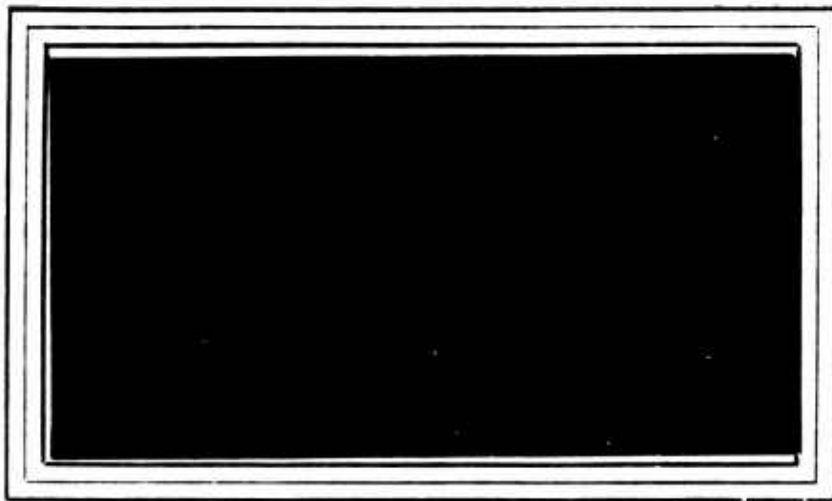


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STUDY OF VISUAL CAST FLARE BINDER MATERIAL

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This report was reviewed for adequacy and technical accuracy by
B. E. Doude.

Released



P. J. SMITH, Manager
Concept Development Division
Research and Development Department

STUDY OF VISUAL CAST FLARE BINDER MATERIAL

Final Report

(13 September 1967 to 18 November 1967)

January 1968

By

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Yoshiyuki Arikawa**

Prepared Under Contract N00164-67-C-0479

for

**U. S. Naval Ammunition Depot
Crane, Indiana**

By

**Ordnance Research Incorporated
Fort Walton Beach, Florida**

ABSTRACT

Castable visual flare formulations and techniques were developed that produce luminous efficiencies greater than 50,000 candle-seconds/gram. Improved luminous efficiencies and ease of casting were made possible with a relatively high binder percentage of sixteen percent. No pressure is required for casting. Liquid polyester binder systems were found to provide optimum characteristics for casting as well as luminous efficiency with their high oxygen and low carbon content. Optimum sodium perchlorate oxidizer to magnesium fuel ratio was determined to be one to one with oxidizer partially dissolved in liquid binder. Flare grains in sizes from 3.2 inches to 4 inches in diameter were cast and tested with no significant change in efficiency versus diameter.

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INTRODUCTION

The study of visual flare binder material undertaken in this contract involved the development and evaluation of a binder suitable for casting visual flare grains. Although a number of commercial polyester resin formulations are available, they are generally formulated to contain styrene (vinyl benzene) monomer which contains no oxygen and has a high carbon content. One of the desirable characteristics of a binder would be to contain a high percentage of oxygen or other oxidizing elements to enhance combustion of the flare grain. Other desirable characteristics would be a minimum of carbon molecules in the binder to reduce formation of elemental carbon in the flare plume during combustion and a binder which can be cast and polymerized readily at room temperature conditions. Earlier studies on castable visual flare formulations established the relationship that a significant decrease in luminous efficiency resulted when the amount of binder was increased. The binders investigated were largely styrene-based resins containing a low oxygen content and high carbon content which tended to shift the radiation spectrum into the infrared region.

The present study, which is essentially a continuation of a previous study (Contract N00164-67-C-0086), concentrated on using a binder system not containing styrene monomer. The oxidizer sodium perchlorate was used largely because of its solubility in certain organic solvents. Sodium nitrate which is used extensively in standard pressed grains is practically insoluble in solvents other than water and offers little utility in formulating grains which contain a high percentage of oxygen and low binder content (a function of the grain solids loading). The technique investigated was to dissolve the oxidizer salt to allow higher solids loading and more uniform oxidizer/fuel distribution. One binder material based on glycidyl methacrylate which could be polymerized predictably and contains 33.8 percent oxygen in its basic molecule offered promise as a candidate binder since sodium perchlorate was somewhat soluble in it. Initial studies conducted on a system based on glycidyl methacrylate revealed that the sodium perchlorate/glycidyl methacrylate combination produced a viscous slurry in contrast to the sodium nitrate/glycidyl methacrylate combination which produced a dilatent slurry. The work performed during the contract period centered largely on evaluating suitable basic polyester resins to improve polymerization characteristics as well as particle wetting characteristics of the solids to facilitate casting.

Several types and combinations of basic polyester resins were evaluated for compatibility with glycidyl methacrylate monomer. The solid resins, Aropol 7200 and CoRezyn 14, copolymerized readily with the monomer but posed problems of dissolving readily in the monomer. Two liquid basic polyester resins, CoRezyn 3 and CoRezyn 10, were also evaluated for compatibility with glycidyl methacrylate monomer. Both resins not only readily dissolved in the monomer but appeared to be highly compatible.

During the last phase of the study, an attempt was made to fabricate flare grains using a nitrated acrylic monomer, 2,2-dinitropropyl acrylate, as a binder. The high oxygen content (47.1 percent) in the basic molecule added to the attractiveness of the acrylic monomer and offered a source of oxygen inherently available in the binder. The monomer was difficult to polymerize by room-temperature curing techniques, even after removal of the inhibitor. Several grains cast using this monomer failed to polymerize even after several weeks at elevated temperatures.

