in Table 7 and the hardness development data in Table 6 showed the new catalyst system to be superior in cure development to the standard MEKP system. The lower the residual energy in the sample the further cured the composite. A relationship between the residual energy determined by DSC and hardness development at 24 and 72 hours is apparent by comparing Tables 6 and 7. There is very little change in the hardness development and residual energy between 24 and 72 hour samples. Typical DSC scans of each of the samples are shown in Figures 1-12. Using the same lot of vinyl ester base resin, the two cure systems were compared for 1/8 inch clear casting physical properties in Table 8. All of the properties evaluated were virtually identical except for the tensile modulus and tensile elongation. The improved cure seen by the new catalyst system yields a higher crosslinked polymer structure, which in turn gave the lower elongation and higher tensile modulus values.

One concern about the TBPO system was the subsequent bonding of laminates to the cured vinyl ester laminate. Composites where the manufacturer wants to bond to the vinyl ester resin laminate with orthophthalic and/or isophthalic polyester resins are the major

concern. Adhering vinyl ester to the air side of a vinyl ester laminate has not presented any problems since vinyl ester resin have such good interlaminar adhesion properties. Orthophthalic resins do not have the adhesion properties inherent to vinyl ester resins, hence it was chosen as the worse case. The adhesion of an orthophthalic laminate to a vinyl ester laminate was determined at 2 and 72 hours after catalyzation, according to ASTM D3846. The results are compiled in Table 9.

The results of the adhesion testing were statistically analyzed. The "T-test" run on the adhesion data showed a 97% probability that the two sets of readings from the laminates at 2 hours were different. The adhesion of the orthophthalic laminating resin to the new system was significantly better at this time compared to the MEKP catalyzed laminate. Analysis of the 72 hour data showed the differences between the two catalyst systems had diminished. Only a 36% probability that the readings on the two sets were different. Overall, the adhesion properties of orthophthalic laminating resin to both catalyst systems were very good with a slight edge given to the new catalyst system.

Conclusions

A novel ambient temperature cure system for vinyl ester resin based on t-butyl peroctoate has been developed. It has the attributes of the conventional methyl ethyl ketone peroxide systems but does not foam. The catalyst is a liquid shippable at room temperature, and sprayable with existing equipment.

The new system offers the composite manufacturer some very useful properties in addition to the fact that it does not gas. The user has the ability to lengthen gel time out to the area of 60 to 90 minutes and still achieve excellent cure in the laminate. Faster cycle and mold turn over time is directly related to the faster hardness development achievable with a variety of gel times, utilizing levels of catalyst ranging from 1 to 2 percent. Excellent hardness development of thin laminates and films are possible without giving up any adhesion properties.

Specific examples of current applications that could use this system are the boat industry for skin coat applications, tooling manufacturers in the early stages of mold making, the corrosion market for tank relining, high performance light weight composites to help promote good cure in thin laminates, and for vacuum bagging to get a long gel time with good cure in the finished product.

Acknowledgements

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TABLE 1 CATALYSTS EVALUATED AS POSSIBLE CANDIDATES FOR THE NEW CURE SYSTEM

CHEMICAL NAME	FORM	10 HOUR 1/2 LIFE TEMPERATURE (°C)	REFRIGERATED SHIPMENT
t-Butyl Perbenzoate	Liquid	104	No
t-Butyl Peroctoate	Liquid	74	Yes
t-Butyl Peroctoate, 50% Dilution	Liquid	74	No
t-Butyl Peroxy Isopropyl Carbonate	Liquid	97	No
Benzoyl Peroxide, 100%	Solid	71	No
Benzoyl Peroxide, 40% Dilution	Suspension	71	No
1,1-Di-t-Butyl Peroxy 3,3,5-Trimethylcyclohexane	Liquid	95	No
2,5-Dimethyl 2,5-di (2-ethyl-hexanoyl peroxy) hexane	Liquid	67	Yes

TABLE 2 DESIGNED EXPERIMENT 1 - EVALUATION OF PROMOTERS AND CATALYST LEVELS ON VINYL ESTER RESIN*

Standard Order	1	2	3	4	5	6	7	8
Run Order	5	4	8	1	7	3	6	2
12% Cobalt, wt. %	0.20	0.20	0.05	0.05	0.20	0.20	0.05	0.05
DMA, wt. %	0.10	0.50	0.50	0.10	0.10	0.50	0.50	0.10
Trigonox 21-OP50, wt. %	2.00	2.00	2.00	2.00	1.20	1.20	1.20	1.20
Gel Time, minutes	46.1	22.9	57.8	127.0	55.3	31.6	72.5	153.4
Gel To Peak Interval, min.	12.5	10.2	12.1	27.0	17.8	16.4	17.5	41.3
Peak Exotherm	170	177	174	167	165	167	163	157

Data was run on VE8320* at 25°C in a 100 gram mass. The catalyst was stirred into the resin for 30 seconds. Ambient temperature was 25±1°C.

