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Fast-Burning Rate/High Slope
Propellant Technology Program
Final Report [U]

by

R. L. Lou

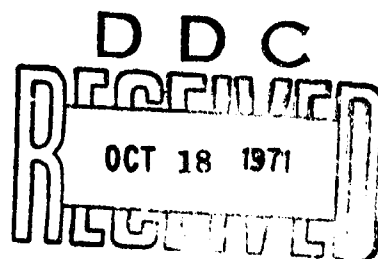
and

A. Katzakian

Aerojet Solid Propulsion Company (ASPC)

for the

Propulsion Development Department



Naval Weapons Center

CHINA LAKE, CALIFORNIA

SEPTEMBER 1971



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ABSTRACT

(U) Two candidate propellant formulations, ANB-3394 and ANB-3395-1, were developed that satisfied all the technical goals. Additionally, these propellants were successfully test fired in small scale motors verifying propellant ballistic properties, excellent liner propellant bonds, and propellant processability adequate for good grains.

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Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

W. J. Moran, RADM, USN Commander
H. G. Wilson Technical Director

FOREWORD

This final report describes work conducted by Aerojet Solid Propulsion Company, Sacramento, California for the Naval Weapons Center, China Lake, California during the period 1 May 1970 through 22 April 1971 under Navy contract N00123-70-C-1457. This work was supported by the Naval Air Systems Command under AirTask WF 19.332.302.

M. F. Pickett of NWC was technical coordinator for this program and has reviewed this report for technical accuracy.

Released by
RAY MILLER, Head
Propulsion Systems Division
1 September 1971

Under authority of
G. W. LEONARD, Head
Propulsion Development Department

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INTRODUCTION

(U) The objective of this 11-month program was to advance the state-of-the-art with regard to formulation of practical fast-burning and high-pressure-exponent propellants by expanding available technology.

(U) The specific goals were the formulation of two propellants, hereinafter referred to as "A" and "B", with respective burning rates of 3.5 and 7.0 in/sec. at 2000 psia and a pressure exponent of about 0.70. Both propellants were to be formulated to deliver a specific impulse (I_{sp}) of at least 240 lbf-sec/lbm with a density of 0.063-0.065 lbs/in.³. The study also included the development of adequate mechanical properties to withstand the temperature range of -40 to 160°F. Other considerations were adequate processing, potlife (4 hrs. @ 135°F), thermal and aging stability and safety characteristics. Only composite propellants were to be considered, with porous AP (PAP) and non-volatile ferrocene derivatives limited to the high burning rate propellant "B".

(U) As a final part of the program ten grains measuring 2 in. dia. x 6.25 in. length and four grains measuring 4.8 in. dia. x 15 in. length of each candidate formulation as well as representative samples of these propellants were forwarded to NWC, China Lake, for further testing.

SUMMARY

(U) Two candidate propellant formulations, ANB-3394 and ANB-3395-1, were developed on this program that satisfied all the technical goals. Additionally, those propellants have been successfully test fired in small scale motors verifying propellant ballistic properties, excellent liner propellant bonds, and propellant processability adequate for good grains. All required grains have been delivered to NWC, China Lake.

(U) Two propellant formulations, ANB-3361 and ANB-3364, from the previous high burning rate/high slope program on Contract No. N00123-69-C-0401 were chosen as baseline formulations. Both baseline formulations were processed at the beginning of this program and were found to be deficient in processing, mechanical, and ballistic properties.

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(U) Improvement in processing properties (viscosity, potlife) was considered to be the key to a successful program because it is a necessity for the processing of large batches for delivery grains and that excess processability may be traded for a higher burning rate. The problem of short potlife was solved by using a modified form of the pre-polymer R-45M. This modification consisted in blocking excess hydroxyl groups with a monoisocyanate which resulted in a three fold increase in potlife for ANB-3394. However, ANB-3395-1, the Catocene containing formulation, did not show improvement in potlife using modified R-45M until acetylacetone (HAA) was also added to the formulation. The Fe^{+++} contamination in the Catocene was catalyzing the isocyanate-hydroxyl reaction and the HAA served to suppress this catalytic effect through chelation.

(U) Improvements in propellant mixing and mechanical properties were achieved with the incorporation of the functional wetting agent DEO and the bonding agent TEA. These ingredients also made the incorporation of finer oxidizer and burning rate catalysts easier, while maintaining or improving mechanical properties.

(U) Significant increases in burning rate were achieved by (1) increasing the propellant mix cycle, (2) replacing the $10\mu \text{NH}_4\text{ClO}_4$ with $5\mu \text{NH}_4\text{ClO}_4$ and, (3) in the case of ANB-3394, replacing the standard Fe_2O_3 with a finely ground, crystalline Fe_2O_3 . For ANB-3395-1, the desired burning rate was achieved by increasing the Catocene to 4% from 3%, and using a more active porous ammonium perchlorate (PAP).

(U) Hazard characteristics of the final formulations were determined in both the uncured and cured states. No unusual processing or handling characteristics were indicated. One batch of ANB-3395-1, however, having a high Shore reading (74), exhibited high friction sensitivity, but all subsequent batches with shore hardnesses of less than 60 showed much greater stability to friction. Both candidate propellants were classified as Class "B" explosives by ICC tests.

(U) Two 175 lb batches, one each of ANB-3394 and ANB-3395-1, were processed from which six - 5 x 19 in. phenolic sleeves were cast from each batch using an improved casting setup; all grains cast were void-free by radiographic inspection. Also, void-free gallon cartons and DPT specimens were cast from each batch to measure mechanical, ballistic and bonding properties. This demonstrated that both candidate formulations have adequate processing characteristics.

(U) Reproducibility in mechanical properties and burning rates were good from batch to batch for each candidate formulation. After one month aging at 135°F each formulation showed increases in tensile strength with small decreases in elongation; burning rates as measured in solid strands appeared unchanged and liner/propellant bonds remained excellent.

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(U) Several small grains were test fired to substantiate solid strand burning rates, propellant/liner bond and grain integrity. Initial firings resulted in erratic pressure-time traces due to aluminum deposition on the nozzles. The following changes were effected to minimize such deposition: (1) Increase L^* by shortening grain to 3 in., (2) cast a 0.25 in. layer of non-aluminized propellant on the main grain to serve as a nozzle warmer, (3) use a contoured boron nitride nozzle, and, (4) change from H-95 to H-60 aluminum. After these changes had been made, good motor firings were obtained which verified the corresponding solid strand burning rates.

TECHNICAL DISCUSSION

(U) The candidate formulations from the previous NWC contract N00123-69-C-0401¹, ANB-3361 and ANB-3364 (Table 1), were selected as baseline formulations, respectively, for propellant "A" (ANB-3394) and propellant "B" (ANB-3395-1). The processing and mechanical properties of the baseline formulations were marginal, and since the target burning rates for propellants "A" and "B" for this program were about 20% higher than the rates for the baseline formulations (Figure 1) we decided to make improvements in processing and mechanical properties first, and then trade them off as needed to make the necessary ballistic improvements. Also, the work centered largely on meeting propellant "A" goals since such progress could be readily used to achieve the corresponding goals for propellant "B".

(U) Since poor propellant/liner bonding was the suspected cause of motor failures in the previous program, early demonstration of good liner bonds and motor firings was planned and demonstrated.

¹(U) Aerojet General Corporation. Fast-Burning Rate/High Slope Propellant Technology Program Final Report 15 March 1969--15 January 1971. Sacramento, California.

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(C) TABLE 1. Composition of Candidate Formulations
Developed for NWC Contract NO0123-69-C-0401

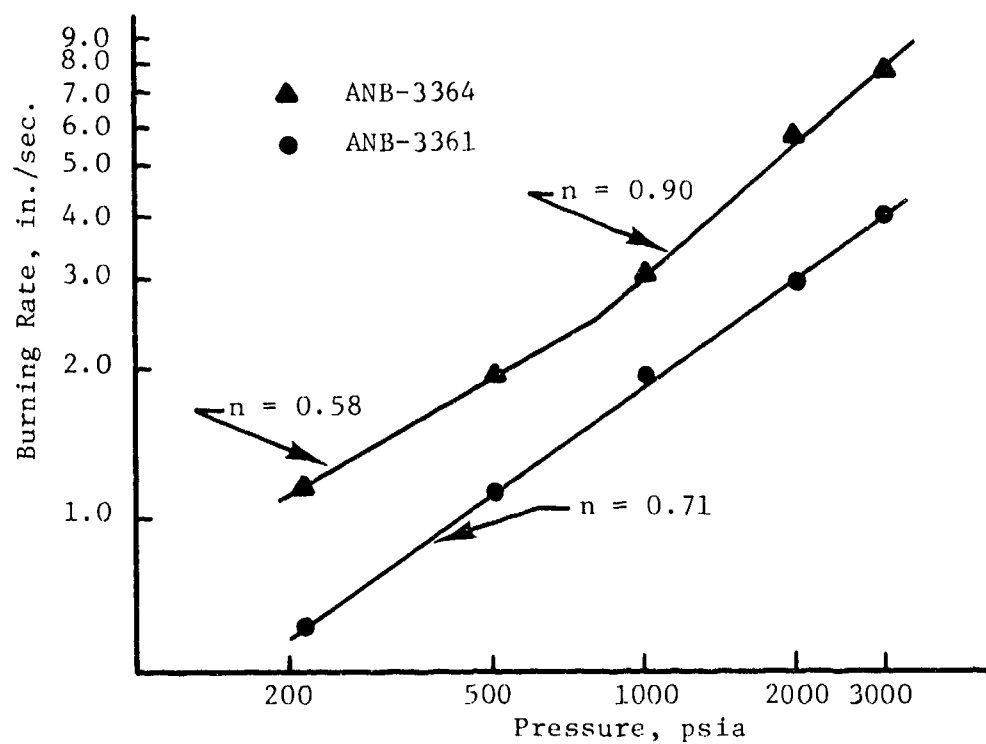
Composition, %		
Ingredients	ANB-3361	ANB-3364
NH_4ClO_4 (0.5 μ) ^a	50.00	35.00
NH_4ClO_4 (7-10 μ)	19.00	25.00
Porous NH_4ClO_4 (180 μ)	...	10.00
Aluminum (H-60)	15.00	15.00
Fe_2O_3	0.50	...
BRA-101	0.50	...
HYCAT-6	...	3.00
Plastinox #711	0.30	0.10
Agerite White	0.20	0.20
Sulfur	...	0.30
Oronite 6	4.50	...
R-45M	9.28	1.00
HT-Telagen	...	9.76
TEA	0.04	...
C-1	...	0.05
IPDI	0.68	0.59
	100.00	100.00

^aBDB coated, 0.5%.

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(U) FIG. 1. Plot of Solid Strand Burning Rates vs. Pressure for Candidate Batches from Previous NWC Contract NO0123-69-C-0401.

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PROCESSING AND MECHANICAL PROPERTY STUDIES

(U) The problems of poor processing and mechanical properties were solved by a combination of approaches involving the use of a functional wetting agent, that also serves as a bonding agent, in combination with a functionally modified prepolymer and second bonding agent. For the Catocene containing propellant the inclusion of a chelating agent greatly increased the potlife. Various other approaches to improving processing and mechanical properties were explored, some moderately successful and others unsuccessful. All the approaches are presented and discussed in the following sections.

Evaluation of Wetting and Bonding Agents

(U) The addition of diethanololeamide (DEO) into the ANB-3361 formulation resulted in greater ease of mixing, a smoother, less pasty appearance to the propellant, noticeably better castability and mechanical properties, but little or no improvement in potlife. The DEO approach was evaluated further in conjunction with TEA. The results of these studies are summarized in Table 2. Inspection of the table reveals some interesting trends. For example, when TEA was eliminated from the formulation a loss in elongation was noted although mixing and casting properties were unchanged. When TEA and DEO were both removed mixing, casting and mechanical properties were all impaired. Having established the need for TEA and DEO, we determined those levels of each that yielded optimum processing and mechanical properties. Referring to Table 2 again, a significant upward trend in mechanical properties was observed with the stepwise increase of DEP at the expense of R-45, holding TEA and IPDI constant. Both tensile strength and elongation increased implying that the DEO was also functioning as a bonding agent. Unfortunately, at the high DEO level the potlife was extremely short resulting in poor castability and a porous sample that prevented the measurement of mechanical properties. The data suggest, however, that an optimum level of DEO is about 0.2% of the formulation corresponding to an equivalence level between 10 and 15. The optimum TEA level is indicated at .02% of the formulation which corresponds to about 5 equivalents. A lower IPDI level is also indicated since a lower modulus and higher elongation is desired.

(U) The addition of TEA after IPDI addition in the mix cycle resulted in a slight increase in elongation with a drop in tensile strength and modulus (Table 2). This technique has shown increases in both tensile strength and elongation in other propellants, but appears here to have simply reduced the effective IPDI level by reaction with ammonia released from $\text{TEA-NH}_4\text{ClO}_4$ interaction, since similar results would be expected.

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(C) TABLE 2. Effects of Wetting and Bonding Agents on Processing and Mechanical Properties

Batch No. AK-	Binder Variations				Mixability	Mechanical Properties @ 77°F			Shore A Hardness
	R-45M (Equiv.)	TEA (Equiv.)	DEO (Equiv.)	IPDI (Equiv.)		σ_m , psi	ϵ_m , %	E_o , psi	
7365-18	90	10	...	80	Poor	165.4	16.7	1001	72
7365-20	90	5	5	80	Fair	154.6	18.9	864	65
7365-22	90	...	10	80	Fair	144.5	15.6	976	70
7365-41	85	10	5	80	Fair	177.5	17.8	1055	...
7365-43	80	10	10	80	Good	194.4	21.7	1071	...
7365-45	70	10	20	80	Good	213.5	20.6	1198	...
7365-63	50	10	40	80	Fair	...	...	...	...
7365-49 ^a	80	10	10	80	Good	156.2	22.2	764	...
7365-53	80	10	10	75	Good	173.0	22.8	853	...
7365-55	80	10	10	70	Good	128.1	23.4	627	...
7591-36 ^{b,c}	100	...	...	70	Poor	81.6	18.5	474	52
7591-38 ^{b,c}	95	5	...	70	Fair	92.2	19.2	507	56
7591-40 ^{b,c}	85	5	10	70	Good	118.0	19.4	674	64

NOTE: Any benefits in castability that would have resulted from the above variations were masked by very short potlife. All batches contain (50%) 0.5 μ UFAP, (19%) MA-AP, (15%) Al-H60, (0.5%) Fe₂O₃, (0.5%) Silon S, (5.0%) Oronite 6 and aging stabilizers unless noted otherwise.

^aTEA added last in mix cycle.

^bBurning rates at 2000 psia and pressure exponents (n) for AK-7591-36, -38, -40 respectively are 3.52 (0.76), 3.40 (0.74) and 3.48 (0.78).

^cContains 5 μ UFAP in place of MA-AP and Al-H95 in place of Al-H60.

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(U) Although this formulation has responded favorably to bonding agents, the effects were not as large as was expected. We suspected, therefore, that the BDB coating on UFAP may either be interfering with the bonding agent, or function as a bonding agent itself. This hypothesis was tested by comparing 0.9 μ UFAP coated with 0.5% Victoria Blue R (a rosanilin dye) against 0.9 μ UFAP coated with 0.5% BDB. The dye coated UFAP mixed and cast with more difficulty and gave a lower burning rate at 2000 psia than the BDB coated UFAP, probably due to differences in deagglomeration rates.

	<u>0.9μ UFAP (0.5% BDB)</u>	<u>0.9μ UFAP (0.5% Dye)</u>
r_b , in/sec @ 2000 psia	2.92	2.73

(U) Although mechanical properties were not measured, it was clearly evident that the BDB coated UFAP produced a propellant with superior mechanical properties.

(U) An unsuccessful attempt to further enhance the beneficial properties of DEO was made by adding a non-functional co-wetting agent such as lecithin to the formulation. This wetting agent adversely affected both the mixing and casting characteristics of the propellant. No further work with co-wetting agents was conducted.

Evaluation of Alternate Prepolymer and Curing Systems

(U) Because of the short potlife exhibited by the R-45M/IPDI binder, alternative prepolymer and curing agents were evaluated in the "A" formulation. However, no significant improvements in processing, potlife or mechanical properties were produced by these systems.

(U) Carboxyl-Terminated Polybutadiene/Epoxy System. The use of HC-434 carboxyl-terminated polybutadiene with epoxide curing agents such as ERL-4221 or ERL-4205 did not improve the potlife of the "A" formulation.

(U) R-45M/Imine System. Utilization of the diimine, BISA, as a curing agent for R-45M in the "A" formulation afforded negligible potlife and resulted in a hard, brittle propellant mass.

(U) R-45M/Epoxy Systems. The application of ERL-4206 epoxide as a curing agent for R-45M provided a 4 hour potlife at 135°F for the "A" formulation. However, a satisfactory elastomeric cure was not achieved. Replacement of ERL-4206 with ERL-4221 in the "A" formulation resulted in a negligible potlife and a brittle propellant.