CASTING PROCEDURE

Preparation of Binder. The basic polyester resin, either a solid or a liquid, is dissolved in the monomer, glycidyl methacrylate. In the case of the solid resin, such as Aropol 7200 or CoRezyn 14, a viscous binder syrup is prepared by stirring in the solid resin for about two hours. the liquid resins dissolve readily in the monomer and the binder syrup is ready to use immediately.

Preparation and Casting of Slurry. For a blend batch of 1,500 grams, one percent benzoyl peroxide catalyst is first added to the binder syrup and stirred until completely dissolved. Approximately 30 ml of the binder is put aside for use later. Sodium perchlorate is added to the remaining binder and blended using a planetary mixer such as the Hobart Model K5-A which was used in preparing slurries for this study. The mixture is blended for fifteen minutes or until homogeneous. Magnesium is then added, starting with the finest particle size, blending completely before adding the next larger particle size. Ten drops of N,N-dimethyl-p-toluidine, a room-temperature curing agent, is added to the 30 ml of binder which was set aside earlier, stirred in completely and immediately added to the slurry. The slurry is then blended for five to ten minutes and cast into flare cases or molds. A mild polymerization exotherm is noticed about 20 to 30 minutes after casting. The cast grains are subjected to a post cure cycle at 150 degrees F to insure complete polymerization. Those grains cast in molds (free-standing grains) are inhibited along the cylindrical surfaces with a laminating compound such as Laminac 4116 to prevent flash-by during burning.

Intensity Measurements. Equipment used to detect flare intensities consisted of the E,G&G 580 Radiometer system; Texas Instruments Oscillo/Riter was used to record intensities and burn times on strip charts. All intensity measurements were conducted at ambient conditions, in the open, with the radiometer system internally adjusted to account for background radiation.

EXPERIMENTAL RESULTS

Solid Basic Polyester Resins (CVF-100 to CVF-107). A cast flare grain, CVF-100, incorporating glycidyl methacrylate/CoRezyn 14 monomer was cast. The unpolymerized composition was somewhat "wetter" than grains previously fabricated using only glycidyl methacrylate as a binder. It is apparent that the addition of 2.0 percent CoRezyn 14 improved particle wetting due to the increase in viscosity. Two days after casting which was followed by an oven post-cure at 160°F, the grain was visually inspected. The lower third of the grain was crumbly with evidence of incomplete polymerization. Another unit was cast to ascertain whether or not a feasible grain can be cast using 2.0 percent CoRezyn 14.

A second unit, CVF-101, was cast using twice as much basic polyester resin (CoRezyn 14) in the monomer - 4.0 percent. The amount of liquid monomer, glycidyl methacrylate, was appropriately reduced from 13.5 percent to 11.5 percent. The unpolymerized composition (CVF-101) appeared smoother and wetter than the composition containing 2.0 percent solid polyester resin. This might largely be due to the use of finer mesh sodium perchlorate (100/200 mesh) together with the more viscous monomer. The grain cast was allowed to cure over night at room temperature. A mild exotherm was noticed approximately two hours after casting. The grain then was subjected to a post cure cycle of four hours at 60°C. In an attempt to remove the grain from its mold, a radial crack around the center of the free-standing grain developed.

A third grain, CVF-102, was cast in the same fashion as the previous two grains but with modifications. The basic formulation was essentially the same as CVF-100 except that: (1) the basic polyester resin was changed from CoRezyn 14 to ADM 7200 and (2) the particle size of the sodium perchlorate was changed from 100/200 mesh to through 200 mesh.

The unpolymerized slurry was somewhat wetter than the previous two compositions; it is believed that this was largely due to the finer particle size of the sodium perchlorate used. The solid polyester resin, ADM Aropol 7200, dissolved at a faster rate in the monomer, glycidyl methacrylate, than CoRezyn 14 and it seemed to produce a more viscous monomer than the CoRezyn 14 system. The cured grain released from the mold rather easily due to a larger percentage of shrinkage of the flare grain.

As a basis for comparison, CVF-103 was blended and cast in the same manner as CVF-102. Sodium nitrate (200/325 mesh size) was substituted for sodium perchlorate (200/325 mesh size). Observations made during the blending stage indicated that the nitrate did not produce as viscous a slurry as the perchlorate but produced a slurry wet enough to be cast. The cured grain did not differ in physical appearance from the perchlorate grains. Both the nitrate-based and perchlorate-based grains were susceptible to moisture attack and adequate protective measures had to be taken.

Grain number CVF-102 which was based on sodium perchlorate produced an estimated luminous efficiency of 36,200 candle-seconds/gram. Due to partial smoke obscuration during combustion, the value above was estimated from the radiometric trace obtained. Grain number CVF-103, which was based on sodium nitrate produced a luminous efficiency of 37,300 candle-seconds/gram. There was no apparent smoke obscuration during the combustion of this grain. On the basis of the results obtained above, it appears that neither sodium perchlorate nor sodium nitrate offered an advantage over the other. However, from the standpoint of ease of fabrication the perchlorate-based grains have a distinct advantage over the nitrate-based grains.

Both CVF-101 and CVF-102 were fabricated from identical formulations, except for the polyester resin. CVF-101 incorporated CoRezyn 14, a solid amber colored unsaturated polyester resin, while CVF-102 incorporated ADM Aropol 7200, a solid amber-colored unsaturated polyester resin. Test results indicate that the grain containing CoRezyn 14 resin produced a higher luminous efficiency, 49,500 candle-seconds/gram than the grain containing ADM Aropol 7200, which produced a luminous efficiency of 37,300 candle-seconds/gram. From the standpoint of fabrication, no difference was noted in casting slurry consistency and polymerization rates of the two grains.