FIGURE 1

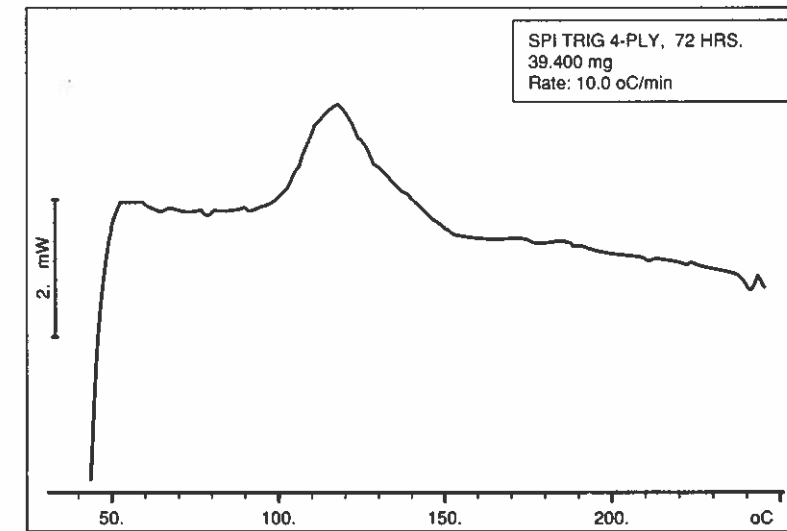


FIGURE 2

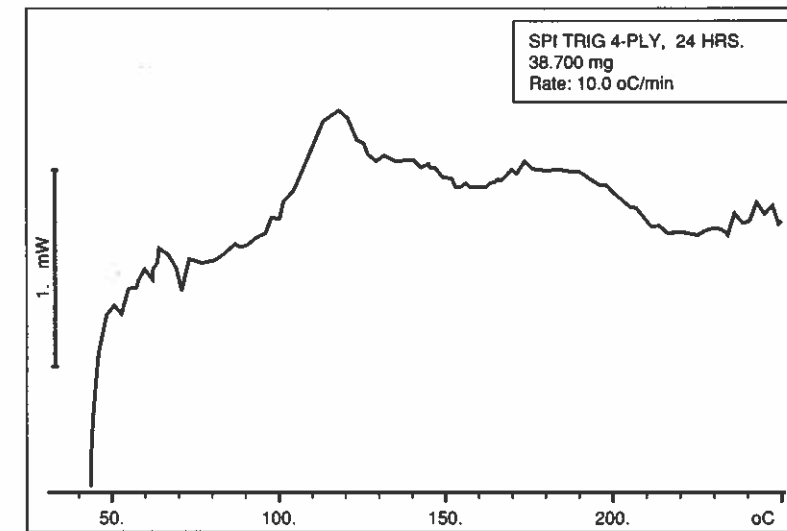


FIGURE 3

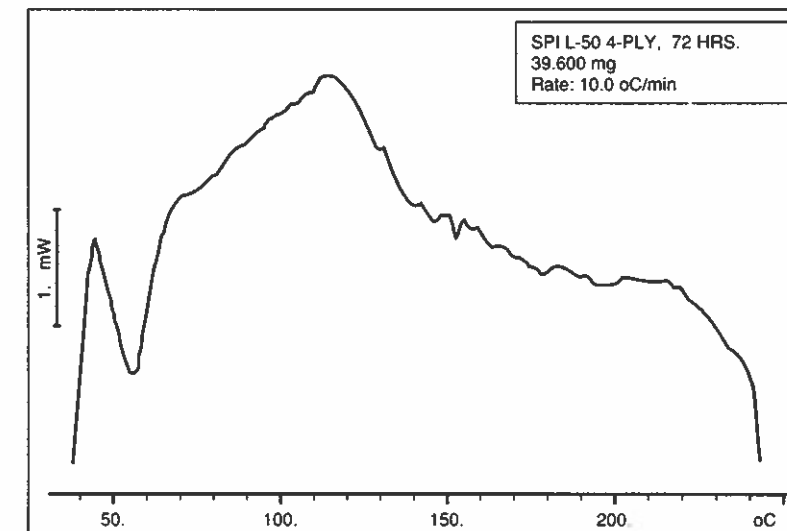


TABLE 9 ADHESION COMPARISON OF CURE SYSTEMS

CURE SYSTEM	TIME AFTER CATALYZATION (hrs)	BOND STRENGTH (psi)	STANDARD DEVIATION (psi)
Standard, MEKP	2	3285	603
Standard, MEKP	72	3480	567
New System, 50% TBPO	2	4365	384
New System, 50% TBPO	72	3684	484