(U) R-45M/Epoxy/IPDI Systems. The use of various epoxides in combination with IPDI were evaluated with the goals of extending potlife and providing propellant with adequate mechanical properties. With the IPDI held at 35 eq. the following diepoxides were formulated at the 65 eq. level in the "A" formulation:

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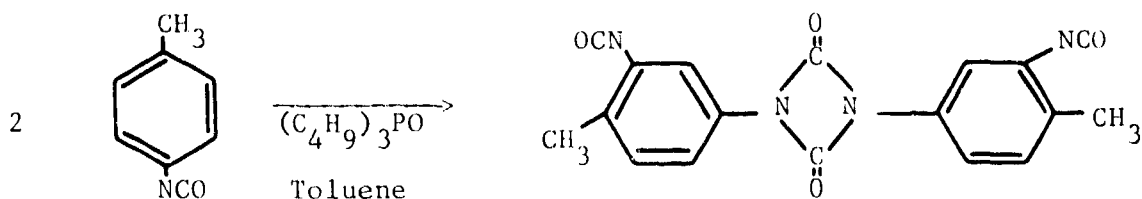
<u>Epoxide</u>	<u>Batch No.</u>
None	AK-7591-24C
Resorcinoldiglycidyl ether (CIBA ERE 1359)	AK-7591-24D
Vinylcyclohexene dioxide (Union Carbide ERL-4206)	AK-7591-24E

(U) The data from these experiments are summarized in Table 3 and show that no significant improvements in potlife or mechanical properties were gained from the epoxide/IPDI curing systems.

(U) Cure Retarders. Experience at ASPC in other propellants has shown that trioctylphosphine oxide (TOPO), phenol and trioctylphosphate (TOF) can be used to extend the potlife of polyurethane propellants. The use of TOPO (0.3%), phenol (0.2%), or TOF (4.5%, as a replacement for the Oronite 6 plasticizer), however, did not increase the potlife of the "A" formulation.

(U) Blocked Isocyanate. Blocked isocyanates have been used to delay polyurethane cure reactions. In order to obtain a blocked isocyanate, TDI was combined with the blocking agent, acetylacetone, for 48 hours prior to use in the propellant. However, no increase in the potlife of the "B" propellant was observed when the blocked TDI was used in place of IPDI.

(U) Dimerized Isocyanate. TDI dimer was obtained via the following reaction.



The dimer was formed by blending 1 mole of TDI in 500 ml toluene with 5 drops of tri-n-butylphosphine as the catalyst. The mixture was stirred overnight and the resulting solid was collected by filtration and washed well with hexane. The vacuum dried material had a m.p. of 154-156°C, identical to the literature value. The I.R. spectrum was also in accord with the expected dimerized structure, giving a strong isocyanate absorption at 2280 cm^{-1} and a strong urea-like carbonyl absorption at 1772 cm^{-1} . The propellants made with this material gave reasonable potlives, but cured rapidly to a hard, brittle material with poor mechanical properties. (Table 3, #AK7591-17, -24A, -24B) Since no advantage in potlife was demonstrated (Figure 2, #AK7591-24A), and since the resultant mechanical properties were poor, no further work was done with this material.

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(C) TABLE 3. Effect of Dimerized TDI and Epoxide Curing Agents on Processing and Mechanical Properties

Batch No. AK-	AP Coarse Fraction, μ	Curing Agent (Equiv.)	Ballistic Prop., 80°F		Mechanical Prop., 77°F			Potlife, hrs ^a	Shore A Hardness
			r ₂₀₀₀ , ips	n	σ_m , psi	ϵ_m , %	E _o , psi		
7591-11 ^b	3	IPDI (70)	3.25	0.78	89.5	19.6	516	...	59
7591-13 ^b	3	IPDI/4206 (35)/(65)	2.98	0.76	43.7	21.9	282	...	12
7591-17	3	TDI-DC(70)	...	...	Poor Properties	Poor Properties	...	...	50
7591-24A	8	TDI-DC(65)	...	...	Poor Properties	Poor Properties	...	1.5	38
7591-24B	8	TDI-DC/4206 (35)/(65)	...	...	...	...	...	1.0	5
7591-24C	8	IPDI (35)	...	...	...	...	...	3.0	0
7591-24D	8	IPDI/RDE (35)/(65)	...	...	...	...	...	1.8	25
7591-24E	8	IPDI/4206 (35)/(65)	...	...	...	...	...	1.5	10

NOTE: All propellants contain 50% 0.4 UFAP, 19% 3-8 UFAP, 15% Al-H95, 0.5% Fe₂O₃, 0.5% Silon-S, 15% R-45M/IPDI binder, except where noted, and mix cycles have been set at 4 hours.

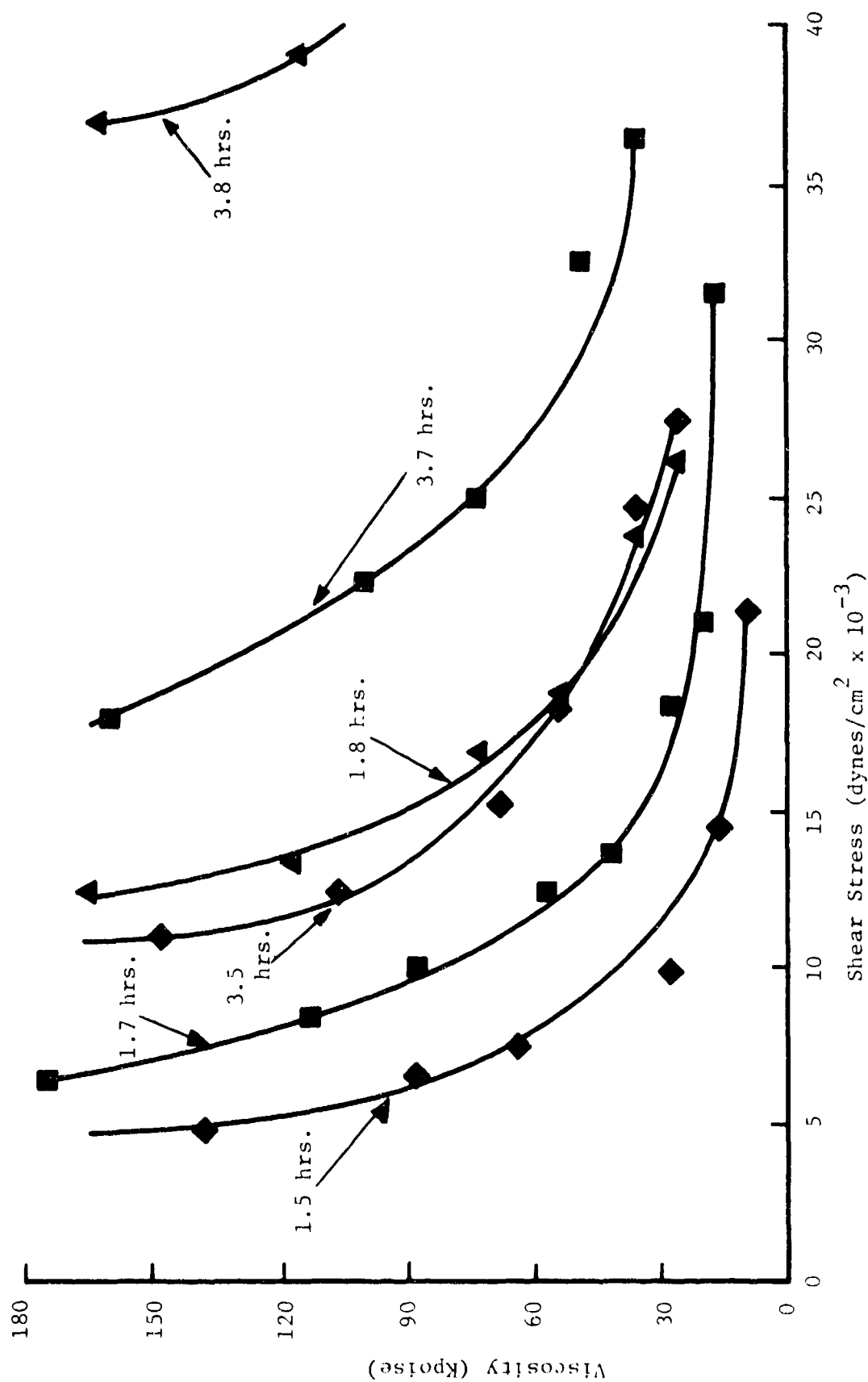
^aTime to 50 kpoise 120°F, 10,000 dynes/cm² Shear Stress

^bContained IDP in place of Oronite 6.

^cDimerized TDI.

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(U) FIG. 2. Viscosity vs. Shear Stress at 120°F and Two Time Intervals. The Time Noted on Curves Denotes Time After IPDI Addition. Curves include (1) ■ Dimer TDI (AK7591-24A), (2) ▲ IPDI 35 eq./4206 65 eq. (AK7591-24E) and (3) ◆ IPDI 35 eq. (AK7591-24C).

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Effect of Plasticizer Type and Level

(U) Because of the much lower viscosity of IDP relative to Oronite 6, it was of interest to determine whether or not IDP would improve processing and mechanical properties. Consequently, a batch of propellant "A" was prepared wherein all the Oronite 6 was replaced with IDP. Although this change resulted in a more processable propellant, no improvement was observed in mechanical properties and the burning rate of the cured propellant was adversely affected (Table 4, #AK7591-11). The decrease in tensile strength was not explainable and may not be a result of using IDP. The depressing effect on burning rate was attributed to the ester group in IDP since such groups do tend to give lower burning rates at high pressures (1000 - 2000 psi). Since losses in burning rate could not be tolerated, IDP was not considered further.

(U) Increasing the Oronite 6 plasticizer from 4.8 to 8.6% did not significantly increase the potlife of the "A" formulation (Table 4, #AK7591-52). Moreover, the burning rate and mechanical properties were adversely affected by the additional plasticizer. Efforts in this direction were discontinued.

(U) Due to the processing improvements that have been made in propellant "A" (TEA-DEO system), lower plasticizer levels were evaluated to see if mechanical properties could be improved while maintaining adequate processability (Table 4, AK7591-79, -81, -83, -85). Unfortunately, only increases in tensile strength were achieved, elongation remaining constant. Moreover, the propellant viscosity increased significantly at the lower plasticizer levels as shown in Figure 3. A comparison of viscosity buildup vs. time under a shear stress of 10,000 dynes/cm² at 120°F is presented in Figure 3 for three plasticizer levels. The potlife, measured as time to 50,000 poise, falls off rapidly as plasticizer decreases. Primarily, this is a result of higher initial viscosities, since the rates of viscosity buildup are similar. Going to higher cast temperatures lowers these initial viscosities, but due to rapid buildup rates, the useful potlife is shortened (Figure 4).

Effect of Aluminum Particle Size, Ballistic Solids And IPDI Level

(U) An enhancement of the mixing operation was realized when the coarser H-95 aluminum was used to replace the H-60 aluminum. The castability was also somewhat better, but the short potlife tended to obscure improvements in this area. No significantly adverse effects were observed on the burning rate.

Pressure	r _b , in/sec	
	A1-H60	A1-H95
500 psia	1.04	1.03
2,000 psia	2.92	2.86

NOTE: Slope of both propellants 0.74.

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(C) TABLE 4. Effect of Plasticizer Type and Level on Processing, Ballistic and Mechanical Properties

Batch No. AK 7591-	Binder Variables			Ballistic Prop., 80°F		Mechanical Prop., 77°F			Potlife, ^a Hrs	Shore "A" Hardness
	R-45M (Eqv)	DEO (Eqv)	Oronite-6 (%)	r ₂₀₀₀ in/sec	n	σ _m , psi	ε _m , %	E _o , psi		
11	75	20	4.80 ^b	3.25	0.78	89.5	19.6	516	...	59
52	55	10	8.00	3.32	0.78	149	11.0	1357	1.5	78
56 ^c	85	10	4.80	3.40	0.78	107	18.3	635	1.0	62
62	85 ^d	10	4.80	3.40	0.78	50.2	30.9	242	2.8	18
76 ^e	85	10	4.50	3.40	0.75	52.1	29.1	251	5.0	28
79 ^f	80	14	4.50	3.37	0.73	109	15.4	770	3.0	62
81 ^f	78	15	4.50	3.40	0.77	86.5	19.1	540	3.2	45
83 ^f	80	14	3.50	3.45	0.77	93.8	18.7	605	2.3	53
85 ^f	81	13	2.50	3.54	0.74	116	19.1	735	1.5	60

NOTE: All batches contain (50%) 0.55 UFAP, (19%) 5 UFAP, 15% Al H-95, and 15% binder with TEA and IPDI held constant at (5 eq) and (70 eq), respectively, unless otherwise noted. Mix cycles are 4 hours.

^aTimed to 50 kpoise at 120°F and 10,000 dynes/cm² shear stress.

^bUsed IDP in place of Oronite 6.

^cUsed new can of same lot of R-45M as used in all other batches.

^dModified R-45M calculated as unmodified R-45M and designated R-45M-50

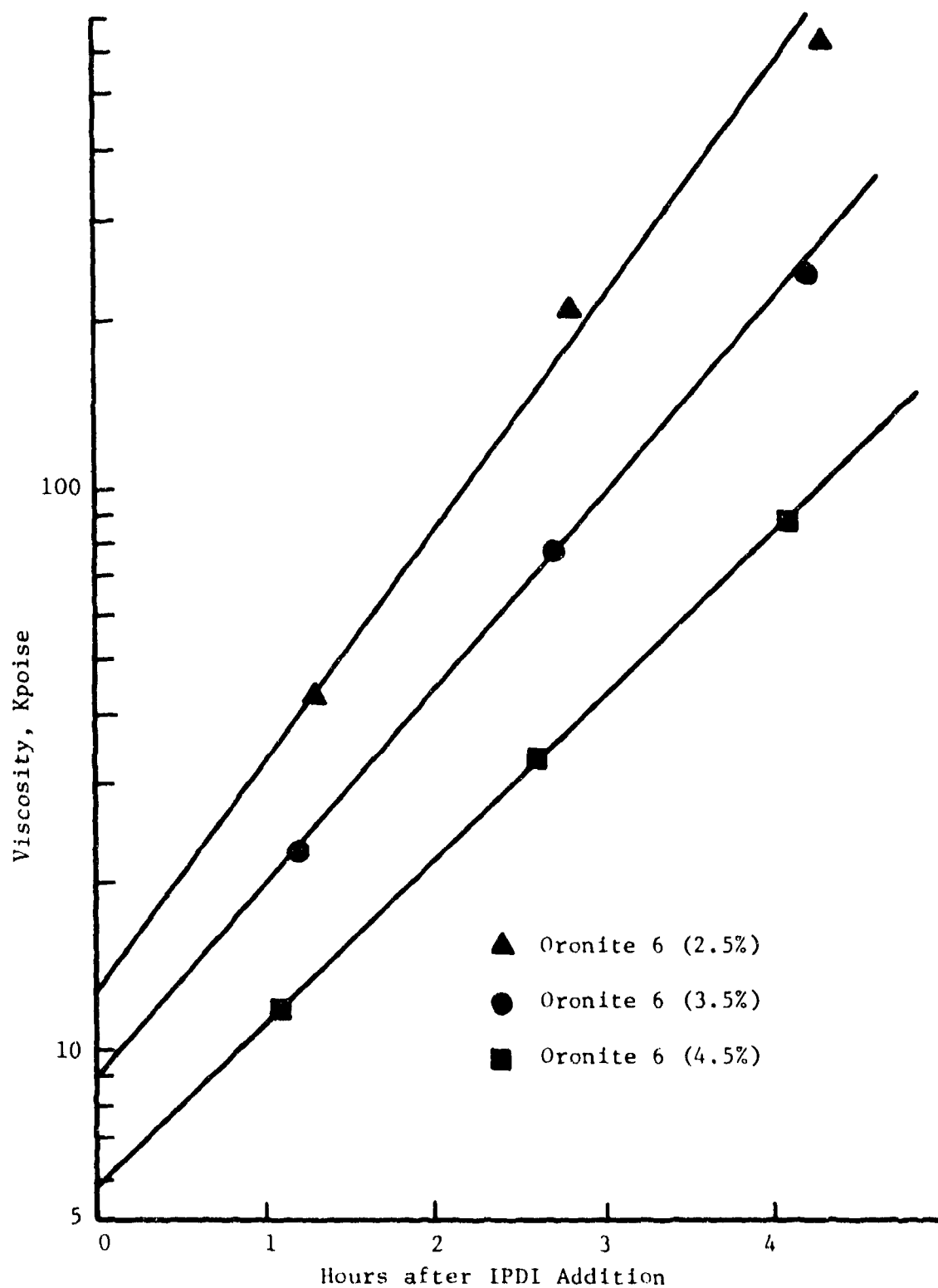
^eSame as (d) but used R-45M-25, 65 equiv. IPDI, ground crystalline Fe₂O₃, (40%) 0.55 UFAP and (29%) 5 UFAP.

^fContains (45%) 0.55 UFAP, (24%) 5 UFAP, modified R-45M, .02% TEA and 100 equiv. IPDI.