A re-evaluation of cast grains based on Sodium Nitrate using Glycidyl Methacrylate monomer and basic polyester resin as a binder was conducted. Due to difficulty encountered in blending, the binder percentage for formulations containing sodium nitrate was increased from 16.0 percent to 18.66 percent to improve particle wetting. CVF-104 was blended using the higher binder percentage and also a mixed-particle distribution of sodium nitrate (25.90 percent -325 mesh and 12.10 percent 200/325 mesh size). The utilization of this higher binder percentage together with the

difficulty encountered in blending (inhomogeneity) reduced the luminous efficiency of the flare formulation to 13,200 candle-seconds/gram. An attempt to cast a grain, CVF-105, containing 16 percent binder was difficult largely due to insufficient particle wetting. A castable slurry could not be produced.

Further investigations of glycidyl methacrylate monomer, CoRezyn 14, and sodium perchlorate formulations were conducted. The effect of altering the monomer to basic polyester resin ratio was studied. As was discussed a binder possessing some degree of viscosity improved particle wetting, thereby facilitating blending and casting of the unpolymerized slurry. On this basis, an attempt was made to increase the viscosity of the binder by increasing the solid basic polyester resin (CoRezyn 14) content in the monomer (glycidyl methacrylate) to study: (1) the effect of binder viscosity upon particle wetting and (2) the luminous efficiency of the flare composition. Compositions investigated thus far contained 4.0 parts of basic polyester resin to 11.5 parts of monomer (glycidyl methacrylate). Attempts to produce binder solutions of higher viscosity with either CoRezyn 14 or Aropol 7200 failed due to the inability of the monomer to dissolve either resin in ratios greater than 1 part of solid resin to three parts of monomer. An alternative method of increasing slurry viscosity was to increase the perchlorate content in the binder. Two grains, CVF-106 and CVF-107, were prepared, the former containing 42 percent perchlorate and the latter containing 45 percent perchlorate, the binder in each case containing no solid polyester resin (CoRezyn 14 or Aropol 7200) to influence viscosity. Insofar as slurry preparation is concerned, both formulations appeared similar in slurry consistency. Test results indicate that the formulation containing 42 percent oxidizer (CVF-106) produced a luminous efficiency of 36,000 candle-seconds/gram, which is lower than what was measured for identical grains prepared earlier in the program, e. g. , CVF-89 yielded 41,200 candle-seconds/gram. CVF-107 containing 45 percent oxidizer yielded a luminous efficiency of 43,000 candle-seconds/gram. The three percent increase in oxidizer percentage did not significantly alter the luminous efficiency of the composition, nor did it alter slurry viscosity. The solubility of the oxidizer (perchlorate) in the monomer (glycidyl methacrylate) was most likely the limiting factor in producing a more viscous binder. The solubility of the solid polyester resin in the monomer was greater than the solubility of the perchlorate in the monomer, thus producing a binder possessing higher viscosity leading to better particle wetting for improved processibility without the tendency for the binder to migrate to the lower portion of the cast grain.

Liquid Basic Polyester Resins (CVF-108 - CVF-120). Two basic polyester resins, CoRezyn 3 and CoRezyn 10, were evaluated for compatibility with the monomer glycidyl methacrylate. CoRezyn 3, an amber-colored resin possessing a viscosity of 100,000 cps at 77°F was copolymerized with glycidyl methacrylate successfully. CoRezyn 10, which has a viscosity of 600-650 cps initiated polymerization with glycidyl methacrylate at a faster rate than CoRezyn 3. Two formulations based on four percent total basic liquid polyester resins, one with CoRezyn 3 (CVF-109) and one with CoRezyn 10 (CVF-108) were blended. The resultant slurries before polymerization were about the same in consistency. However, the amount of catalyst, benzoyl peroxide, was reduced from 1 percent to 0.5 percent because of the reactive nature of the liquid polyester resins. To improve particle wetting, the percentages of liquid polyester resins were raised from 4 percent to 7.75 percent of the total composition and the effect upon blending and polymerization was observed for formulations containing both CoRezyn 3 and CoRezyn 10 (CVF-110 and CVF-111). The increase in the amount of basic polyester resin, with a resultant increase in viscosity, improved particle wetting and blending operations. Intensity measurements made for grains containing the liquid polyester resins compared favorably with those fabricated from the solid polyester resins. The formulation containing 7.75 percent CoRezyn 10 (CVF-111) appeared to give a higher luminous efficiency, (50,500 and 51,200 candle-seconds/gram for two samples tested) than formulations previous tested. To evaluate ease of blending and casting as well as luminous efficiency of the best formulation prepared to that date, alterations were made in the oxidizer to fuel ratio. When the oxidizer, sodium perchlorate, was increased from 42.0 to 44.0 percent (CVF-112) with a subsequent decrease in fuel, magnesium, the slurry was not as castable as the previous formulation, CVF-111, containing 2 percent less oxidizer. Also, the best luminous efficiency recorded for this formulation was 48,600 candle-seconds/gram. When the oxidizer percentage was reduced by 2 percent from 42.0 percent to 40.0 percent, the casting slurry was somewhat more fluid, but again, the best luminous efficiency of the formulation was 49,800 candle-seconds/gram, slightly but not significantly, lower than what was obtained from CVF-111 (51,200 candle-seconds/gram). Upon further lowering the oxidizer percentage, from 42.0 percent to 36.0 percent (CVF-114), the casting slurry became even more fluid. However, test results indicated decrease in luminous efficiency, from 51,200 candle-seconds/gram to 44,200 candle-seconds/gram. The results confirm what was reported in the previous study that the luminous efficiencies of formulations containing an excess of oxidizer, sodium perchlorate, tended to decrease and, conversely, the luminous efficiencies of formulations containing a slight excess of magnesium produced only a slight change. Best luminous efficiencies were obtained when the oxidizer (sodium

perchlorate) to fuel (magnesium) weight ratio was 1:1.