In plane interlaminar shear strength of orthophthalic laminating resin to vinyl ester resin tested according to ASTM D3846.

TABLE 3 ANALYSIS OF DESIGNED EXPERIMENT 1

	Gel Time (min.)	Interval (min.)	Peak Exotherm (C)
12% Cobalt, 0.05 to 0.20% by weight	-64.6	-42.4	+4.5
DMA, 0.10 to 0.50% by weight	-49.3	-39.4	+5.5
Trigonox 21-OP50, 1.20 to 2.00cc phr	-14.75	No Effect	+15.0
Interaction, 12% Cobalt/DMA	*	No Effect	No Effect
Coefficient of Variance	27.29	11.31	1.08
Regression Coefficient, R ²	0.8710	0.9645	0.9529
Transformation of Data for Analysis	None	Inverse	None

*When 12% Cobalt is 0.05% by weight the increase in DMA shortens the gel time by 12 minutes. When 12% Cobalt is 0.20% by weight the increase in DMA shortens the gel time by only 2 minutes.

TABLE 4 DESIGNED EXPERIMENT 2 - EVALUATION OF PROMOTERS AND CATALYST LEVELS ON VINYL ESTER RESIN*

Standard Order	1	2	3	4	5	6	7	8	9	10	11
Run Order	3	2	11	8	6	12	7	4	13	1	5
12% Cobalt, wt. %	0.30	0.30	0.20	0.20	0.30	0.30	0.20	0.20	0.25	0.25	0.25
DMA, wt. %	0.20	0.40	0.40	0.20	0.20	0.40	0.40	0.20	0.30	0.30	0.30
Trigonox 21-OP50, wt. %	2.00	2.00	2.00	2.00	1.20	1.20	1.20	1.20	1.60	1.60	1.60
Gel Time, minutes	22.2	17.2	23.4	28.0	28.6	21.9	29.1	37.3	21.4	22.9	23.2
Gel To Peak Interval, min.	11.7	10.5	10.9	12.6	12.1	11.2	11.5	12.9	12.0	11.7	12.2
Peak Exotherm	177	179	175	177	173	176	172	175	174	178	173

The data was run on VE8320 * at 25°C in a 100 gram mass. The catalyst was stirred into the resin for 30 seconds. Ambient temperature was 25±1°C.

TABLE 5 ANALYSIS OF DESIGNED EXPERIMENT 2

	Gel Time (min.)	Interval (min.)	Peak Exotherm (C)
12% Cobalt, 0.20 to 0.30% by weight	-6.0	-0.6	+1.5
DMA, 0.20 to 0.40% by weight	-7.0	-1.2	No Effect
Trigonox 21-OP50, 1.20 to 2.00cc phr	-6.5	-0.5	+0.3
Interaction, DMA/Trigonox 21-OP50	No Effect	No Effect	*
Coefficient of Variance	4.41	1.92	0.99
Regression Coefficient, R	0.9730	0.9407	0.7032
Transformation of Data for Analysis	None	None	None

*When DMA is 0.20% by weight, the change in 12% Cobalt level has 1°C effect on the peak exotherm. When DMA is 0.40% by weight, the change in 12% Cobalt level has 4°C effect on the peak exotherm.

TABLE 7 DSC ANALYSIS OF LAMINATES AND CASTINGS

COMPOSITE	4 Ply Laminate		2 Ply Laminate		1 Gallon Lid Casting	
	VE8320	VE8300	VE8320	VE8300	VE8320	VE8300
RESIN	VE8320	VE8300	VE8320	VE8300	VE8320	VE8300
12% COBALT LEVEL	0.20	0.20	0.20	0.20	0.20	0.20
DMA LEVEL	0.40	0.05	0.40	0.05	0.40	0.05
CATALYST	Trig 21-OP50	L-50	Trig 21-OP50	L-50	Trig 21-OP50	L-50
LEVEL, % by Weight	1.20	1.20	2.00	2.00	1.20	1.20
RESIDUAL ENERGY DETERMINED BY DSC, Joules/gram of sample.						
TIME AFTER CATALYZATION						
24 Hours	7.10	27.45	26.93	37.79	14.51	16.25
72 Hours	6.69	10.51	27.82	40.65	10.95	18.20