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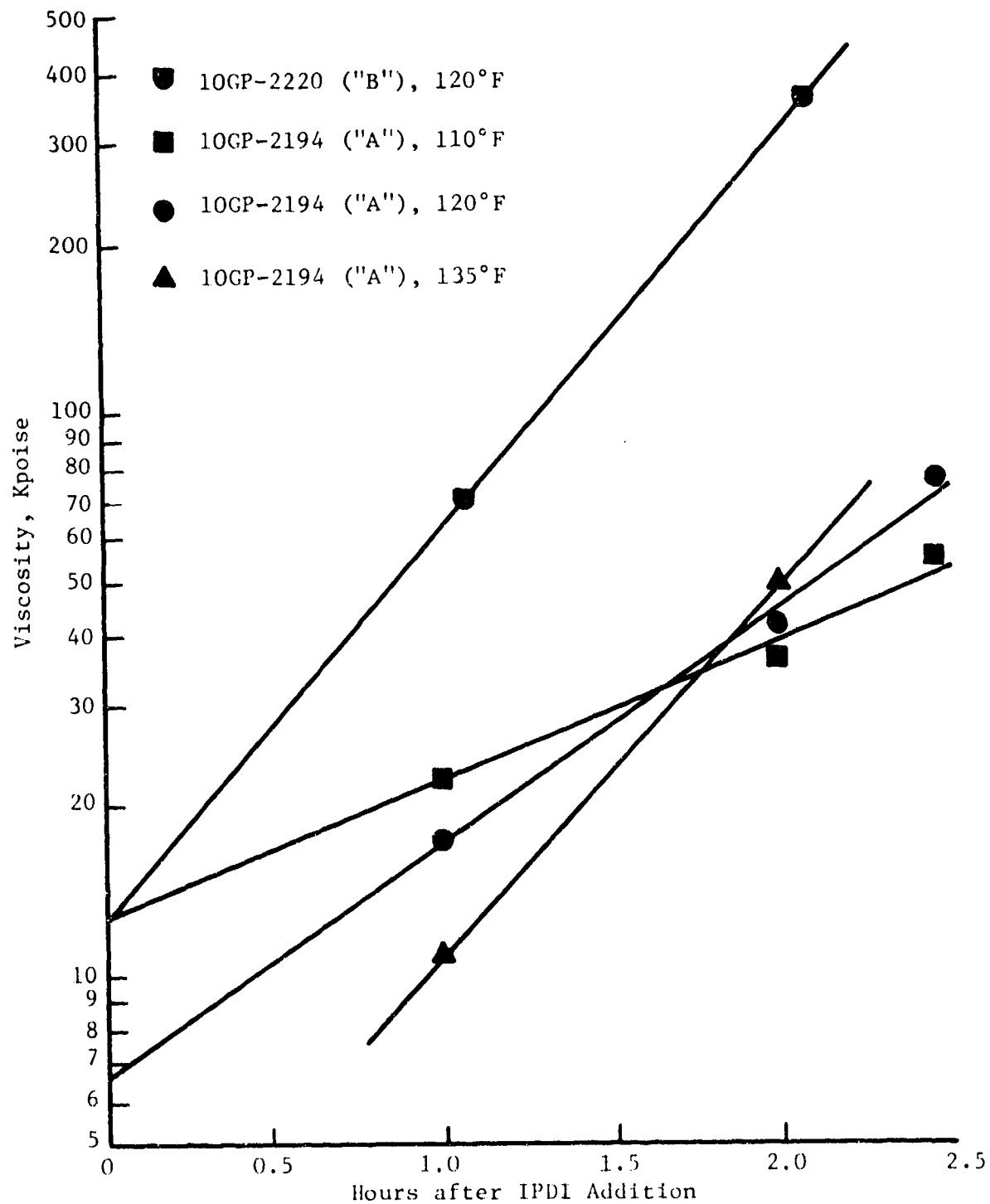


(U) FIG. 3. Effect of Oronite 6 Level on Propellant "A" Viscosity vs. Time at 10,000 dynes/cm² Shear Stress and 120°F.

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(U) FIG. 4. Viscosity Buildup of Candidates "A" (110°F, 120°F, and 135°F) and "B" (120°F), at 10,000 dynes/cm² Shear Stress.

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H-95 Al was used until near the end of the program when nozzle deposition was shown to be a problem in small motor testing. The final formulations used the finer H-60 Al.

(U) Because of the long interim mix cycle and the coarse aluminum used in these propellants, it was desirable to know whether or not the aluminum was producing any side effects as a result of abrasion. One batch was therefore prepared in which the H-95 Al was added after the interim mix cycle. The data (Table 5, #AK7591-26) indicate a slight lowering of the burning rate and a somewhat harder cure than is normally seen. The lower burning rate could be due to less efficient breakup of the UFAP particles and the harder cure may be attributed to less reaction of the fresh aluminum surface with the hydroxyl groups thereby allowing more complete reaction with the isocyanate curing agent. The effect is small enough, though, to be considered as a normal variation for this propellant.

(U) Two batches were made in which the ballistic solids were lowered by one and two percent, respectively (Table 5, #AK5691-42 and -28). Significant improvements in processing and mechanical properties were seen, especially for the 83% solids formulation. The sacrifice in burning rate, however, was too great to give serious consideration to this approach to improving processing and mechanical properties.

(U) Observation that residual R-45M on the outside of the container eventually formed a polymer led to the speculation that oxidative crosslinking may be slowly causing a viscosity increase in the R-45M being used. An unopened can of the same lot of R-45M was evaluated to see if any differences in processing were apparent (Table 5, #AK7591-56). Although the end of mix viscosity data show no significant differences, due to rapid cure, there was a noticeable improvement in the mix viscosity indicating that the exposed container of R-45M had undergone a small amount of oxidative crosslinking.

(U) Since previous work had shown that 70 equivalents of IPDI still produced too hard a propellant (Table 5, #AK7365-71) and current work (Table 5, #AK7591-24C) showed a significant increase in potlife by lowering IPDI, a series of three batches were prepared (Table 5, #AK7591-30, -32, -34) varying the IPDI from 45-65 equivalents. Rotovisco data (Figure 5) were taken on these batches to determine the viscosity buildup at each IPDI level. The data indicated that an IPDI level of 55-60 equivalents would be desirable from the standpoint of processing and mechanical properties.

Improved Potlife With Modified R-45M and Acetylacetone (hAA)

(U) No significant increase in the potlife of propellant "A" was realized until modified R-45M was used in place of R-45M. This modification was accomplished by blocking a portion of the hydroxyl groups on R-45M with a mono isocyanate, hence, the designation R-45M-25 means 25% of the hydroxyl groups are blocked, R-45M-35 means 35% are blocked, etc. Using R-45M-25 resulted in an increase in potlife (Table 6, #AK7591-76, -70) two and one half times that obtained with

(C) TABLE 5. Effects of Varying Solids and IPDI Level on Processing, Mechanical and Ballistic Properties

Batch No. AK-	Formulation Variables		Ballistic Prop., 80°F		Mechanical Prop., 80°F			Potlife ^a (Hrs.)	Shore "A" Hardness
	Solids Level (%)	IPDI Level (Equiv)	r 2000 in/sec	n	C _m , psi	ε _m , %	E _o , psi		
7591-26 ^b	85	70	3.37	0.76	153	19.9	847	1.0	75
7591-42 ^c	84	70	3.25	0.76	129	21.8	660	2.0	68
7591-28 ^d	83	70	3.07	0.72	147	30.5	563	3.0	67
7591-56 ^e	85	70	3.40	0.78	107	18.3	635	1.0	62
7365-71 ^f	86	70	3.05	0.76	129	18.3	760	...	71
7591-24 ^g	85	35	...	...	...	...	...	3.0	0
7591-30	85	45	3.28	0.80	55.1	33.8	243	1.0	18
7591-32	85	55	3.39	0.79	71.2	25.7	344	0.8	33
7591-34	85	65	3.51	0.78	120	14.2	935	0.5	65

NOTE: All formulations contain (50%) 0.55_u UFAP, (19%) 5_u UFAP, (15%) Al-H95, and (15%) R-45M/IPDI binder with TEA, DEO and R-45M held constant at 5, 20 and 75 equivalents respectively, unless otherwise noted.

^aTime to 50 kpoise at 120°F and 10,000 dynes/cm² shear stress.

^bAluminum added one half hour prior to IPDI addition.

^cAluminum decreased two percent and 5_u UFAP increased one percent.

^dAluminum decreased two percent.

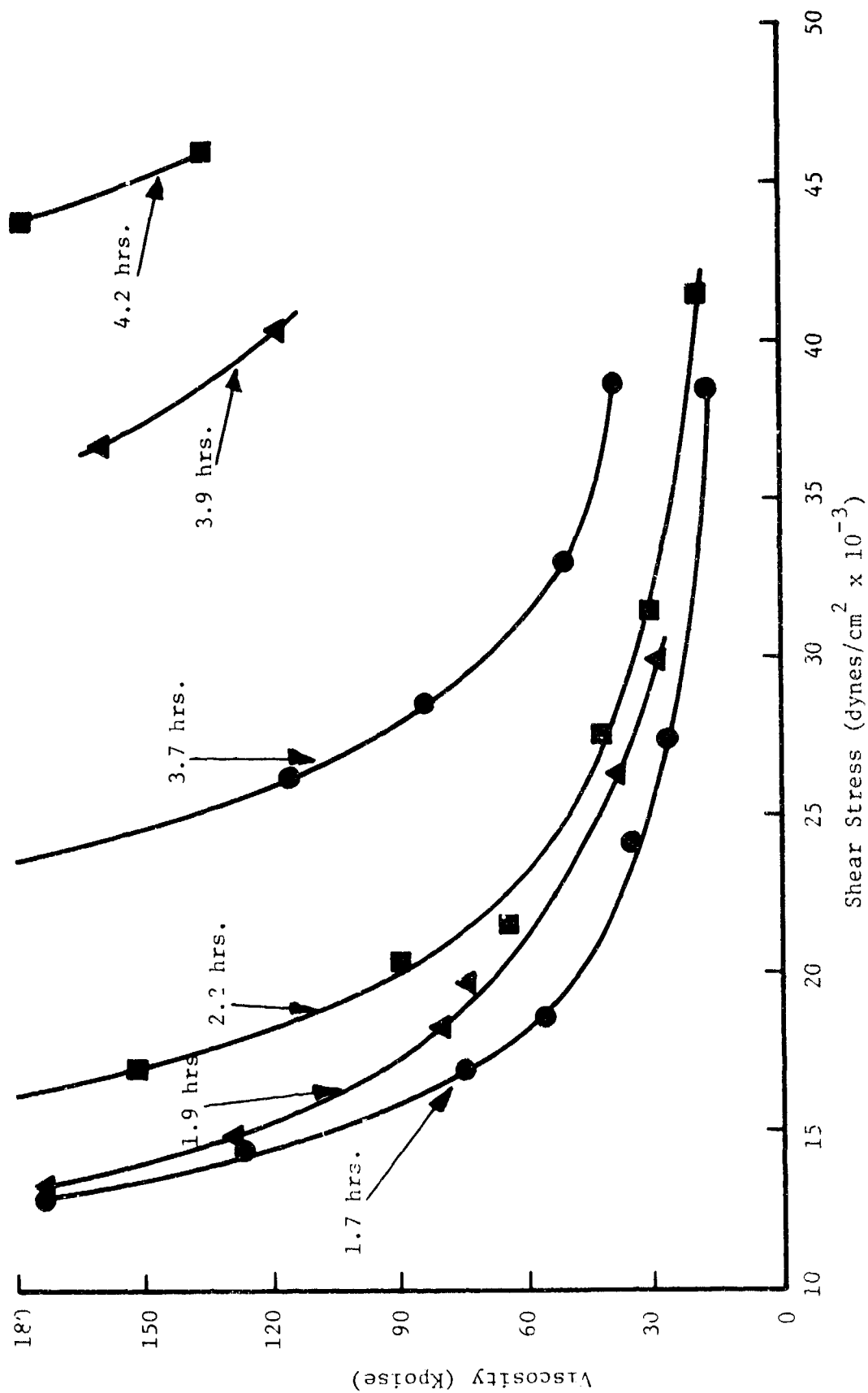
^eUsed new container of the same lot R-45M used in other batches.

^fUsed 20% NH₄ClO₄ (MA) in place of 5_u UFAP.

^gUsed NH₄ClO₄ (MA) in place of 5_u UFAP.

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(U) FIG. 5. Viscosity vs. Shear Stress at 120°F and Two Time Intervals. The Time Noted on Curves Denotes Time After IPDI Addition. Curves Include (1) ● IPDI 45 eq. (AK7591-30), (2) ▲ IPDI 55 eq. (AK7591-32) and (3) ■ IPDI 65 eq. (AK7591-34)

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(C) TABLE 6. Effect of Modified R-45M and Acetylacetone (HAA) on Potlife and Mechanical Properties

Batch No. AK-	HTPB (Type)	Formulation Type	Ballistic Prop., 80°F		Mechanical Prop., 77°F			Potlife ^a (Hrs)	Shore "A" hardness
			v ²⁰⁰⁰ in./sec	n	σ _m psi	ε _m %	E _o psi		
7591-70	R-45M	"A"	3.38	0.75	76.6	24.1	353	2.0	44
7591-76	R-45M-25	"A"	3.39	0.75	78.4	25.7	349	5.0	28
7591-81	R-45M-35	"A"	3.40	0.77	86.3	19.2	535	3.2	45
7591-62	R-45M-50	"A"	3.38	0.78	50.2	41.8	242	5.0	18
7591-89	R-45M-25	"B"	6.78	0.90	115	16.7	781	...	70
10CP-2248	R-45M-35	"B"	6.70	0.90	85.6	16.8	637	1.2	48
10CP-2457 ^b	R-45M-35	"B"	6.65	0.88	78.7	22.5	483	2.8	43

NOTE: All "A" formulations contain 69% (0.5 and 5%) UFAP, 15% Al, 0.5% Fe₂O₃, 0.5% Silon S and 15% HTPB binder. The "B" formulations contain 70% AP (0.5%, NA, and PAP), 15% Al, 4% catocene and 11% HTPB binder.

^aTime to 50 kpoise at 120°F and 10,000 dynes/cm² shear stress.

^bContains 0.2% HAA.

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unmodified R-45M). A graphic illustration of this potlife effect is shown in Figure 6, where viscosity buildup for the two batches is measured with time at two different shear stresses.

(U) The desired level of blocking was chosen at 35% (R-45M-35) as a reasonable compromise to achieve reasonable potlife, with adequate cure and mechanical properties. These experiments are summarized in Table 6. Although propellant "A" responded to modified R-45M with a significant potlife increase, such was not the case for propellant "B". Assuming that the catalytic effect of Fe^{+++} contamination in the Catocene was overriding the potlife effect of the modified R-45M, acetylacetone (HAA) was added to the formulation to deactivate this catalytic species by chelation. This resulted in a potlife (Table 6, #10GP-2457) comparable to that achieved for propellant "A" with modified R-45M. The small drop in mechanical properties noted for the HAA containing batch was attributed to incomplete cure, since later aging results have yielded almost identical properties to the "B" formulation without HAA (Table 6, #10GP-2248). The conclusion was that HAA has no significant effect other than increasing potlife.