During the second phase of the evaluation of liquid polyester resins, the particle distribution of the oxidizer was altered to include equal parts of three distinct screen classifications, namely, 100/200 mesh, 200/325 mesh and -325 mesh cuts. The magnesium particle distribution was restricted to 100/200 mesh (JAN-M-382A). During the slurry blending stage, little viscosity change was noted between formulations containing a single particle distribution of the perchlorate and the formulations containing three different particle distributions prior to the addition of magnesium. After the addition of magnesium, the formulations containing the single particle distribution of magnesium (CVF-115 to CVF-120), were somewhat wetter than previous compositions which contained a trimodal distribution of magnesium powder. Luminous efficiency measurements for these grains tended to be lower than comparable grains containing a trimodal distribution of magnesium powder, cf. CVF-113 and CVF-116.

In addition, these grains (CVF-115 to CVF-117) burned slower than the previous grains (see Table V). In an attempt to increase burn rates and luminous efficiencies, the amount of binder was reduced from 16.0 percent to 12.9 percent (CVF-118 to CVF-120). The reduction in binder content increased both burn rates (from .06 in/sec to .08 in/sec) and luminous efficiency (from 43,700 candle-seconds/gram to 46,800 candle-seconds/gram).

Nitrated Acrylic Binder Evaluation (CVF-121 - CVF-122).

Initial investigation of 2,2-dinitropropyl acrylate was conducted to ascertain polymerization characteristics. The monomer as received with inhibitor was difficult to polymerize by conventional means. Several caustic washes were necessary to remove the inhibitor. After inhibitor removal the monomer was difficult to polymerize and required elevated temperatures (100-240°F) to cure. A binder consisting of approximately 50 percent glycidyl methacrylate and 50 percent 2,2-dinitropropyl acrylate was formulated. Even with the addition of glycidyl methacrylate to the binder, the slurry was difficult to cast and, consequently, the binder percentage in the formulation was increased to 20 percent. A double catalyst system consisting of benzoyl peroxide and MEK peroxide was employed to initiate polymerization; after being subjected to elevated temperature several grains failed to cure. One grain, CVF-121, appeared to cure; however, upon testing the grain deflagrated shortly after ignition and continued to burn irregularly emitting burning particles. This irregular combustion characteristic of the grain seemed to indicate failure of the binder to polymerize completely, leaving unpolymerized zones within the grain itself.

CONCLUSIONS AND RECOMMENDATIONS

Castable visual flare formulations producing luminous efficiencies up to 51,000 candle-seconds/gram based on a relatively high binder percentage (sixteen percent) have been developed. Liquid polyester resins greatly facilitated the preparation of the binder and fabrication of flare grains. Although no significant difference in luminous efficiencies was noted between binder systems incorporating solid polyester resins and liquid polyester systems, the ease of preparation of liquid polyester binder systems tend to favor the latter. Optimum results were obtained when the oxidizer to fuel ratio was maintained near the 1:1 range. A trimodal distribution of the fuel, magnesium, appeared to alter slightly slurry rheology but produced faster burning grains and higher luminous efficiencies. Conversely, trimodal distribution of the oxidizer, sodium perchlorate, did not alter slurry rheology nor affect the burn rate and luminous efficiency. No significant difference in luminous efficiency was evident between the 3.2 inch diameter grain and the 4.0 inch diameter grain.

Although the theoretically high oxygen content found in 2,2-dinitropropyl acrylate would make it an attractive binder candidate for cast systems, the difficulty encountered in effecting polymerization, plus the present cost and availability of the monomer, precludes its use as a binder in cast systems.

It is recommended that further study be accomplished on flare grains greater than 4 inches in diameter using the techniques and formulations described in this report.

TABLE I

	CVF-100	CVF-101	CVF-102	CVF-103	CVF-104	CVF-105	CVF-106	CVF-107
Glycidyl Methacrylate	13.5 %	11.5 %	11.5 %	11.5 %	14.60 %	11.5 %	15.5 %	15.5 %
Ethylene Dimethacrylate	.5	.5	.5	.5	.45	.5	.5	.5
CoRezyl 14	2.0	4.0	----	----	----	4.0	----	----
Arapol 7200	----	----	4.0	4.0	3.61	----	----	----
Sodium Perchlorate	42.0	42.0	42.0	----	----	----	42.0	45.0
Sodium Nitrate	----	----	----	42.0	38.00	44.5	----	----
Magnesium 22 microns	14.0	14.0	14.0	14.0	14.45	13.0	14.0	13.0
Magnesium 125 microns	14.0	14.0	14.0	14.0	14.45	13.0	14.0	13.0
Magnesium 200 microns	14.0	14.0	14.0	14.0	14.45	13.5	14.0	13.0