VE8320 promoted with 0.20% of 12% Cobalt and 0.40% of DMA by weight and catalyzed with 1.20cc phr of Trigonox 21-OP50, had a gel time of 18.00 minutes, gel to peak exotherm interval of 12.25 minutes and a peak exotherm of 173°C in a 100 gram mass at 25°C. VE8300 promoted with 0.20% of 12% Cobalt and 0.05% of DMA by weight and catalyzed with 1.20cc phr of L-50 had a gel time of 17.50 minutes, gel to peak exotherm interval of 13.50 minutes and a peak exotherm of 167°C in a 100 gram mass at 25°C. Ambient temperature was 25±1°C.

TABLE 6 A COMPARISON OF HARDNESS DEVELOPMENT DATA

COMPOSITE	4 Ply Laminate		2 Ply Laminate		1 Gallon Lid Casting	
	Trig 21-OP50	L-50	Trig 21-OP50	L-50	Trig 21-OP50	L-50
CATALYST TYPE	Trig 21-OP50	L-50	Trig 21-OP50	L-50	Trig 21-OP50	L-50
LEVEL, % by Weight	1.20	1.20	2.00	2.00	1.20	1.20
HARDNESS READINGS (934-1)						
45 Minutes	20-30	0	0	0	10-25	0
60 Minutes	30-40	0	20-30	0	25-30	22-28
75 Minutes	40-45	0	20-30	0	25-33	25-30
90 Minutes	40-50	0	30-40	0	25-33	28-30
105 Minutes	40-50	10-20	30-40	0	25-33	27-30
120 Minutes	40-50	20-25	30-40	1-10	25-33	28-30
24 Hours	40-45	20-30	30-40	20-30	29-33	27-30
72 Hours	40-50	25-30	30-40	25-35	30-34	28-30

VE8320 promoted with 0.20% of 12% Cobalt and 0.40% of DMA and catalyzed with 1.2% Trigonox 21-OP50, made by Akzo Chemie of America, had a gel time of 18.00 minutes, gel to peak exotherm interval of 12.25 minutes and a peak exotherm of 173°C in a 100 gram mass at 25°C. VE8300 promoted with 0.20% of 12% Cobalt and 0.05% of DMA and catalyzed with 1.20% L-50 had a gel time of 17.50 minutes, gel to peak exotherm interval of 13.5 minutes and a peak exotherm of 167°C in a 100 gram mass at 25°C. Laminate hardness was monitored with the Barber Coleman GYZJ 934-1 Impressor Gauge. The ambient temperature during the test was 25°C. The fiberglass used was PPG's chopped strand mat. 1.5 ounce/ft².

TABLE 8 PHYSICAL PROPERTIES OF VINYL ESTER CLEAR CASTINGS

Cure System	Standard	New-TBPO
Resin	VE8300	VE8320
12% Cobalt, wt. %	0.20	0.20
DMA, wt. %	0.05	0.40
Catalyst	L-50	Trigonox 21-OP50
Catalyst Level, cc phr.	1.20	1.20
Flexural Strength, ASTM D790, psi	17,000 ±149	17,800 ±328
Flexural Modulus, ASTM D790, psi	3.7x10 ⁸	3.8x10 ⁸
Tensile Strength, ASTM D638, psi	12,600 ±264	12,600 ±434
Tensile Modulus, ASTM D638, psi	4.4x10 ⁸	4.7x10 ⁸
Percent Elongation	5.9	4.5
Heat Distortion Point, ASTM D648, C	102	103
Barcol Hardness, ASTM D2583, 934-1	34-36	34-36
Compressive Strength, ASTM D695, psi	17,900 ±343	18,000 ±387
Impact Energy, ASTM D3763, ft./lb.	2.24 ±.46	1.94 ±.54
Impact Deflection, ASTM D3763, in.	0.27	0.27
Specific Gravity, ASTM D792	1.1334	1.1304

The physical properties were run on a 1/8 inch thick clear casting. The castings were made at room temperature, allowed to sit for 24 hours, then post cured by ramping the temperature up to 121°C over 3 hours where it was held at that temperature for 2 additional hours. They were conditioned at 25°C for 24 hours before testing.