BALLISTIC STUDIES

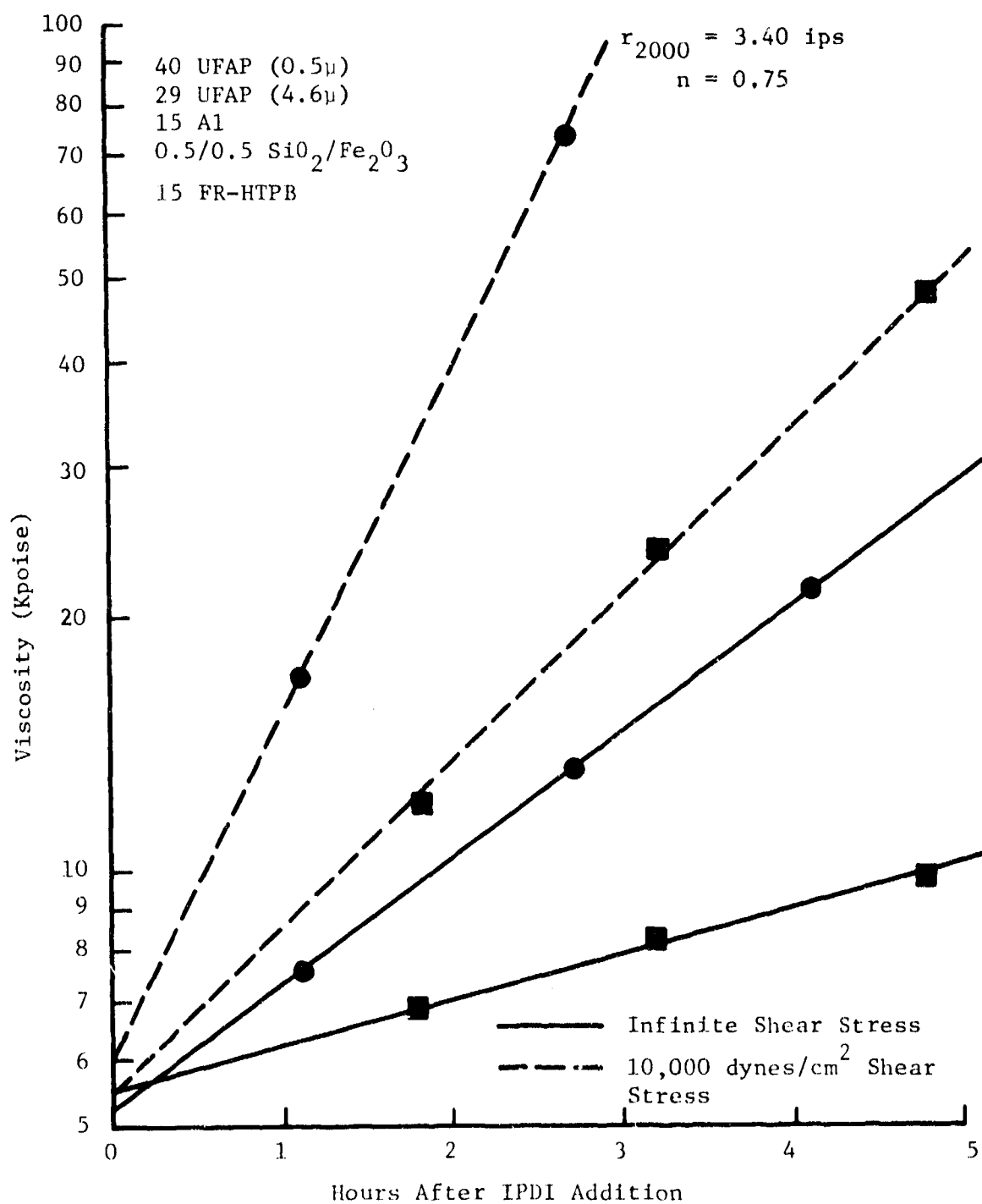
(U) Because of the previously described processing improvements, finer oxidizer blends as well as very fine iron oxide were able to be processed into propellant "A", which in combination with a long mix cycle yielded the desired burning rate of 3.5 in./sec at 2000 psia. Likewise the goal of 7.0 in./sec for propellant "B" was very nearly realized. In this case attainment of the desired burning rate was made somewhat less difficult because porous ammonium perchlorate (PAP) and Catocene were allowed in the formulation.

Importance of Amount and Particle Size of Ammonium Perchlorate

(U) As in the processing and mechanical properties study, we felt that any progress made on propellant "A" could be applied toward achieving the burning rate goal for propellant "B". Conventional methods were used to accomplish this goal, such as increasing ballistic solids and/or fine oxidizer content. The burning rate data are summarized in Table 7. As can be seen from the table, the major increase in burning rate was realized when the 8 μ AP (MA) was replaced with uncoated 3.1 μ UFAP. A result that was initially puzzling was derived from the 86 and 87% solids propellants wherein the solids increase was due to 7-10 μ AP (MA). Neither exceeded the burning rate of the 85% solids control formulation even though they showed an internally consistent rate increase. This was explainable, however, in light of later data (Table 7, #AK7365-71) acquired on an identical 86% ballistic solids batch. The mix cycle of this batch was increased by one hour over the former 86% solids batch, resulting in a 97% increase in the burning rate. Apparently the increased mixing time further deagglomerates the UFAP which increases the burning rate.

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(C) FIG. 6. Viscosity Buildup at 120°F on Propellant "A" with (1) ● Regular R-45M (AK7591-70) and (2) ■ Modified R-45M (AK7591-76).

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(C) TABLE 7. Effect of Oxidizer Particle Size and Level on Solid Strand Burning Rates of Propellants "A" and "B"

Batch No. AK-	Ballistic Variables						Mix Cycle, hrs.	Burning Rate r, in./sec.		n
	% UFAP (0.4 μ) ^a	% UFAP (0.9 μ) ^a	% UFAP (3.1 μ) ^b	% AP (MA)	% AP (UNG)	% PAP (UNG)		500 psi	2000 psi	
7365-33 ^c	50.0	...	...	19.0	...	...	1.3	1.083	3.026	0.75
7365-35	...	50.0	...	19.0	...	...	1.3	1.041	2.922	0.74
7365-51 ^d	50.0	...	...	19.0	...	...	1.1	1.021	2.767	0.72
7365-67	50.0	...	...	20.0	...	...	1.3	0.975	2.844	0.75
7365-69	50.0	...	...	21.0	...	...	1.3	1.043	2.974	0.76
7365-71	50.0	...	...	20.0	...	...	2.1	1.084	3.052	0.75
7365-75	50.0	...	19.0	...	...	...	1.3	1.074	3.148	0.78
7365-77	55.0	...	...	14.0	...	...	1.6	1.063	3.018	0.75
7365-79	55.0	...	...	...	14.0	...	1.6	0.987	2.856	0.76
7365-81 ^e	51.0	...	...	19.0	...	...	1.6	0.735	2.266	0.82
7365-87 ^f	40.0	...	...	20.0	...	10.0	1.6	1.901	6.477	0.878

NOTE: Unless otherwise indicated, all batches contain Al-H95 (15%), Silon S (0.5%), Fe₂O₃ (0.5%), with HTPB binder making up remainder.

^aBDB coated, 0.5%.

^bUncoated.

^cControl formulation, contains Al-H60 as does AK-7365-35.

^dFe₂O₃ replaced with ferrocene-formaldehyde polymer, contains Al-H60.

^eBurning rate catalysts omitted.

^fContains 3% catocene and no Fe₂O₃ or Silon S.

^gAverage between 500 and 2000 psia.

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(U) Increasing the UFAP content at the expense of the 7-10 μ AP (MA) also failed to show any increase in burning rate. Again this was understandable, in light of the effect of mix time on burning rate. Replacing the 8 μ AP (MA) of this batch with 180 μ AP (unground (Ung)) resulted, however, in a 5-6% lowering of the burning rate. This result coupled with the rate increasing effect of the 3.1 μ UFAP underscores the importance of the coarser oxidizer fraction in influencing the burning rate. Strangely enough, though, little effect on burning rate was noted in going from 0.4 μ to 0.9 μ UFAP. This either reflects the insensitivity of burning rate to UFAP particle sizes less than 1.0 μ or indicates the difficulty in breaking up fine UFAP agglomerates in the sub-micron range. This latter explanation is consistent with the observed effect of processing time on burning rate, and significant burning rate increases were later realized with the finer UFAP and long mix cycles. There does appear to be a practical limit to increasing the burning rate by decreasing the particle size of the AP since a burning rate of 3.5 in./sec at 2000 psia was also demonstrated using a 0.55 μ UFAP. Evidently sufficient deagglomeration of the UFAP does not take place in this system to distinguish between 0.40 and 0.55 μ UFAP.

(U) Using the binder system and some of the ballistic knowledge developed for propellant "A", a batch of propellant "B" was prepared that nearly achieved the 7.0 in./sec target burning rate (Figure 7). The ballistic modifications consisted of increasing the 0.5 μ UFAP by 5%, incorporating a more active PAP and replacing Hycat 6 with catocene which is believed to be more effective (Table 7, #AK7365-87). The attempt here was to achieve the desired burning rate without drastically increasing the propellant sensitivity with higher levels of PAP and Catocene than were used in ANB-3364. By increasing the processing time and making minor ballistic modifications the target burning rate for "B" was achieved as shown in the next section. This illustrates how progress made on propellant "A" was adapted to meeting propellant "B" requirements.

Evaluation and Comparison of Burning Rate Catalysts

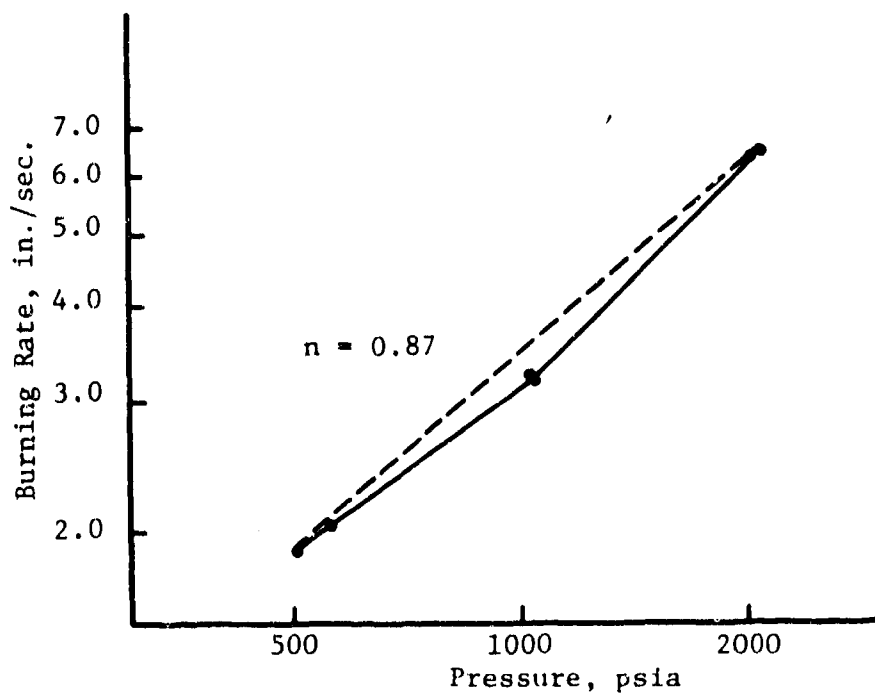
(U) A significant increase in the burning rate of propellant "A" was achieved (Table 2, #AK7591-93, -75) by replacing the pigment grade iron oxide ordinarily used (C. K. Williams, Lot #RY2196) with a red crystalline iron oxide (F. C. Davis Company), a sample of which was provided by the Naval Weapons Center. No other effects, adverse or otherwise, were observed with this new iron oxide; therefore, it was used in all subsequent propellant "A" formulations. This increase brought to three the number of independently achieved burning rate increases to date, the other two being achieved by (1) replacing the 8 μ MA AP with 3 μ UFAP and (2) increasing the length of the mix cycle (see the previous section). All three factors were combined into one propellant to yield a solid strand burning rate of 3.62 in./sec at 2000 psia (Table 8, #AK7591-1) which exceeded the minimum program goal for propellant "A". An identical batch prepared to confirm this burning rate (Table 8, #AK7591-19), yielded a burning rate of 3.4 in./sec at 2000 psia. The reason for the lower rate is uncertain, but may be a

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<u>Ingredients</u>	<u>wt. %</u>
UFAP (0.39 μ) (0.5% BDB)	40.00
AP (MA)	20.00
PAP (UNG)	10.00
Al-H95	15.00
Agerite White	0.10
Plastinox	0.10
Catocene	3.00
Oronite 6	1.80
R-45M (75 eq)	8.90
DEO (20 eq)	0.39
TEA (5 eq)	0.02
IPDI (70 eq)	0.69
	<u>100.00</u>



(C) FIG. 7. (Upper) Propellant "B" Formulation (Batch No. AK-7365-87) with (lower) Corresponding Plot of Solid Strand Burning Rate vs. Press.

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(C) TABLE 8. Effect of Catalyst and Coarse NH_4ClO_4 Fraction on Ballistic Properties

Batch No. AK-	Burning Rate Catalyst at 1%	Coarse NH_4ClO_4 Fraction at 19%	Ballistic Prop., 80°F		Mix Cycle (Hrs)
			r 2000 in./sec	n	
7365-81 ^a	None	10μ	2.27	0.82	1.5
7365-57	50/50 Silon S/ Fe_2O_3	10μ	2.86	0.74	1.1
7365-75	50/50 Silon S/ Fe_2O_3 ^b	3μ	3.15	0.78	1.3
7365-93	50/50 Silon S/ Fe_2O_3	10μ	3.20	0.77	1.5
7365-51	50/50 Silon S/Ferrocene ^c	10μ	2.77	0.72	1.1
7365-50	Ferrocene ^d	5μ	2.92	0.67	4.0
7591-1	50/50 Silon S/ Fe_2O_3 ^b	3μ	3.62 ^e	...	4.5
7591-19	50/50 Silon S/ Fe_2O_3 ^b	3μ	3.40	0.77	4.5
7591-5A	Fe_2O_3	3μ	3.00 ^e	...	2.5

NOTE: All formulations contain (50%) 0.4μ UFAP, (15%) Al-H95 and the remainder HTPB binder, unless noted otherwise.

^aContains (1%) 0.4μ UFAP in place of (1%) burning rate catalyst.

^bRed, crystalline Fe_2O_3 .

^cFerrocene-formaldehyde polymer.

^d2% ground ferrocene-formaldehyde polymer and 14% Al-H95.

^eOne inch micro strands fired in closed bomb.

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result of different testing methods used. In the former batch, the strands used were exactly 1 inch long and were fired in a closed bomb. The latter batch was tested in regular fashion with standard 5 inch strands.

(U) It was of interest at this time to learn if the same burning rate achieved with the 50/50 mixture of Silon S and the red crystalline iron oxide could be achieved or surpassed by using this new iron oxide as the sole burning rate catalyst at the same total percent. The rate achieved (Table 8, #AK7591-5A) did not equal the rate (Table 8, #AK7365-93) achieved by the 50/50 combination of Silon S and the same crystalline iron oxide. A synergistic effect is indicated by this and data from another program regarding the effect of Silon S concentration.

(U) To determine just how much the catalyst was contributing to the burning rate, a batch was prepared in which the 0.4 μ UFAP was increased by 1%, replacing the catalyst (Table 8, #AK7365-81). The data indicate that the catalyst system contributes approximately 25% to the burning rate at 2000 psia. However, due to a higher slope, 0.82 versus 0.77 for the catalyzed propellant, the contribution increases with decreasing pressure.

(U) As a possible replacement for Fe_2O_3 , a solid ferrocene-formaldehyde polymer was evaluated with Silon S (Table 8, #AK7365-51). A lower burning rate and pressure exponent (n) resulted. It appears this ferrocene polymer does not dissolve to any appreciable extent in the binder, solution being important if ferrocene compounds are to be effective burning rate catalysts. To offset this lack of solubility the ferrocene polymer was ground to a very fine powder and evaluated at the 2% level (Table 8, #AK7591-50) to see if it would now approximate the behavior of soluble ferrocene derivatives, i.e., show a nearly linear increase with level. Not only did it not significantly increase burning rate, but it severely curtailed processability and promoted a very rapid cure. A possible explanation for its poor behavior as a burning rate catalyst is its high polymeric nature which reduces its ability to interact with the NH_4ClO_4 , contrary to the low molecular weight liquid and solid ferrocene derivatives, such as catocene and n-butyl ferrocene.

(U) Having settled on the red crystalline Fe_2O_3 as the type of Fe_2O_3 to be used in propellant "A", a comparison of activity of the sample of crystalline Fe_2O_3 (Lot 15) from NWC was made with a 10 lb lot of crystalline Fe_2O_3 purchased from Frank C. Davis Company to see if lot-to-lot variations existed. No differences in burning rate were observed (Table 9, #AK7591-48, -58), but the batch containing the (Lot 15) Fe_2O_3 did process somewhat better. A significant increase in burning rate (Table 9, #AK7591-60) was achieved, though by grinding a portion of the crystalline Fe_2O_3 from the 10 lb lot for two hours in Freon using Al_2O_3 1/4 inch cylinders for grinding, and a mechanical paint shaker to provide agitation. The resulting powder was much finer than the unground material and was redder in appearance; the average particle size was not determined. The finer Fe_2O_3 also appeared to function as a better cure catalyst since the data show a shorter potlife for this batch.

(C) TABLE 9. Effect of Catalyst Variations and UFAP Level on Processing, Ballistic and Mechanical Properties

Batch No. AK-7591-	Oxidizer		Ballistic Prop., 80°F		Mech. Prop., 77°F			Potlife ^a Hrs	Shore "A"
	% UFAP (0.55 μ)	% UFAP (5 μ)	r ₂₀₀₀ in./sec	Pressure Exponent n	σ_m , psi	ϵ_m , %	E _o , psi		
AK7365-81 ^b	51.00	19.00	2.27	0.82	...	...	...	...	...
48 ^c	50.00	19.00	3.40	0.76	96.0	16.6	616	1.0	65
58 ^d	50.00	19.00	3.40	0.77	118	19.8	670	0.7	66
60 ^e	50.00	19.00	3.56	0.79	124	18.1	772	0.5	63
68 ^{e,f}	45.00	24.00	3.47	0.77	73.2	25.1	344	1.0	37
70 ^{e,f}	40.00	29.00	3.40	0.75	76.6	24.1	353	2.0	44

NOTE: All batches contain 15% H-95 Al, 0.5% Silon S, 0.5% Fe₂O₃, 15% binder [(0.2% aging stabilizers, (4.8%) Oronite 6, (85 eq.) R-45M, (10 eq.) DEO, (5 eq.) TEA, (70 eq.) IPDI] unless otherwise noted. Mix cycles are 4 hours.