Benzoyl Peroxide: 1.0 percent of monomer

N,N Dimethyl p-toluidine: 10 drops/1,500-gram batch

TABLE II

	<u>CVF-108</u>	<u>CVF-109</u>	<u>CVF-110</u>	<u>CVF-111</u>	<u>CVF-112</u>	<u>CVF-113</u>	<u>CVF-114</u>
	. 5 %	. 5 %	. 5 %	. 5 %	. 5 %	. 5 %	. 5 %
Ethylene Dimethacrylate	11.5	11.5	7.75	7.75	7.75	7.75	7.75
Glycidyl Methacrylate	4.0	-----	-----	7.75	7.75	7.75	7.75
CoRezyn 10	-----	-----	-----	-----	-----	-----	-----
CoRezyn 3	-----	4.0	7.75	-----	-----	-----	-----
Sodium Perchlorate	42.0	42.0	42.00	42.00	44.00	40.00	36.00
Mg 22 mic MIL-P-14067	14.0	14.0	14.00	14.00	14.00	15.00	16.00
Mg 125 mic MIL-P-14067	14.0	14.0	14.00	14.00	13.00	15.00	16.00
Mg 200 mic MIL-P-14067	14.0	14.0	14.00	14.00	13.00	14.00	16.00

Benzoyl Peroxide: 0.5 percent of binder (ethylene dimethacrylate, glycidyl methacrylate, CoRezyn resin)

N,N Dimethyl p-toluidine: (Room-temperature curing agent) 1 drop per 150 grams of composition.

TABLE III

	<u>CVF-115</u>	<u>CVF-116</u>	<u>CVF-117</u>	<u>CVF-118</u>	<u>CVF-119</u>	<u>CVF-120</u>
	.50 %	.50 %	.50 %	.50 %	.52 %	.52 %
Ethylene Dimethacrylate	7.75	7.75	7.75	6.20	6.20	6.20
Glycidyl Methacrylate	7.75	7.75	7.75	6.20	6.20	6.20
CoRezyn 10	14.67	13.33	12.00	13.80	15.20	12.40
Sodium Perchlorate (100/200)	14.67	13.33	12.00	13.80	15.20	12.40
Sodium Perchlorate (200/325)	14.67	13.33	12.00	13.80	15.20	12.40
Sodium Perchlorate (-325)	40.00	44.00	48.00	45.70	41.50	49.80
Mg JAN-M-382A (100/200)						

Benzoyl Peroxide: .1 g/100 g composition

N, N Dimethyl p-toluidine: 1 drop/100 g composition

TABLE IV

	<u>CVF-121</u>	<u>CVF-122</u>	<u>CVF-123</u>
Glycidyl Methacrylate	9.8 %	9.8 %	9.8 %
2,2-Dinitropropyl Acrylate	10.0	10.0	10.0
1,3-Butylene Dimethacrylate	.2	.2	.2
Sodium Perchlorate	38.0	38.0	38.0
Magnesium MIL-P-14067 22 microns	42.0	----	14.0
Magnesium MIL-P-14067 125 microns	----	----	14.0
Magnesium MIL-P-14067 200 microns	----	----	14.0
Magnesium JAN-M-382A 100/200	----	42.0	----

Benzoyl Peroxide: 1.0 percent of binder (glycidyl methacrylate, 2,2-dinitropropyl acrylate, 1,3 butylene

Lupersol DDM (MEK Peroxide): 2.0 percent of binder

TABLE V

<u>Serial Number</u>	<u>Luminous Efficiency Candle-Seconds/Gram</u>	<u>Burn Rate Inch/Second</u>
CVF-101	49,500	.0674
CVF-103	37,300	.0787
CVF-104	13,200	.0682
CVF-106	48,600*	.114
CVF-107	43,000	.0837
CVF-109	34,900	
CVF-110	47,000; 40,000	.077; .070
CVF-111	50,500; 51,200	.076; .073
CVF-112	44,200; 48,600	.0915; .107
CVF-113	49,800; 39,800	.085; .096
CVF-114	44,300; 28,800	.075; .0765
CVF-115	43,700	.052
CVF-116	39,500	.067
CVF-117	42,800	.061
CVF-118	46,800	.082
CVF-119	36,000*	.126

* Smoke Obscuration Estimated Value

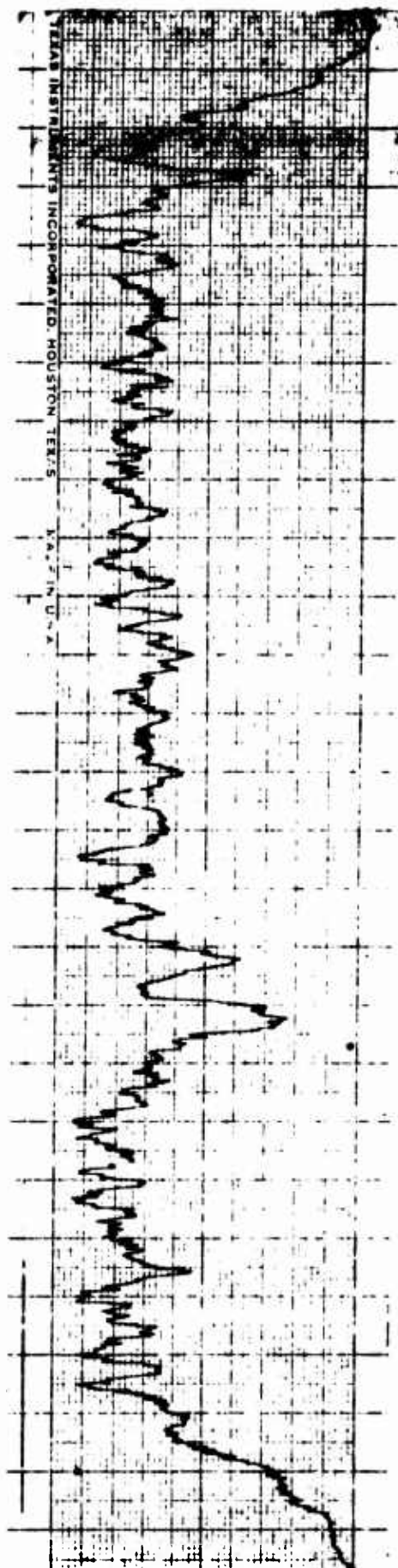


FIGURE 1

Serial No.: CVF-101
 Detector: E, G&G
 Distance: 70 feet
 Burn Time: 52 seconds
 Burn Rate: 0.067 inches per second
 E: 49,500 candle-seconds/gram

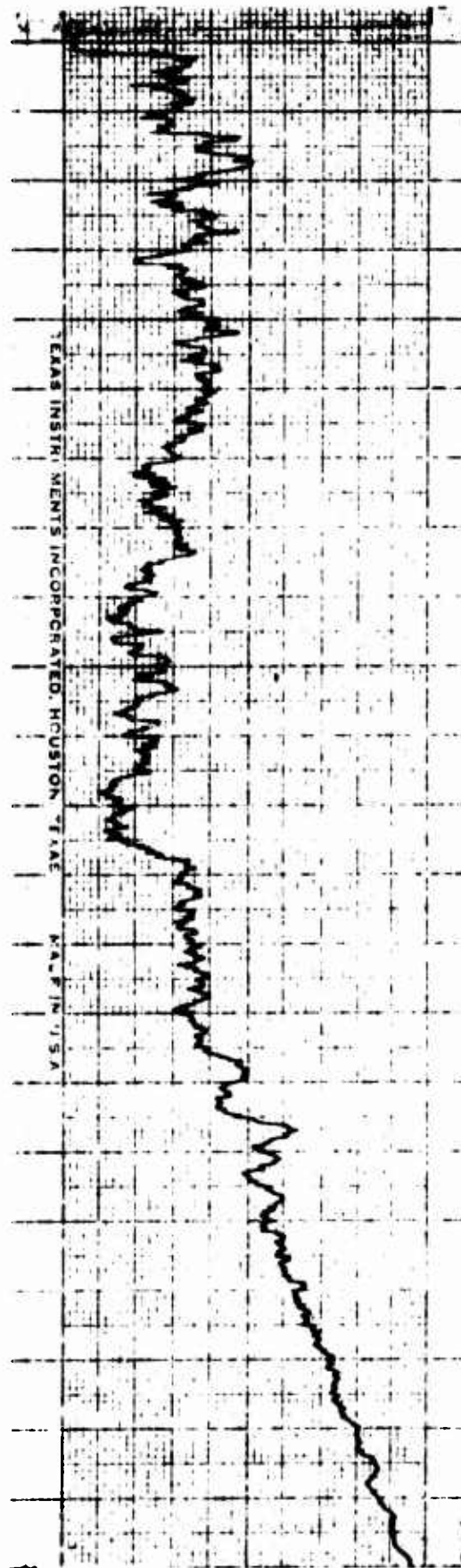


FIGURE 2

Serial:	CVF-10
Detector:	E, G&G
Distance:	70 feet
Burn Time:	44.5 seconds
Burn Rate:	0.079 in/sec
E:	37,300 candle-seconds/gram

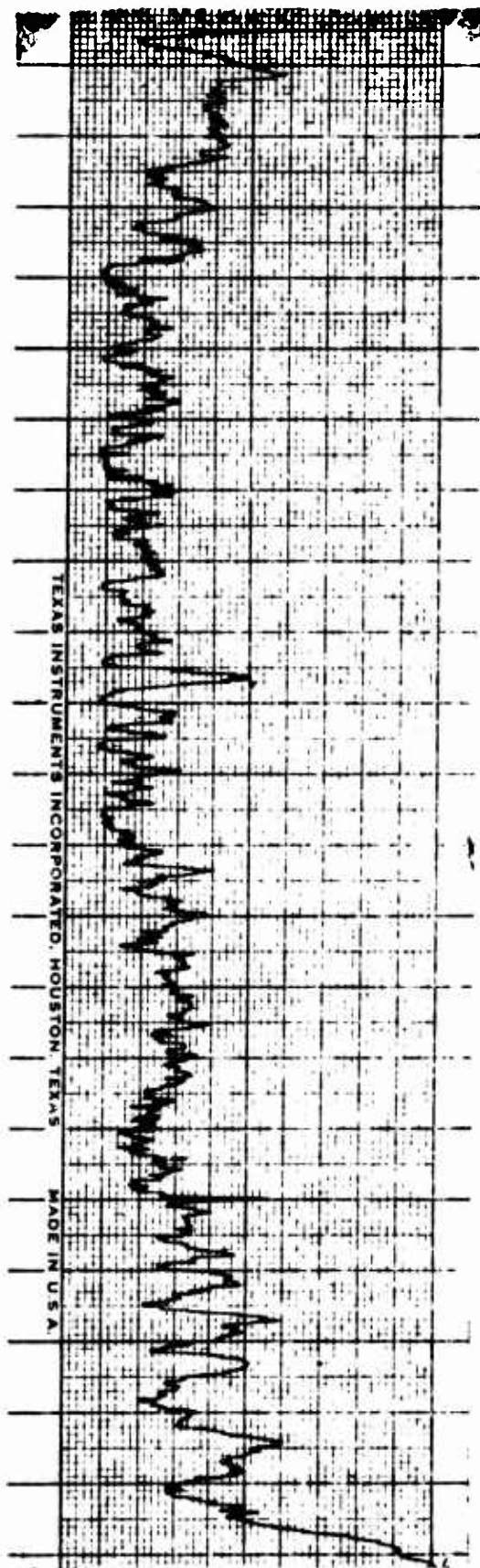


FIGURE 3

Serial No.: CVF-111 4.0 Inches Diameter
Detector: E, G&G
Distance: 60 feet
Burn Time: 43 seconds
Burn Rate: .076 in/sec
E: 50,500 candle-seconds/gram