^aTime to 50 kpoise at 120°F and 10,000 dynes/cm² shear stress.

^bContains (1%) 0.4 μ UFAP in place of 1% burning rate catalyst.

^cContains new lot crystalline Fe₂O₃ received from NWC.

^dContains new 10# lot of crystalline Fe₂O₃ purchased from Frank C. Davis Co.

^eContains new 10# lot of crystalline Fe₂O₃ ground 2 hrs. on a paint shaker.

^fContains (65 eq.) IPDI, (4.5%) Oronite 6, (0.5%) aging stabilizers.

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(U) Since the ground Fe_2O_3 gave a faster burning rate than as-received, an evaluation was made to determine if the concentration of 0.55μ UFAP could be reduced and still meet the 3.5 in./sec, burning rate goal at 2000 psia. The data (Table 9, #AK7591-68, -70) indicate that a drop of 5 wt% in this fine oxidizer very nearly meets the desired burning rate. Also, the processability improves very rapidly as the level of 0.55μ UFAP is lowered. The binder was altered for these batches to provide a softer propellant, which explains the lower tensile and higher elongation values.

(U) Utilizing the information gained in developing propellant "A", a batch of propellant "B" was prepared (Table 10, #AK7591-54) that exceeded the 7.0 in./sec burning rate goal at 2000 psia using four percent Catocene. Additionally, better mechanical properties were realized than before, but the Shore "A" hardness was too high and the potlife was not as long as desired. It was expected that the potlife would be significantly extended by the use of modified R-45M, but as stated earlier, no improvement in potlife was realized until 2,4-pentanedione was incorporated in the formulation.

(C) Although the burning rate goal at 2000 psia for propellant "B" was exceeded using 4% Catocene and 8% unground PAP, a series of batches were prepared in which various combinations of oxidizer blend and Catocene level were evaluated to determine how low in Catocene and UFAP level the desired burning rate could be achieved (Table 10). This was desirable from the standpoint of improving the processing and safety characteristics of this propellant. The study revealed that the catalyst level was significantly more effective than the 0.55μ UFAP level in raising the burning rate. Also, to improve processing the coarse NH_4ClO_4 fraction was changed from 5μ to 10μ average particle size with a small loss in burning rate. The final choice in Catocene level was 4% since hazard tests showed little change in safety characteristics in going from the 3 to 4% level, thus allowing improved processability.

Evaluation of Alternate Metal Fuels, Oxidizer and Fluorocarbon Plasticizer

(U) A number of ballistic modifications were evaluated that had shown ballistic improvements in other propellant systems at Aerojet Solid Propulsion Co. It was hoped that they might do so with the propellant "A" formulation, but no advantages were observed and in one case processing was severely degraded. These modifications are discussed in the following paragraphs.

(U) Magnesium and Magnesium/Aluminum Alloy Powders. The replacement of aluminum with magnesium powder and a powder consisting of a 65/35 magnesium/aluminum alloy showed no improvement in burning rate (Table 11, #AK7591-5B, 5C, 5D). The failure, however, of magnesium to elevate the burning rate was not too surprising, since burning rate increases observed with this metal powder were in propellants containing varying amounts of fluorocarbons. The magnesium powder did not adversely affect processing, cure or mechanical properties.

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(C) TABLE 10. Effect of Catocene Level and Oxidizer Particle Size on Ballistic Properties of Propellant "B"

Batch No. AK-7591-	Ballistic Variables			Ballistic Prop.		Mechanical Prop.			Potlife ^a (Hrs)	Shore "A" Hardness
	% UFAP (0.55 μ)	% UFAP (5 μ)	Catocene %	r_{2000} in./sec	b	σ_m , psi	ϵ_m , %	E_o , psi		
54	45.00	17.00	4.0	7.30	0.84	145	20.0	901	0.5	72
66	50.00	12.00	3.0	6.40	0.85	74.6	22.6	433	...	45
72	45.00	17.00	3.0	6.55	0.85	60.8	28.4	307	0.8	32
74	40.00	22.00	3.0	6.40	0.84	53.1	30.3	240	1.0	30
87	45.00	17.00	3.5	6.98	0.86	149	16.1	1074	...	70
89	40.00	22.00	4.0	6.78	0.80	115	16.7	781	...	67

NOTE: All batches contain (8%) Ung PAP, (15%) Al H-95, and remainder R-45M/IPDI binder, unless otherwise noted. Mix cycles are 4 hours.

^aTime to 50 kpoise at 120°F and 10,000 dynes/cm² shear stress.

^bAverage between 500 and 2000 psia.

^cUsed R-45M-25 in place of R-45M.

^dUse (MA) NH₄ClO₄ in place of (5 μ) UFAP.

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(C) TABLE 11. Effect of Ballistic Variations on Burning Rate of Propellant "A"

Batch No. AK-	Ballistic Variables			Mix Cycle, hrs.	r ²⁰⁰⁰ in./sec
	Burning rate catalyst at 1%	Metal Powder at 15%	Coarse AP at 19%		
7365-81 ^a	None	Al-H95	(5μ)	1.6	2.27
7365-93	50/50 Silon S/Fe ₂ O ₃	Al-H95	(10μ)	1.5	3.20
7591-5B	50/50 Silon S/Fe ₂ O ₃ ^b	Mg/Al alloy (65/35)	(3μ)	2.5	3.15 ^c
7591-5C	50/50 Silon S/Fe ₂ O ₃ ^b	Mg	(3μ)	2.5	3.14 ^c
7591-5D	50/50 Silon S/Fe ₂ O ₃	Al Class II	(3μ)	2.5	3.14 ^c
7591-19	50/50 Silon S/Fe ₂ O ₃	Al-H95	(3μ)	4.5	3.40
7365-89 ^d	50/50 Silon S/Fe ₂ O ₃	Al-H95	(10μ)	1.6	3.03

NOTE: All formulations contained 50% UFAP (0.4μ) and 15% R-45-IPDI binder.

^aControl batch. Contains (1%) 0.4μ UFAP in place of 1% burning rate catalyst.

^bRed crystalline iron oxide.

^cSmall solid strands fired in a closed bomb.

^dContains (45%) 0.4μ UFAP and (5%) unground methylamine perchlorate (MAP).

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(U) Methylamine Perchlorate (MAP). A portion of the 0.4 μ UFAP was replaced with a like amount of unground MAP to see if a significant increase in burning rate could be achieved. The burning rate achieved (Table 11, #AK7365-89), however, was not quite as good as that for the control (Table 11, #AK7365-93).

(U) Fluorocarbon Plasticizer. An attempt was made to incorporate a fluorocarbon ester into propellant "A" and evaluate its effect on burning rate. This ester was prepared by condensing 216 gms (0.5 mole) of 1,1,9-trihydrohexadecafluoro-1-nonanol with 144 gms (1.0 mole) of 2-ethylhexanoic acid catalyzed with one gm of conc. H₂SO₄ all in 250 ml of toluene. The solution was refluxed for 6 hrs in which time nine ml of water were azeotroped off by the toluene signifying completion of the reaction. The toluene solution was washed twice with distilled water dried over anhydrous MgSO₄ and filtered to remove drying agent. The toluene was removed under vacuum on a rotary film evaporator and the resultant oil was distilled under vacuum to yield ~200 gms of the desired ester boiling at 107-109°C/3mm Hg. Only half of the Oronite 6 was replaced with this material, but it made the propellant difficult to process resulting in a brittle propellant which could not be tested for burning rate. Since it appeared that significant amounts of fluorine could not be incorporated into this propellant system without severely degrading processing and mechanical properties, no further effort in this direction was planned.

LINER/PROPELLANT BOND STUDIES

(U) One of the problem areas identified in the 1969 program was the poor bonding between the propellant and the liner which was suspected to be the cause of motor failures. Therefore, motor tests were conducted early in the current program to demonstrate that successful tests could be made. In preparation for an early motor demonstration test, promising liners developed on another program were evaluated with representative propellants of this program.

(U) To measure liner propellant bond, 434-4 liner, both partially cured and completely cured prior to casting, as well as SD-898 were evaluated (Table 12). It is noteworthy that the excellent propellant-liner bond was achieved with the 434-4 liner in light of the fact that good bonding to HTPB propellant has been, heretofore, difficult to achieve, especially with UFAP containing propellants.

(U) DPT molds were prepared with each candidate propellant using a modified 434-4 liner. Previous tests had shown 434-4 liner to give good bonds to these propellants. The modified 434-4 liner also gave good bonds to these propellants as shown on page 33.

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(U) TABLE 12. DPT Liner Evaluation Using 86% Solids^a
10-lb Batch of Propellant "A".

Liner	Cure state	Tensile, psi	Type of failure
SD-898	Cured	50.8	Adhesive
434-4	Cured	52.5	Adhesive
434-4	Partially cured ^b	92.8	Cohesive

Liner Formulations

Ingredients	SD-898 (wt.%)
Sb ₂ O ₃	9.50
P-33	9.50
Refracil	6.00
Agerite White	2.00
Plastinox 711	1.00
Thixcin E	1.00
ZrAA	1.00
Cr Oleate	0.50
HC-434	63.52
DER-332	5.98
	<hr/> 100.00

^aBatch No. AK-7365-73.

^bCured 4 hrs. @ 135°F.

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DPT Values for Candidate Propellants Using Modified 434-4 Liner at 74.6°F

	ANB-3394 (10GP-2213)	ANB-3395 (10GP-2248)
Tensile, psi	68.9	94.9
Type of Failure	In Propellant	In Propellant

Liner modification consisted simply in reducing the filler concentrations to improve the viscosity and flow properties of the 434-4 liner. No changes were made in the polymer composition.

(U) Since this modified liner appeared to be satisfactory, it was used as the liner for the propellant grains that were prepared and delivered to Naval Weapons Center as per contractual requirements.

HAZARD TESTING OF PROPELLANTS "A" AND "B"

(U) Safety data acquired on the propellant "B" formulation containing four percent Catocene indicated this propellant had high friction sensitivity. At three percent Catocene the friction sensitivity was quite low indicating a less hazardous propellant. Unfortunately, the more sensitive propellant also had a high Shore hardness while the less sensitive one had a low hardness reading, and since friction sensitivity tends to go up with propellant hardness it was not known whether high catocene, high Shore hardness or both were responsible for the increased friction sensitivity. Since subsequent batches at four percent Catocene and lower Shore "A" hardness values did not show high friction sensitivity it was concluded that hardness level was responsible.

Hazards Test Data

Propellant "B"

<u>Batch No.</u>	AK7591-54 (See Table 10)	AK7591-74 (See Table 10)
<u>Bureau of Mines Impact</u>		
50% Fire Point	11 cm/2 kgm	...
<u>Friction (Rotary)</u>		
Gms load/RPM	400/3000	2000/3000
<u>DTA</u>		
Onset of Exotherm	328°F	...
Exothermic Peak	380°F	...
Autoignition	423°F	...

(U) In selecting the final composition for propellant "B", consideration was given to the hazard characteristics of the two compositions from which the candidate formulation was selected. The desired composition from the standpoint of processing, AK7591-89, contained 40% 0.5μ UFAP and 4% Catocene and it was feared that the

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higher Catocene level of the former would give a less safe propellant. The data shown below, however, indicated little or no differences between the two, allowing the desired choice to be made based on processability. In addition, hazard tests were run on the uncured propellants to see if any special processing or handling techniques were required. The data indicated both uncured propellants were quite safe to handle in ordinary fashion.

Hazard Tests on Propellant "B" Uncured and Cured

	Batch AK7591-87 (See Table 10)		Batch AK7591-89 (See Table 10)	
	<u>Cured</u>	<u>Uncured</u>	<u>Cured</u>	<u>Uncured</u>
<u>Bureau of Mines Impact</u>				
50% Fire Point, cm/2kg	10.0	18.7	11.4	19.2
<u>Friction, Rotary</u>				
Gms load/RPM	<u>2300</u> 3000	<u>3000</u> 5200	<u>2200</u> 3000	<u>3000</u> 4700
<u>DTA</u>				
Onset of Exotherm	329			
Exothermic Peak, °F	395	...	309	...
Ignition, °F	444	...	432	...

(U) Both candidate formulations from 10-lb batches were again checked for impact and friction sensitivity in the uncured state to determine possible differences in hazard properties due to scale-up. None were evident from the data.

Safety Tests on Both Uncured Candidate Propellants

	<u>ANB-3394</u> <u>(10GP-2194)</u>	<u>ANB-3395</u> <u>(10GP-2220)</u>
<u>Bureau of Mines Impact</u>		
50% Fire Point	26 cm/2kg	14.4
<u>Rotary Friction</u>		
gm load/3000 RPM	2420	3200

(U) I.C.C. hazard classification tests were run on ANB-3394 and -3395 as outlined in TB-700-2. The results (Table 13) show both propellants to be Class "B" explosives.

SELECTION OF CANDIDATE FORMULATIONS

(U) In selecting the candidate formulations for this program the following criteria were used in decreasing order of importance: (1) burning rate, (2) processing characteristics, (3) mechanical properties and (4) hazard characteristics.

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(U) TABLE 13. Safety Data, NWC Candidate Propellants

	Candidates	
	A (ANB-3394)	B (ANB-3395)
1. Bureau of Mines Impact 50% pt., cm/2 Kg. wt.	17.0	13.5
2. DTA Results		
Onset of Exotherm, °F	335	328
Exotherm Peaks, °F	435	385
Ignition, °F	451	428
3. Copper Block		
Autoignition, °F	433	368
4. Thermal Stability at 75°C for 48 hr.	No change	No change
5. Detonability with No. 8 Blasting Cap	Burned in 8 sec.	Burned in 4 sec.
6. Unconfined Burning for 2 in. cube	9 sec.	4 sec.
7. Friction Rotary, 50% point	1750 gm. load 3000 rpm	1700 gm. load, 3000 rpm
8. Spark Gap Test, 50% pt.	3.30 joules	2.70 joules

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Candidate "A" (ANB-3394)

(U) The final formulation selected for candidate "A" (ANB-3394) is shown in Table 14. The extent to which this formulation satisfied the selection criteria is summarized below:

(U) Burning Rate. The desired goal was 3.5-4.0 in./sec at 2000 psia. This formulation achieves the low end of this range. Although rates higher than 3.5 in./sec have been achieved, too great a sacrifice in processing properties was required to make those compositions feasible.

(U) Processing Characteristics. A potlife of at least three hours at 120°F was required to successfully scale-up this formulation and cast motor grains. With the use of modified R-45M this minimum potlife was realized. This formulation had virtually no static flow characteristics, but under suitable vibration flow was adequate to cast void-free grains.

(U) Mechanical Properties. Tensile strengths of 100-150 psi and elongations of 30% were desired. This formulation was low on both properties; however, it represented an adequate compromise between formulations that achieved the desired tensile strengths but were very low on elongation, and vice versa.

(U) Hazard Characteristics. A formulation was desired that would qualify as a Class "B" explosive. This formulation was classified as such by I.C.C. tests.

Candidate "B" (ANB-3395-1)

(U) The final formulation selected for candidate "B" (ANB-3395-1) is shown in Table 14. The extent to which this formulation also satisfied the selection criteria is summarized below:

(C) Burning Rate. A burning rate of 7.0 in./sec or higher at 2000 psia was sought for this formulation. The rate achieved, however, is about 4-5% low for this candidate formulation. Rates greater than 7.0 in./sec were achieved in other compositions, but again, as in ANB-3394, the sacrifices in processing characteristics were too great to make these compositions feasible. Also, the overall pressure exponents were too high in some cases.

(U) Processing Characteristics. As in ANB-3394, a potlife of at least three hours at 120°F was required to successfully scale-up this formulation and cast motor grains. This minimum potlife was achieved with the use of modified R-45M and HAA. This formulation also exhibited static flow and under vibration was more than adequate to cast void-free grains.

(U) Mechanical Properties. Mechanical property requirements were the same as for ANB-3394. This formulation also fell short of the minimum desired properties, but more nearly achieved them than did ANB-3394.

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(C) TABLE 14. Candidate Formulations, Propellants "A" and "B".

Designation	A (ANB-3394)	B (ANB-3395-1)
Ingredients	wt. %	wt. %
NH ₄ ClO ₄ (0.5μ)	45.00	42.00
NH ₄ ClO ₄ (5μ)	24.00	--
NH ₄ ClO ₄ (10μ)	--	20.00
NH ₄ ClO ₄ (Porous, 180μ)	--	8.00
Al-H60	15.00	15.00
Catocene	--	4.00
Fe ₂ O ₃ (crystalline)	0.50	--
Silon S	0.50	--
Agerite White	0.20	0.20
Plastinox #711	0.30	0.30
HAA	--	0.20
Oronite 6	4.50	0.30
R-45M-35 (78 eq.)	9.08	9.08
DEO (15 eq.)	0.21	0.21
TEA (7 eq.)	0.02	0.02
IPDI (100 eq.)	0.69	0.69
	100.00	100.00

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(U) Hazard Characteristics. This formulation was expected to qualify as a Class "B" explosive. I.C.C. tests confirmed this classification.