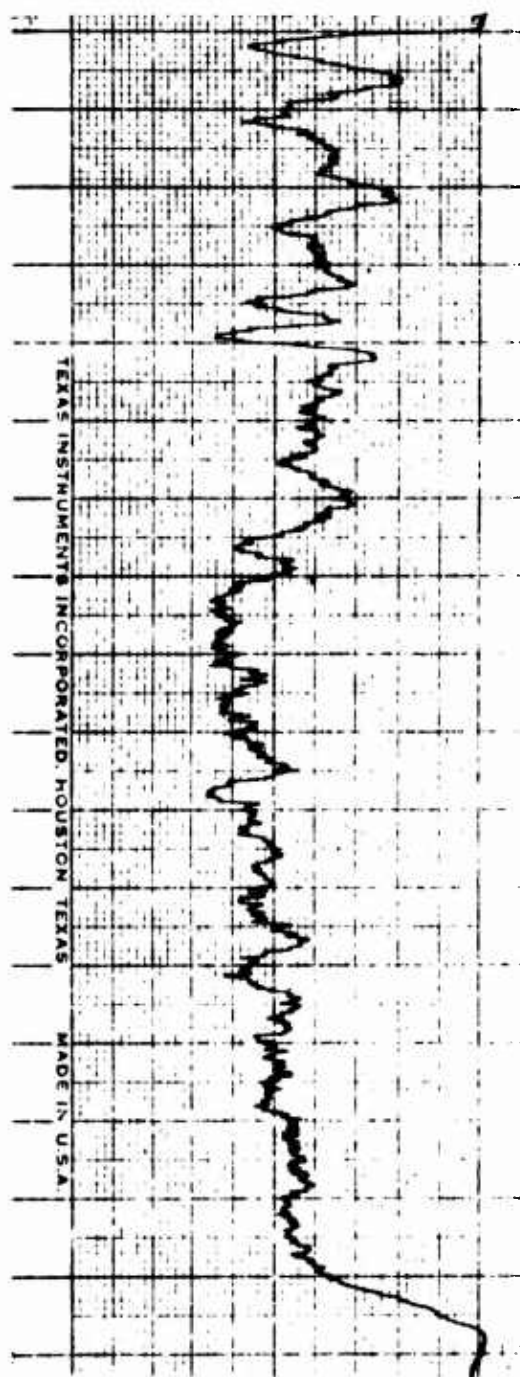


FIGURE 4

Serial No.:	CVF-1111	3 2 In. Diam.
Detector:	E, G&G	
Distance:	60 feet	
Burn Time:	33 2 Sec	
Burn Rate:	.073 in/sec	
E:	51,200 candle-seconds/gra	

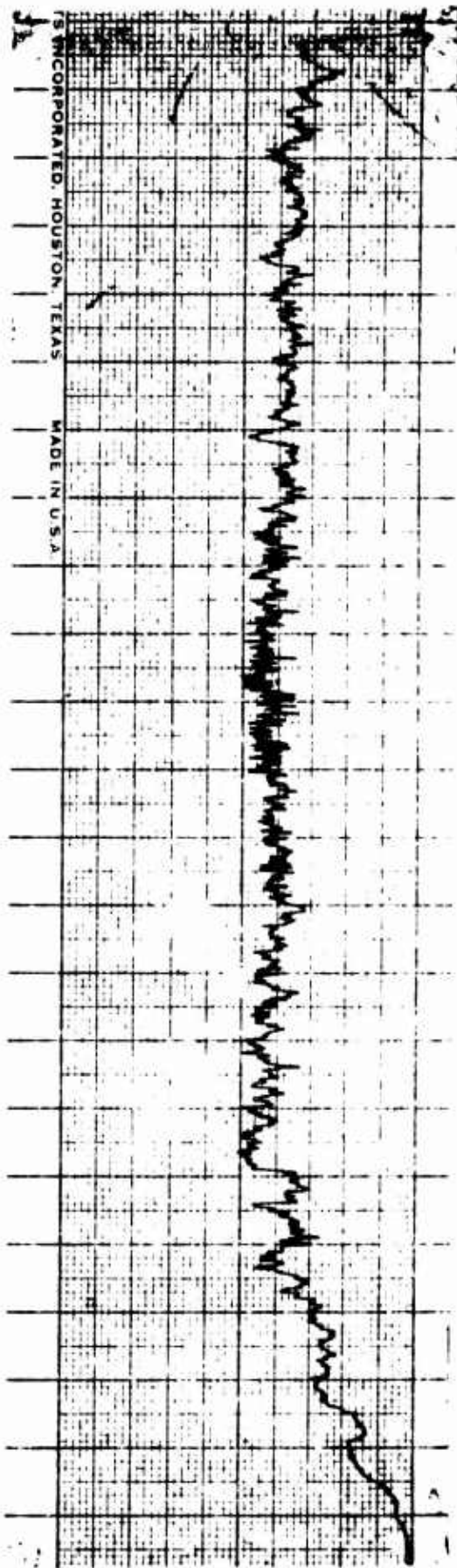


FIGURE 5

Serial No.: CVF-115 4.0 in Diam
 Detector: E, G&G
 Distance: 70 feet
 Burn Time: 43.6 seconds
 Burn Rate: .052 in/sec
 E: 43,700 candle-seconds/gram

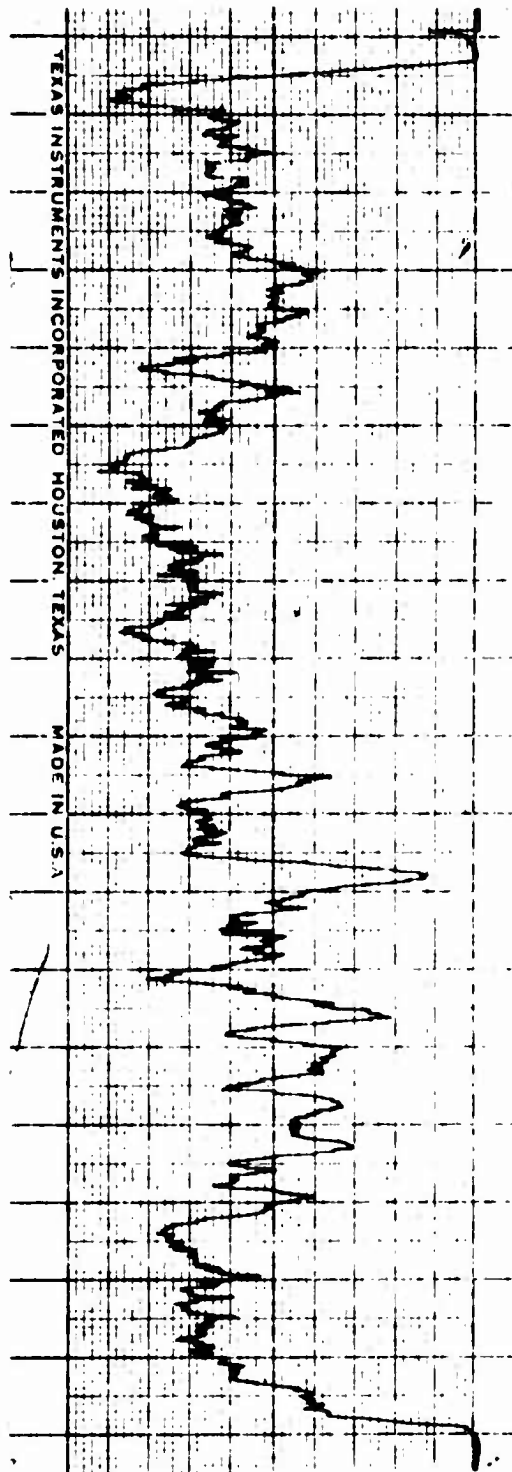


FIGURE 6

Serial No.:	CVF-118	4.0 in Diam
Detector:	E, G&G	
Distance:	70 feet	
Burn Time:	35.2 seconds	
Burn Rate:	.082 in/sec	
E:	46,800 candle-seconds, gram	

LIST OF MATERIALS

Glycidyl Methacrylate	American Aniline & Extract Co., Inc. Philadelphia, Pennsylvania
1,3-Butylene Dimethacrylate	Rohm & Haas, Philadelphia, Penna. Sartomer Resins, Inc., P.O. Box 56, Essington, Pennsylvania
Ethylene Dimethacrylate	Sartomer Resins, Inc., P. O. Box 56 Essington, Pennsylvania
Benzoyl Peroxide	Cadet Chemical Corporation Burt, New York
MEK Peroxide (Lupersol DDM)	Lucidol Division, Wallace & Tiernan, Buffalo, New York
N, N-Dimethyl p-Toluidine	Aldrich Chemicals, Milwaukee, Wisconsin
2,2-Dinitropropyl Acrylate	Hummel Chemical Company, 185 Foundry Street, Newark, New Jersey
Sodium Perchlorate	American Potash and Chemical Corp., 99 Park Avenue, New York, New York
Sodium Nitrate, MIL-S-322B	Davis Nitrate Company, Inc. Metuchen, New Jersey
Magnesium, MIL-P-14067	Valley Metallurgical Processing Co. Essex, Connecticut
Magnesium, JAN-M-382A	Valley Metallurgical Processing Co. Essex, Connecticut
CoRezyn 14, CoRezyn 3, CoRezyn 10	Commercial Resins Division, Interplastic Corporation, Minneapolis, Minnesota
Aropol 7200	Archer, Daniels, Midland Company 3552 Zip Industrial Boulevard, S.E., Atlanta, Georgia

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13. ABSTRACT Castable visual flare formulations and techniques were developed that produce luminous efficiencies greater than 50,000 candle-seconds/gram. Improved luminous efficiencies and ease of casting were made possible with a relatively high binder percentage of sixteen percent. No pressure is required for casting. Liquid polyester binder systems were found to provide optimum characteristics for casting as well as luminous efficiency with their high oxygen and low carbon content. Optimum sodium perchlorate oxidizer to magnesium fuel ratio was determined to be one to one with oxidizer partially dissolved in liquid binder. Flare grains in sizes from 3.2 inches to 4 inches in diameter were cast and tested with no significant change in efficiency versus diameter.		

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