PROPELLANT SCALE-UP AND GRAIN PREPARATIONS

(U) Early in this program an 86% solids version of propellant "A" was scaled up to a 10-lb batch size (Table 15) to determine scale-up problems, if any, and to obtain viscosity buildup, liner bonding and grain casting data. The batch mixed well, using a mix cycle one hour longer than had been used in the 300 gm batch studies, and was vacuum castable. However, the material flowed only with vibration and had a very short potlife (Figure 8). Ballistic and mechanical property data were measured on this formulation, showing it to have adequate mechanical properties, but falling about 13% low in achieving the desired burning rate (Table 16). Subsequent 10-lb batches were not prepared until the candidate formulations, ANB-3394 and ANB-3395 (ANB-3395-1 was a later modification involving the addition of HAA) were selected. Three 10-lb batches of each candidate formulation were prepared to provide sufficient propellant to cast 28 phenolic sleeves, 2.00 in. dia x 7.00 in. long. These sleeves were lined with modified 434-4 liner that was precured for 1.5 hours at 75°C prior to casting with propellant. Final cure of the liner took place with the propellant cure after it was cast, which resulted in excellent liner/propellant bonds.

(U) Both candidate propellants were mixed without difficulty, however ANB-3394 had noticeably better potlife than ANB-3395. Viscosity buildup data (Figure 9) also indicated that ANB-3395 had far less potlife than ANB-3394, due to the catalytic effect of catocene accelerating the cure rate. This problem was later resolved with the addition of HAA (0.2%) to the formulation, thereby changing the designation to ANB-3395-1. Mechanical properties were measured on both candidate formulations over the temperature range of 160 to -40°F (Table 17) showing good agreement within each three batch set as well as very little variation in elongation over the entire temperature range. However, nearly all the grains cast contained voids as revealed by X-radiography, requiring the preparation of additional 10-lb batches to prepare sufficient good grains for delivery to NWC, China Lake. This time, however, casting procedures were modified to assure a higher yield of good grains. The modifications included: (1) overcast additional 1-inch, (2) low frequency - medium amplitude cast vibration and (3) small stream casting. These changes resulted in a much higher yield of void-free grains, sufficient in number to meet contractual requirements.

(U) The scale-up of ANB-3394 and ANB-3395-1 to 175-lb batch size to cast the 5-in. dia x 15-in. long grains, was accomplished essentially without problem. All grains and cartons cast were shown to be void-free by X-radiography. This success was largely attributed to the availability and use of casting equipment that allowed all the units to be kept under vacuum throughout the whole casting operation and beyond, while being subjected to low frequency - medium amplitude vibration.

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(C) TABLE 15. 86% Solids - 10-1b Scale-Up Batch
Of Propellant "A"^a

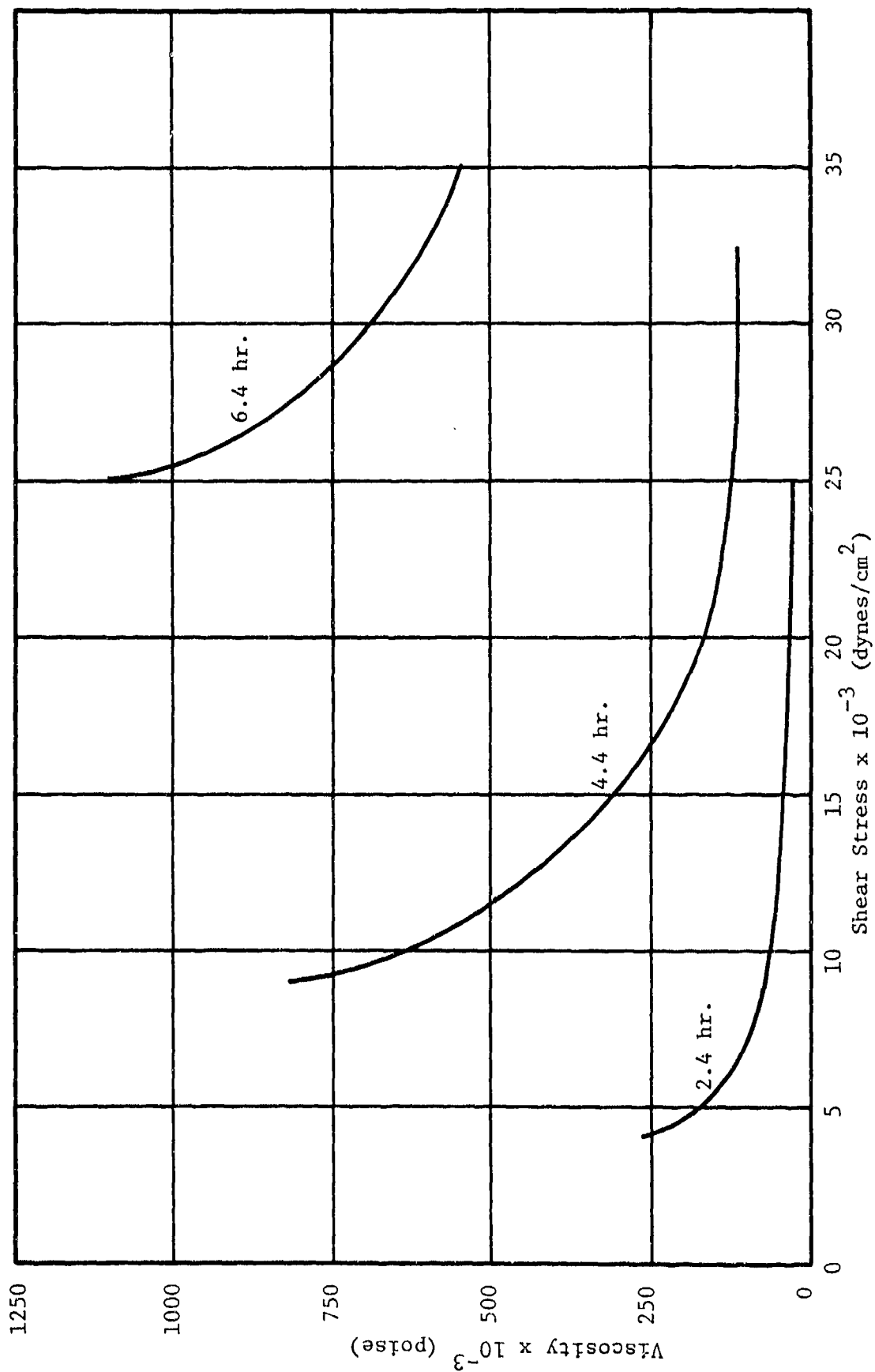
Ingredients	Weight %
UFAP (0.39 μ) (0.5% BDB)	50.00
AP (MA)	20.00
Al-H95	15.00
Fe ₂ O ₃	0.50
Silon S	0.50
Agerite White	0.10
Plastinox 711	0.10
Oronite 6	4.80
R-45 M (75 eq)	8.01
DEO (20 eq)	0.35
TEA (5 eq)	0.02
IPDI (70 eq)	0.62
	<hr/> 100.00

^aThe TEA was added after IPDI in the mix cycle.

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(U) FIG. 8. Viscosity vs. Shear Stress at 110°F Taken at Two-Hour intervals^a for 10-lb Batch Of Propellant "A" (Batch # AK 7365-73). (a) Time taken from IPDI addition.

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(U) TABLE 16. Processing, Mechanical and Ballistic Properties of
86% Solids Formulation^a for Propellant "A"

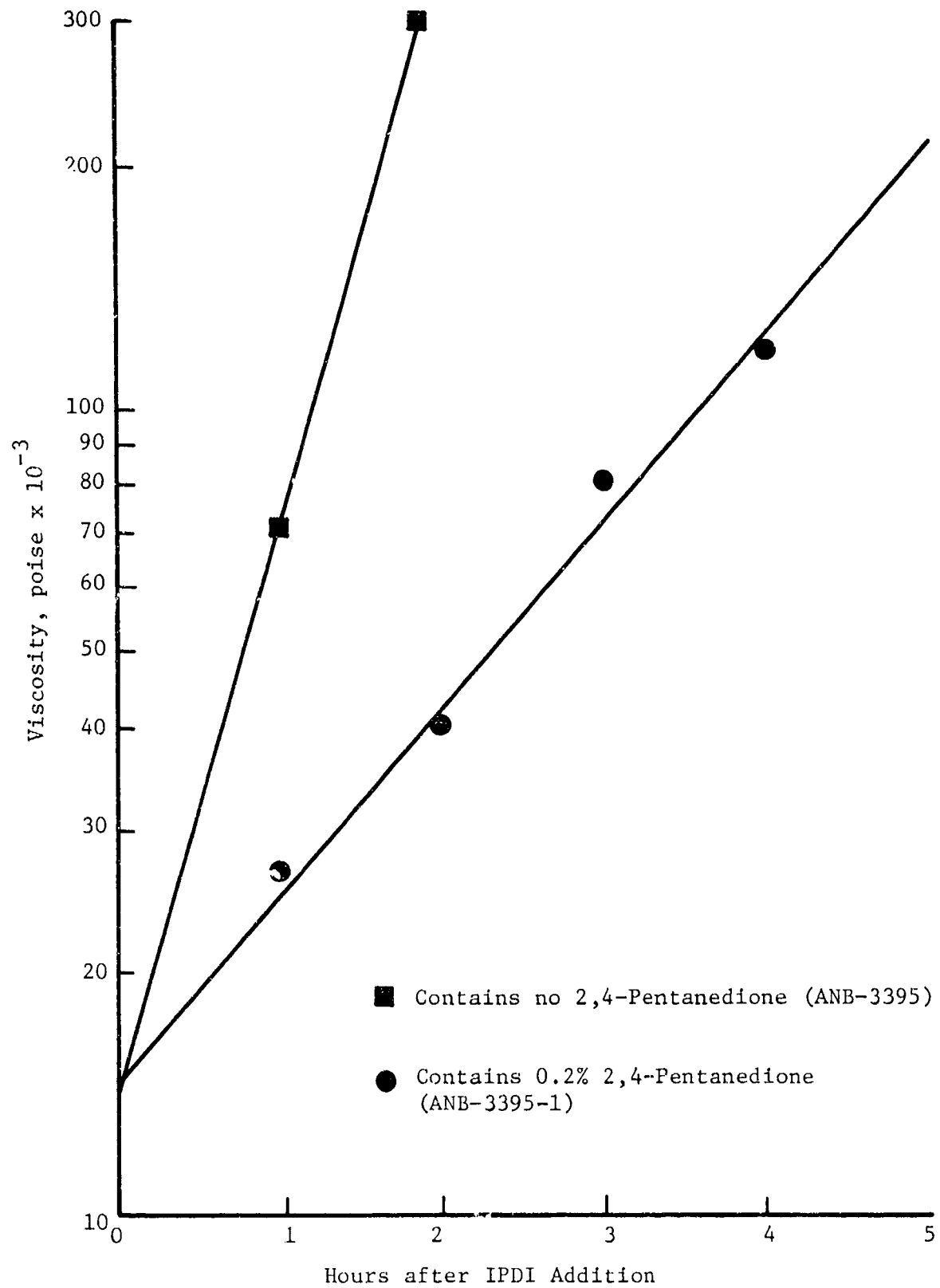
Processing Properties ^b				
Viscosity buildup, 110°F, at infinite shear (kpoise), hrs after IPDI addition	2.4 hrs	4.4 hrs	6.4 hrs	
	17	55	71	
Mechanical Properties				
σ_m , psi ϵ_m , % ϵ_b , % E_o , psi	160°F	77°F	-40°F	
	78.0	129.0	227.3	
	16.1	18.3	17.0	
	16.7	18.9	17.3	
	495	760	1829	
Ballistic Properties				
R_B , in./sec n	500 psia	1000 psia	2000 psia	
	1.084	1.884	3.052	
	0.75			

^aOne-lb batch no. AK-7365-71.^bDetermined on ten-lb batch no. AK-7365-73 of identical formulation to AK-7365-71.

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(U) FIG. 9. Viscosity Build-up of ANB-3395 (B) at 120°F and 10,000 dynes/cm² Shear Stress with and without 2,4-Pentanedione.

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(U) TABLE 17. Mechanical and Ballistic Properties of ANB-3394 ("A") and ANB-3395 ("B")

Batch No. 10GP-	Mechanical Properties					Ballistic Properties, 80°F				
	Shore "A"	Temp., °F	σ_m , psi	ϵ_m , %	E_o , psi	r_{500} in/sec	r_{1000} in/sec	r_{1500} in/sec	r_{2000} in/sec	n
2194 ^a	28	77	68.2	25.1	337	1.21	2.06	--	3.43	0.75
2212 ^a	31	77	59.7	17.9	395	1.20	2.04	--	3.45	0.76
2213 ^a	40	77	78.2	18.5	488	1.20	2.02	2.74	3.40	0.74
2213	--	160	47.2	14.0	358	--	--	--	--	--
2213	--	0	150.3	19.4	1029	--	--	--	--	--
2213	--	-40	327.1	17.7	2419	--	--	--	--	--
2220 ^b	48	77	84.1	17.5	609	2.19	3.58	--	6.50	0.86 ^c
2228 ^b	47	77	76.7	15.3	586	2.27	3.55	--	6.60	0.88 ^c
2248 ^b	48	77	85.6	16.8	637	2.17	3.54	5.15	6.70	0.90 ^c
2248	--	160	61.7	16.4	433	--	--	--	--	--
2248	--	0	197.7	16.9	1535	--	--	--	--	--
2248	--	-40	445.2	14.0	4192	--	--	--	--	--

^a Candidate "A" propellant.^b Candidate "B" propellant.^c Measured in pressure range 1000 - 2000 psi.

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Additionally, multiple small stream casting was used to enable sufficient deaeration to take place.

STRAIN MEASUREMENTS ON CANDIDATE PROPELLANTS

(U) Bore strain measurements were made on both ANB-3394 and -3395-1 candidate formulations. Two sets of four 2 x 3-in. steel strain cylinders were lined with modified 434-4 liner. Each set of four cylinders was fitted with cores having the diameters 0.5, 0.6, 0.7 and 0.8 inches and cast with a candidate propellant. Since 135°F was the cure temperature for both sets, this temperature was taken as the zero strain temperature. All the strain cylinders were then lowered to -40°F in discrete temperature intervals for fixed time periods, and the change in bore diameter was measured at each temperature. These data were used to measure bore strains. If the propellants survived this cycling down to -40°F, they were returned to room temperature and then cycled directly down to -40°F. This cycle was repeated five more times or until propellant failure occurred, whichever came first. ANB-3395-1 survived all the cycles at all the strain levels, but ANB-3394 failed during the first cycle (Table 18). Inspection of the failure cracks along the bore revealed that they propagated axially rather than longitudinally as is usually the case. They also were found to originate from subsurface voids generated during the casting of these cylinders, as a result of poor propellant flow characteristics coupled with reduced casting volume due to the presence of the cores. It is expected, but has not been demonstrated on this program that grains of ANB-3394 would show greater strain capabilities if void free.

SMALL MOTOR TEST FIRINGS

(U) Initial test firings of ANB-3394 and ANB-3395 in 2-in.-dia x 6.25-in.-long end burning grains resulted in erratic pressure-time traces (Figures 10 and 11). Initial deposition of condensable material on the nozzle was blamed for these results and subsequent firings (Figures 12 and 13) used contoured boron nitride nozzles. Boron nitride nozzles have shown more resistance to deposition than carbon nozzles and contouring was expected to provide smoother gas flow.

(U) As can be seen from the pressure-time traces, going to contoured boron nitride nozzles showed some improvement but did not adequately solve the deposition problem. It appears that the coarse H-95 aluminum is not completely burned in the initial phase of the firing, which in combination with a low motor L^* and an unfavorable aft-closure design, causes deposition of condensable species in the exhaust. The shape of the pressure-time (p-t) trace and level of the equilibrium pressure of these firings, however, indicate that grain integrity is not a contributing factor to the pressure irregularities. The problem of low L^* and consequently low residence time is frequently encountered when high r propellant is test fired in motors designed for low r propellants. The average pressures were calculated from these pressure-time traces and the resulting burning rates were in good agreement

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(U) TABLE 18. Results of Strain Measurements

ANB-3394

Strain Cylinder, no.	1	2	3	4
Bore Diameter, in.	0.50	0.60	0.70	0.80
Cycles Completed	None	None	None	None
Failure Temp., °F	40	40	20	0
% Strain at Failure	7.2	8.9	8.3	7.1
Cause of Failure	Void	Void	Void	Void

ANB-3395-1

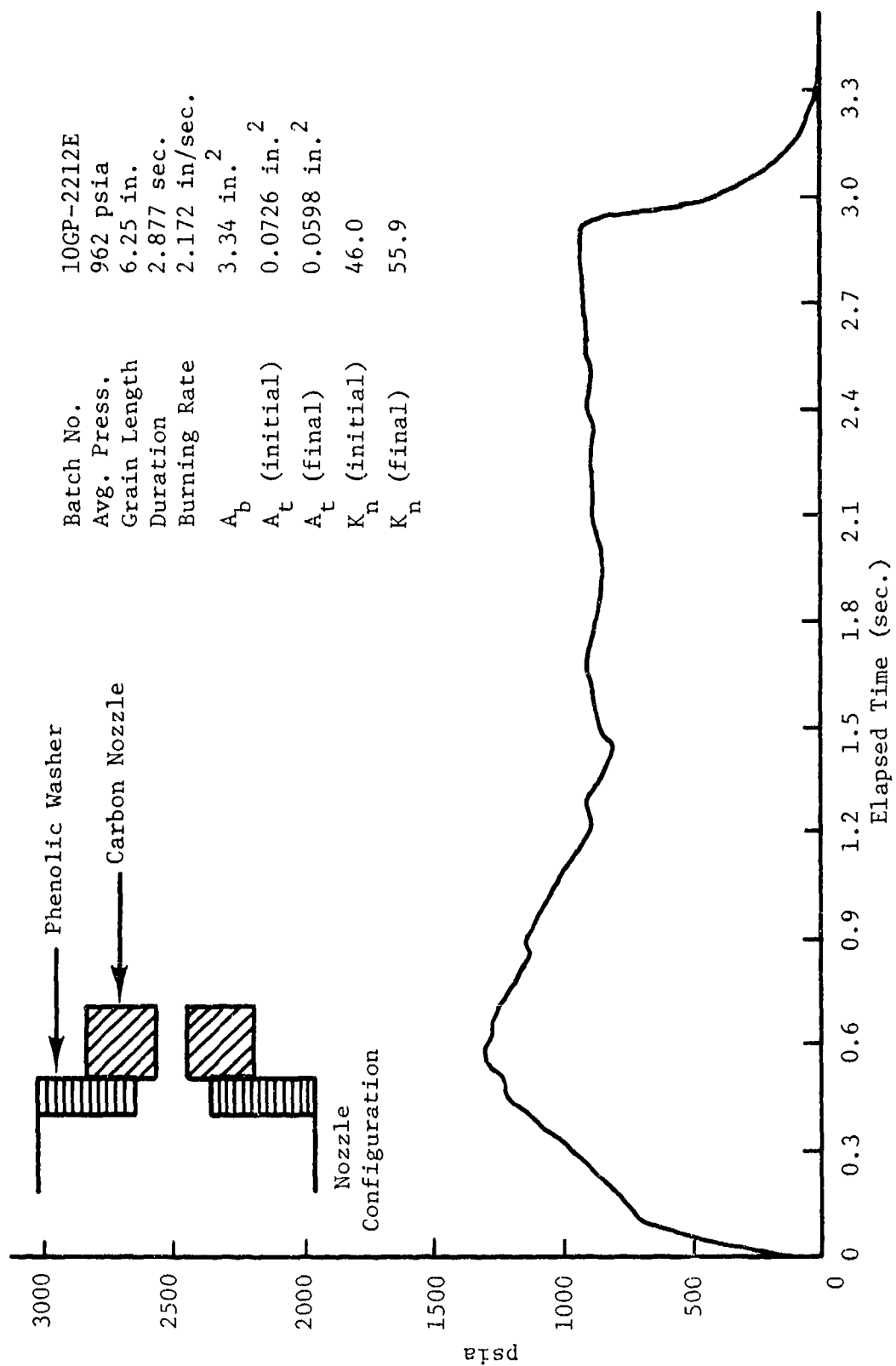
Strain Cylinder, no.	1	2	3	4
Bore Diameter, in.	0.50	0.60	0.70	0.80
Cycles completed	1	2	2	6
Failure Temp., °F	-40	-40	-40	... ^a
% Strain at Failure	18.7	15.6	11.8	9.4 ^a
Cause of Failure	ESC ^b	ESC ^b	ESC ^b	...

^aDid not fail.^bExceeded strain capabilities.

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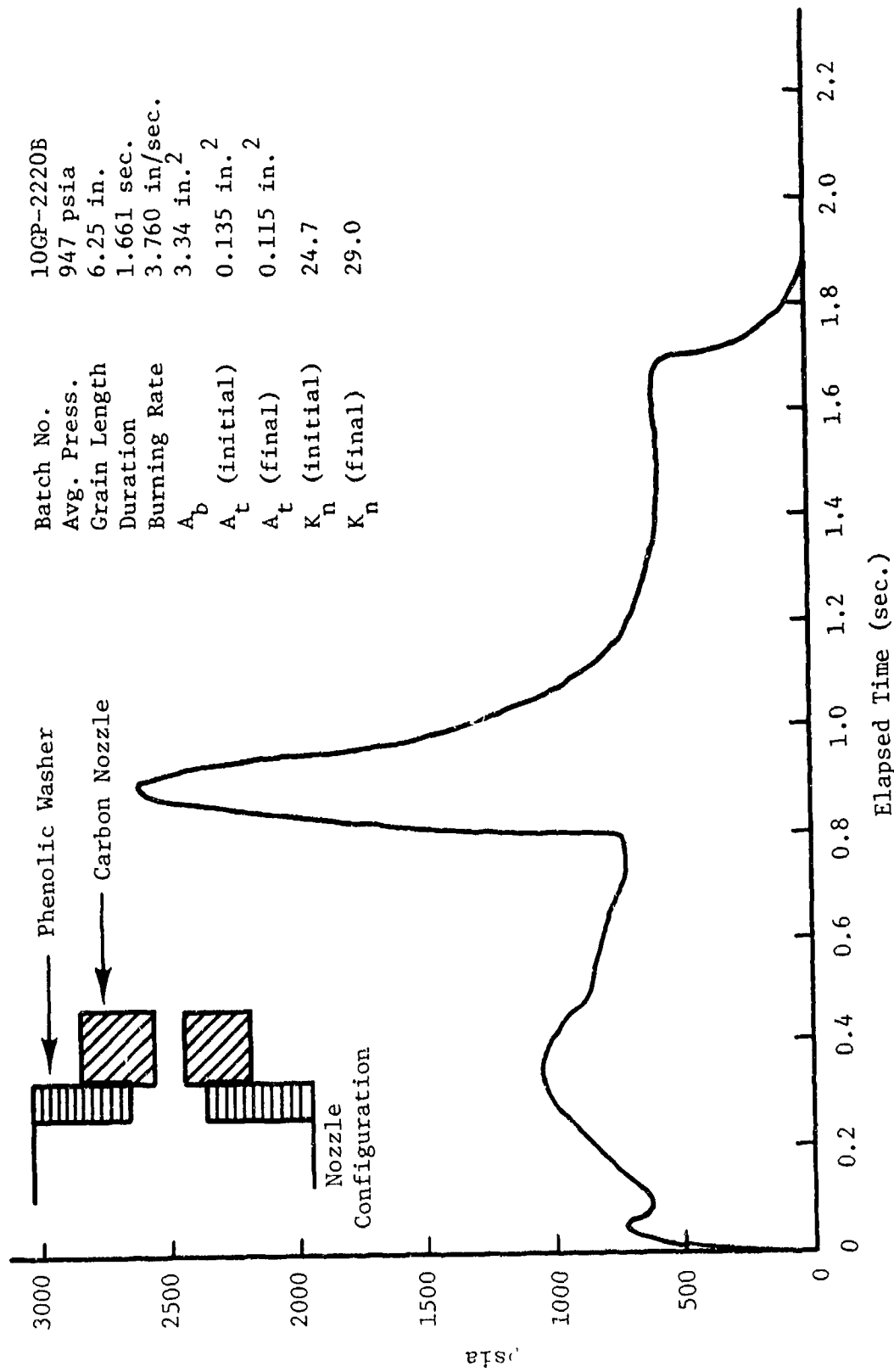


(U) FIG. 10. Pressure-Time Trace of ANB-3394 (A) Motor Firing Using a Non-Contoured Carbon Nozzle

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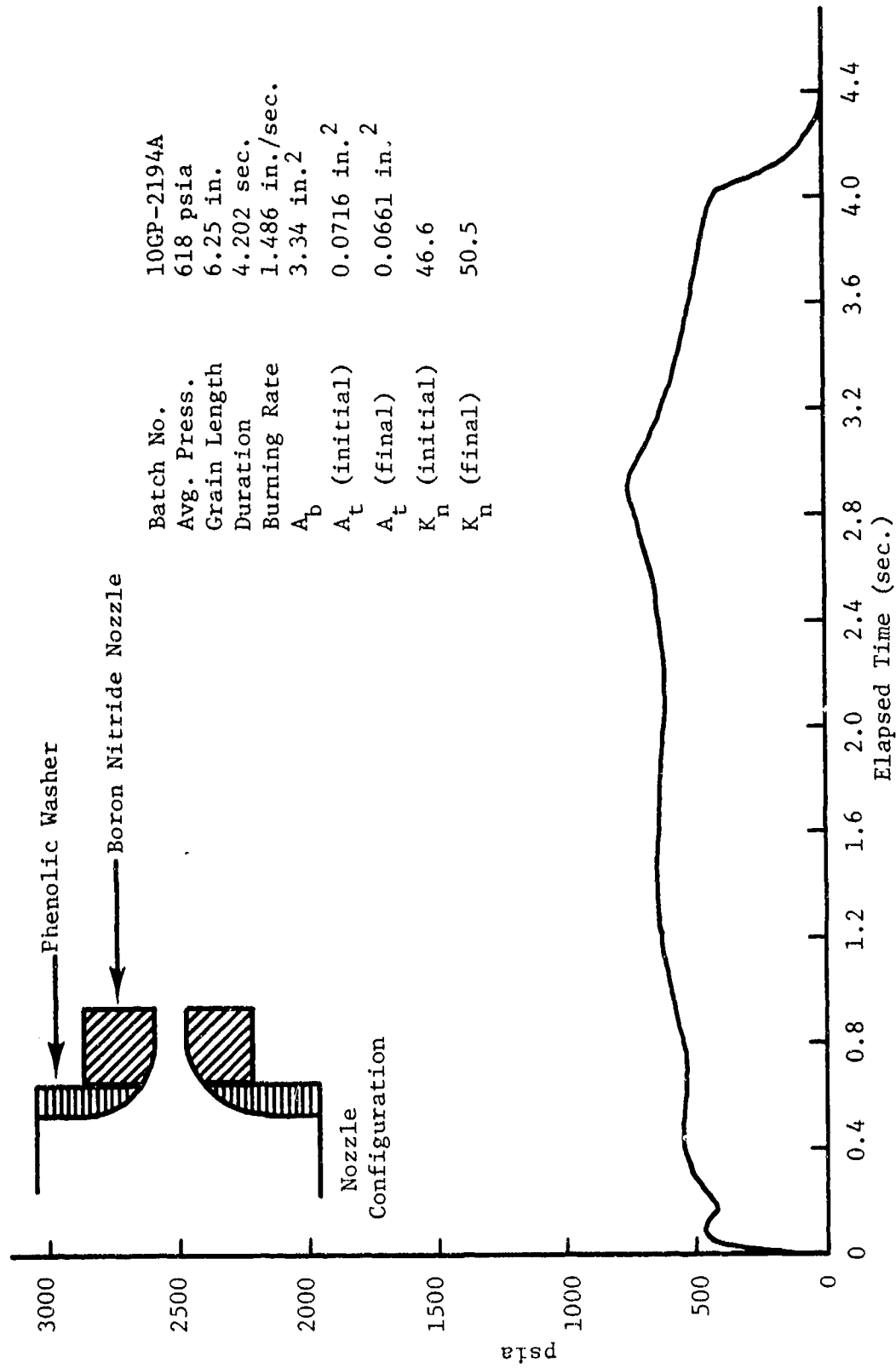


(U) FIG. 11. Pressure-Time Trace of ANB-3395 (B) Motor Firings Using a Non-Contoured Carbon Nozzle

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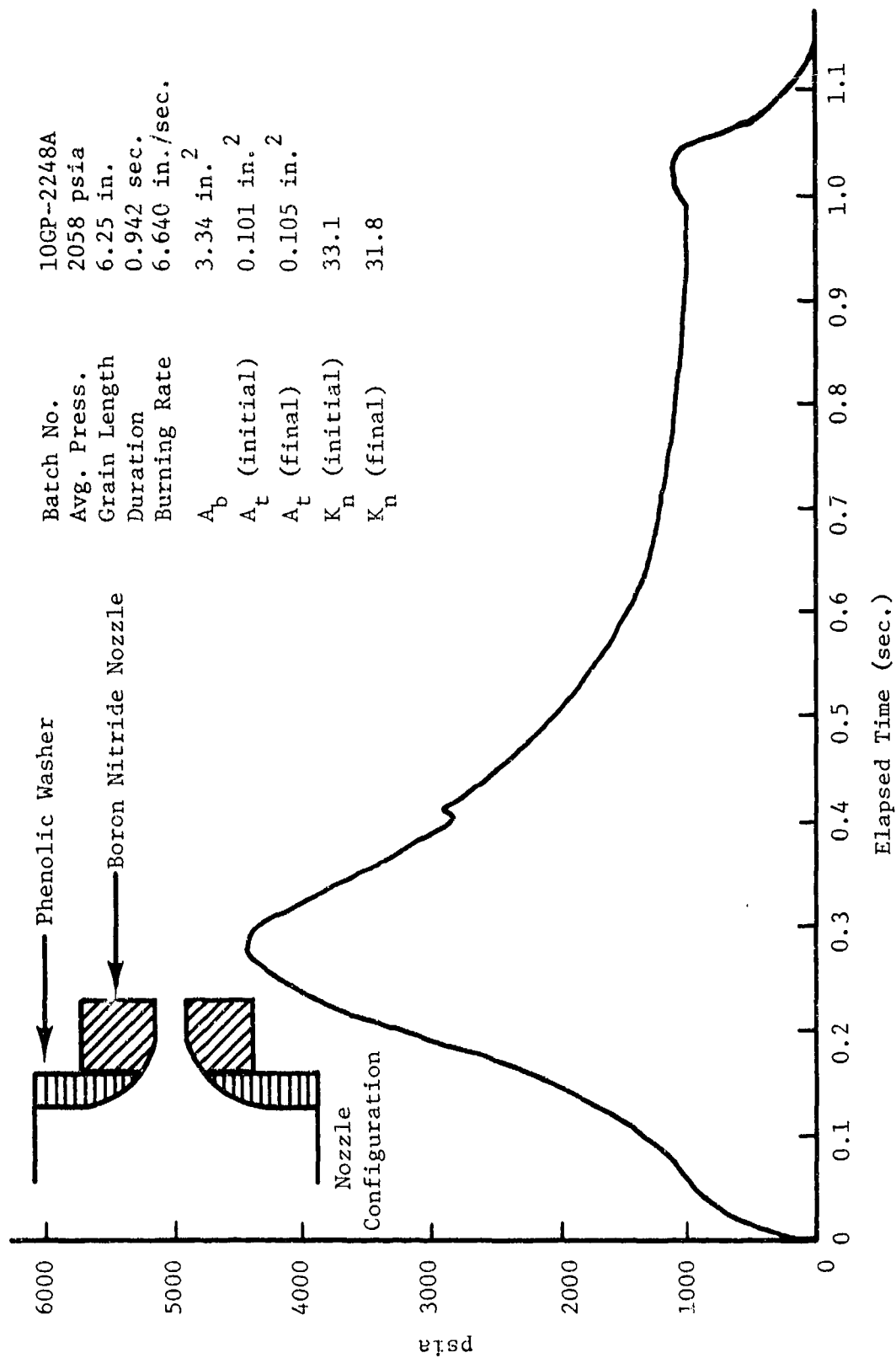


(U) FIG. 12. Pressure-Time Trace of ANB-3394 (A) Motor Firing Using a Contoured Boron Nitride Nozzle.

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(U) FIG. 13. Pressure-Time Trace of ANB-3395 (B) Motor Firing Using a Contoured Boron Nitride Nozzle.

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with the solid strand rates from the same propellants (Figure 14).

(U) Subsequent batches were prepared with H-60 aluminum replacing the coarser H-95 aluminum. This was expected to improve the combustion efficiency of the aluminum and thereby reduce deposition. To increase L^* , firings were made using 3-in. grains. Also, 0.25 in. of a non-aluminized propellant was cast on top of these grains that served to preheat the nozzle prior to ignition of the candidate propellants. Preheating the nozzle was expected to further minimize deposition and ignition of the main grain was signaled by a sharp rise in pressure. All these grains (Figures 15-17) exhibited successful motor firings. Some of the grains exhibited progressive pressure-time traces which could have been a result of uneven ignition of the main grain by the prewarming grain. Interestingly, one motor fired successfully without the benefit of the prewarming grain (Figure 18), but postfiring inspection of the motors disclosed slag on the nozzle that was not present when the prewarming grain was used. This was interpreted as a positive contribution by these grains towards minimizing deposition.

SUMMARY OF PROPERTIES AND AGING RESULTS FOR ANB-3394 AND ANB-3395-1

(U) The processing, mechanical, ballistic and liner/propellant bond properties are summarized for ANB-3394 and ANB-3395-1 in Tables 19 and 20, respectively. In addition, the results of one month aging at 135°F on these properties are also presented in these tables. The major changes brought on by this short aging period were chiefly in the mechanical properties. Both formulations showed increased Shore "A" hardness readings which were probably a result of incomplete cure at the time of initial property measurements, progressing to final cure during aging.

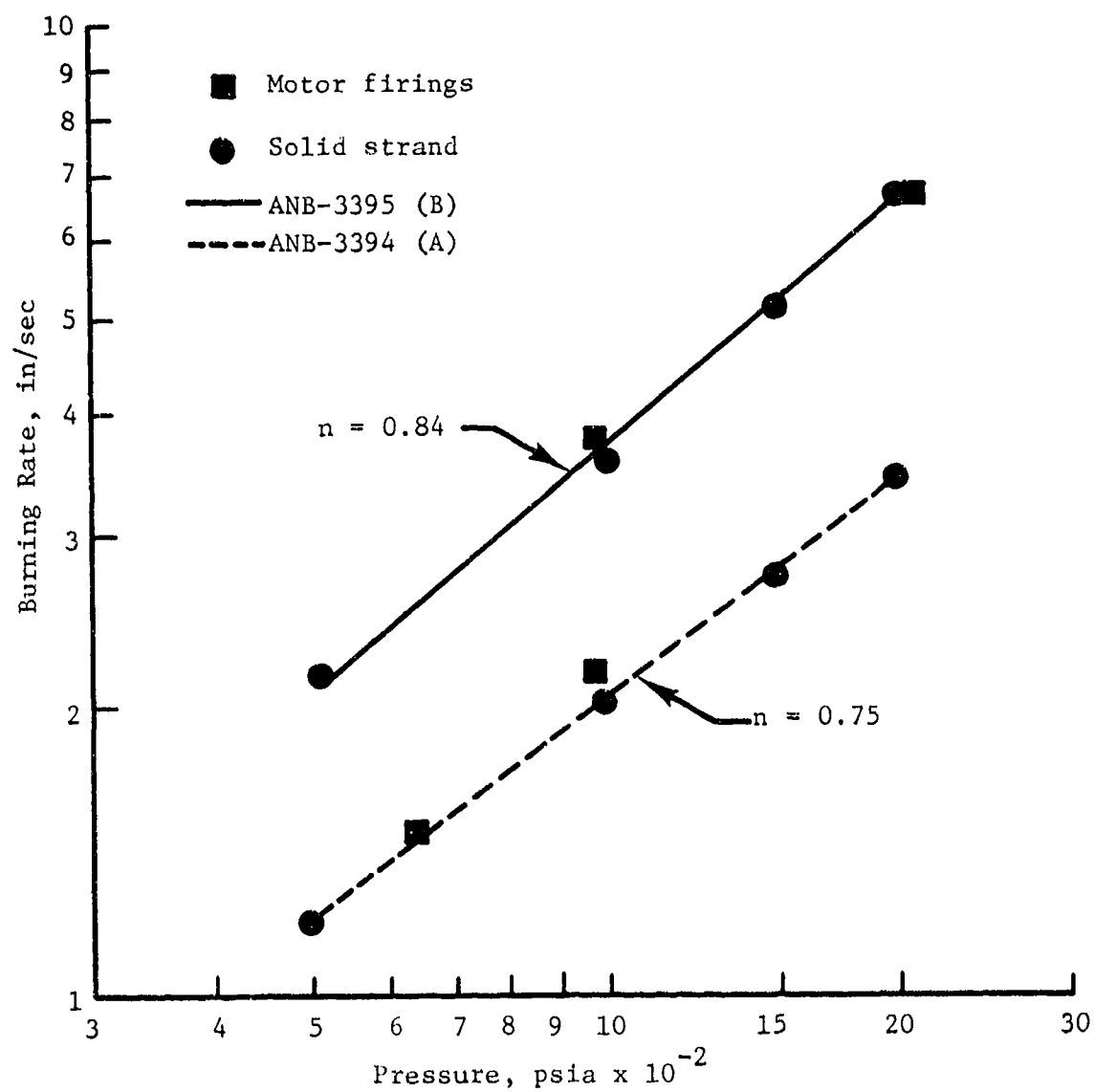
(U) The liner/propellant bond properties only showed improvement on aging with failure occurring in the propellant, and the ballistic properties essentially remained unchanged. Solid strand and motor burning rates are presented in Figure 19 for both candidate formulations and show excellent agreement with each other.

RECOMMENDATIONS FOR FUTURE WORK

(U) We recommend that additional work be initiated to improve the potlife and mechanical properties of both propellants. An approach to improving potlife would be an evaluation of the cure catalytic effect of the coated UFAP. A coating without catalytic properties should greatly increase potlife. Further, mechanical properties could be improved by lowering or eliminating plasticizer if sufficient increase in potlife is realized to allow processing at higher temperatures.

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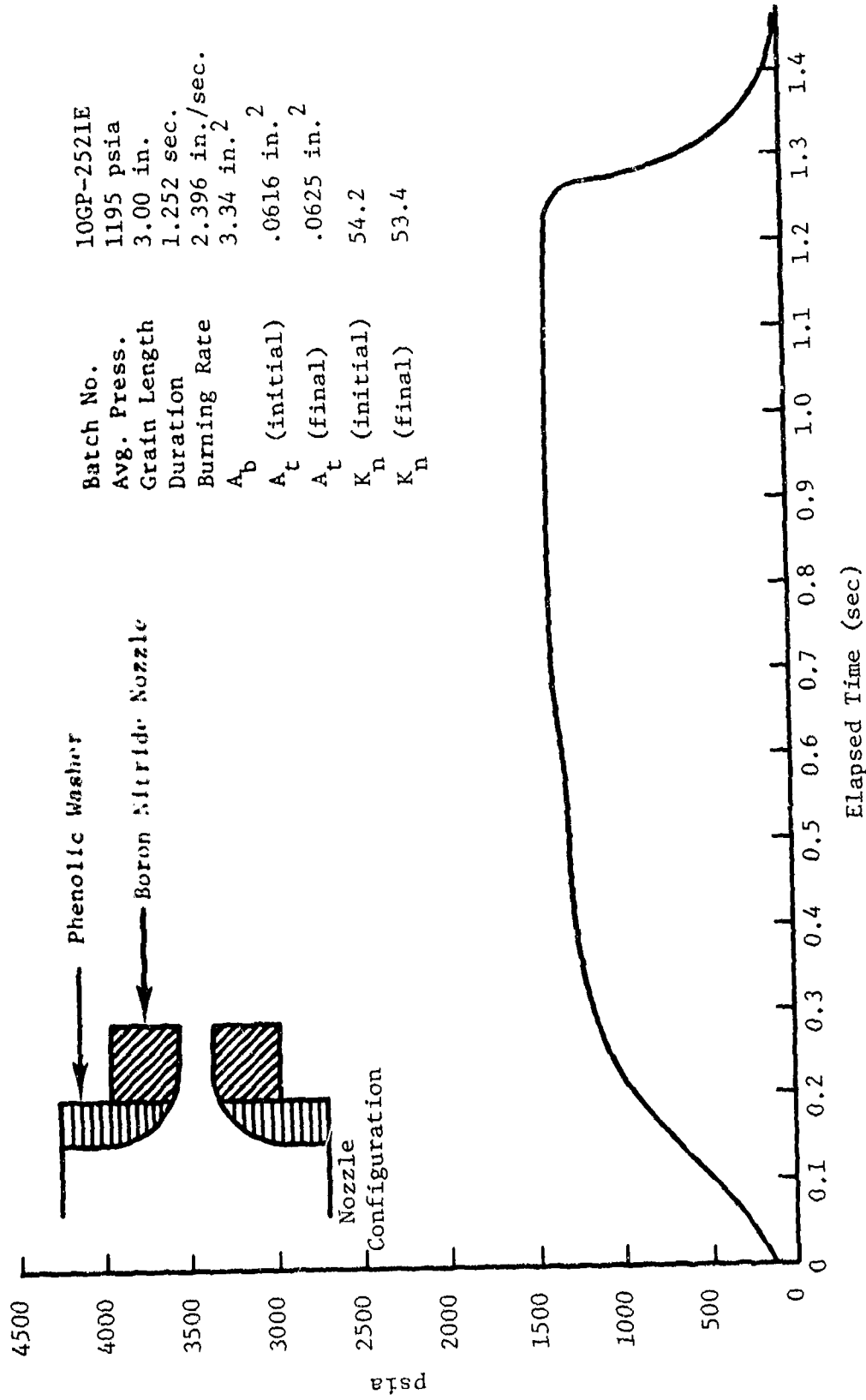


(U) FIG.14. Solid Strand and Motor Burning Rate Curves for ANB-3394 (A) and ANB-3395 (B) Propellant Formulations.

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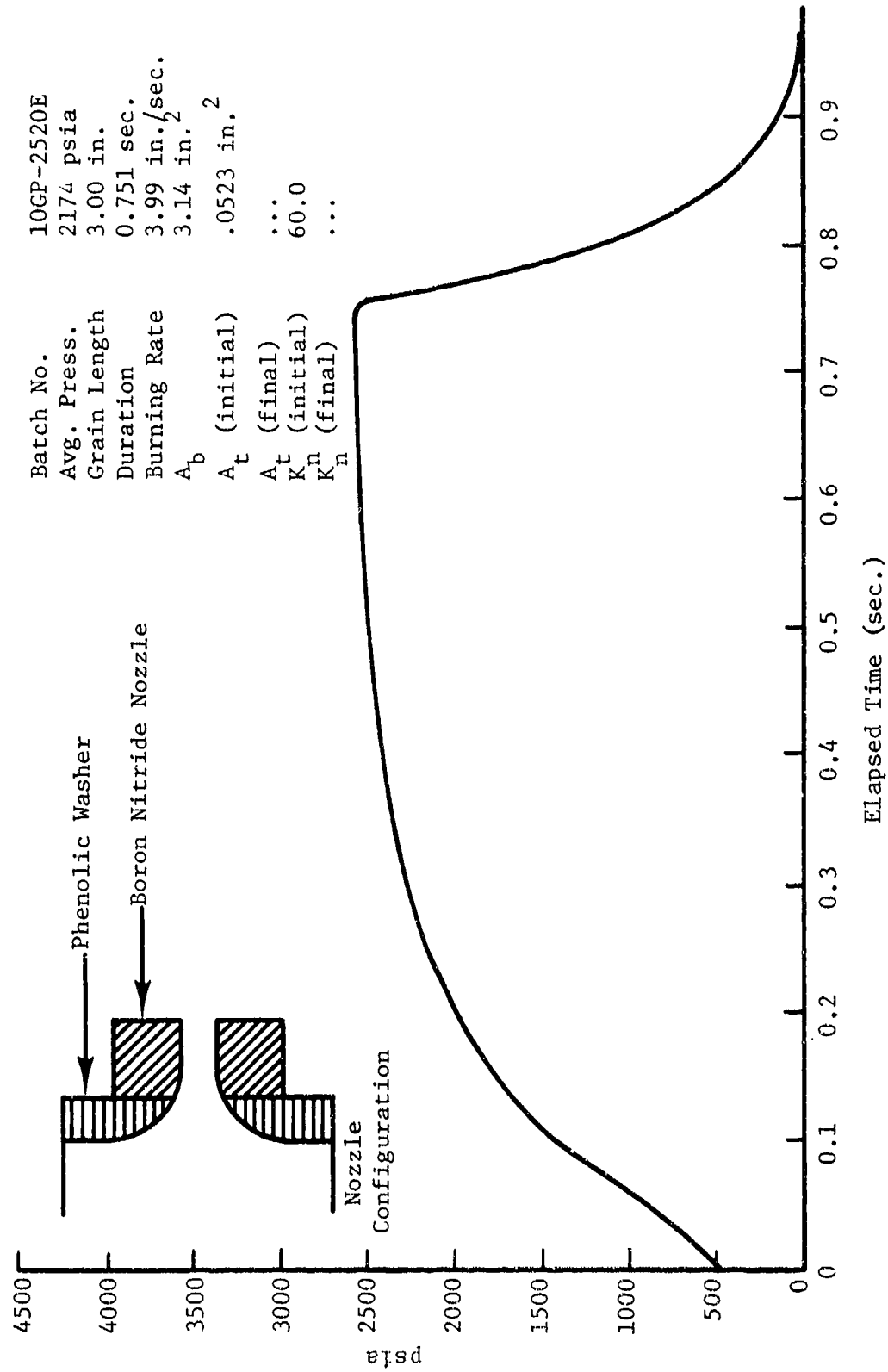


(U) FIG. 15. Pressure-Time Trace of ANB.3394 Motor Firing Using A Contoured Boron Nitride Nozzle. A Non-Aluminized 0.25 in. First Fire Grain Was Cast Onto Main Grain to Prewarm Nozzle (P-T Trace Not Shown).

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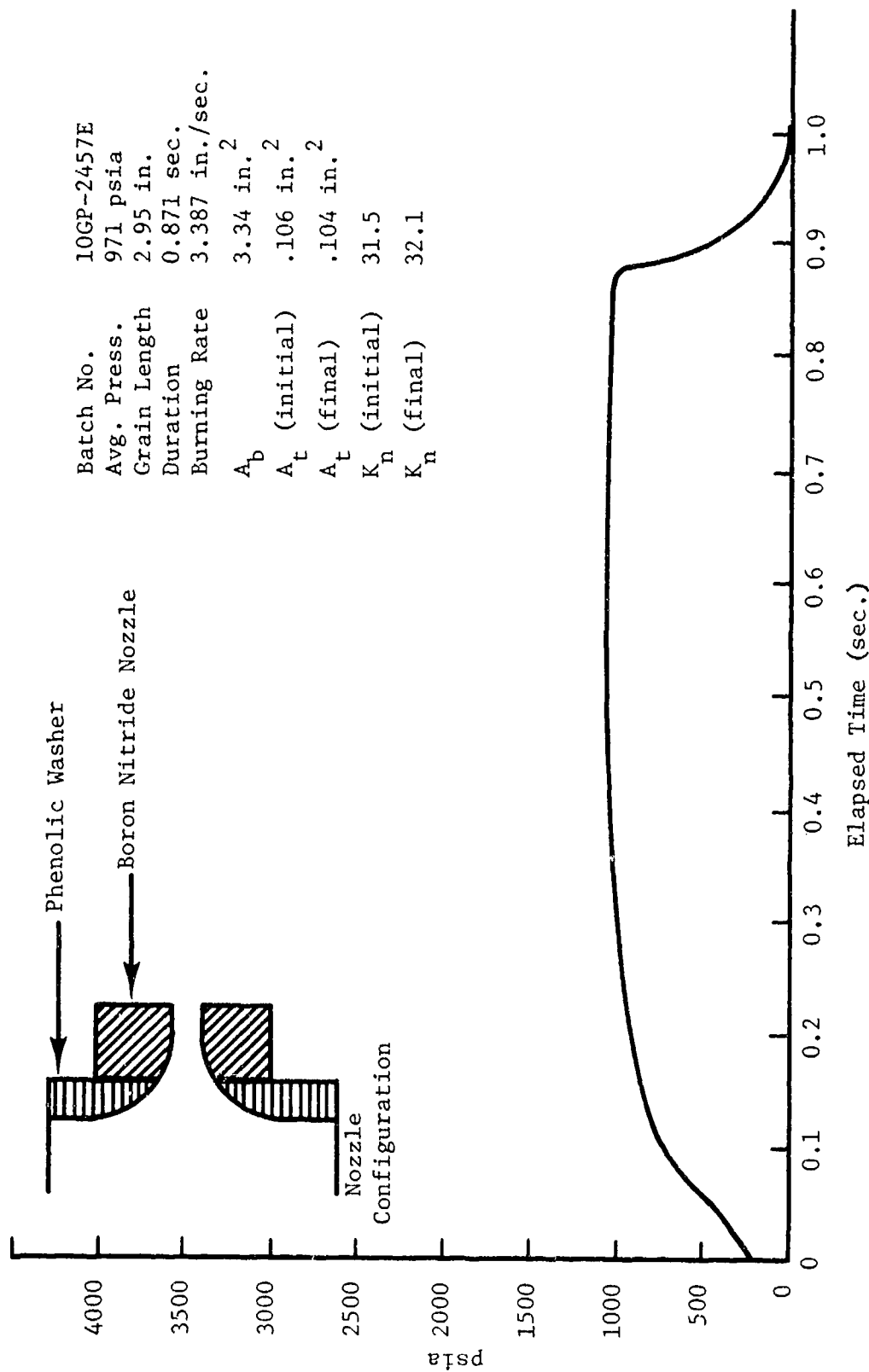


(U) FIG. 16. Pressure-Time Trace of AN3-3394 Motor Firing Using A Contoured Boron Nitride Nozzle. A Non-Aluminized 0.25 in. First Fire Grain Was Cast Onto Main Grain to Prewarm Nozzle (P-T Trace Not Shown).

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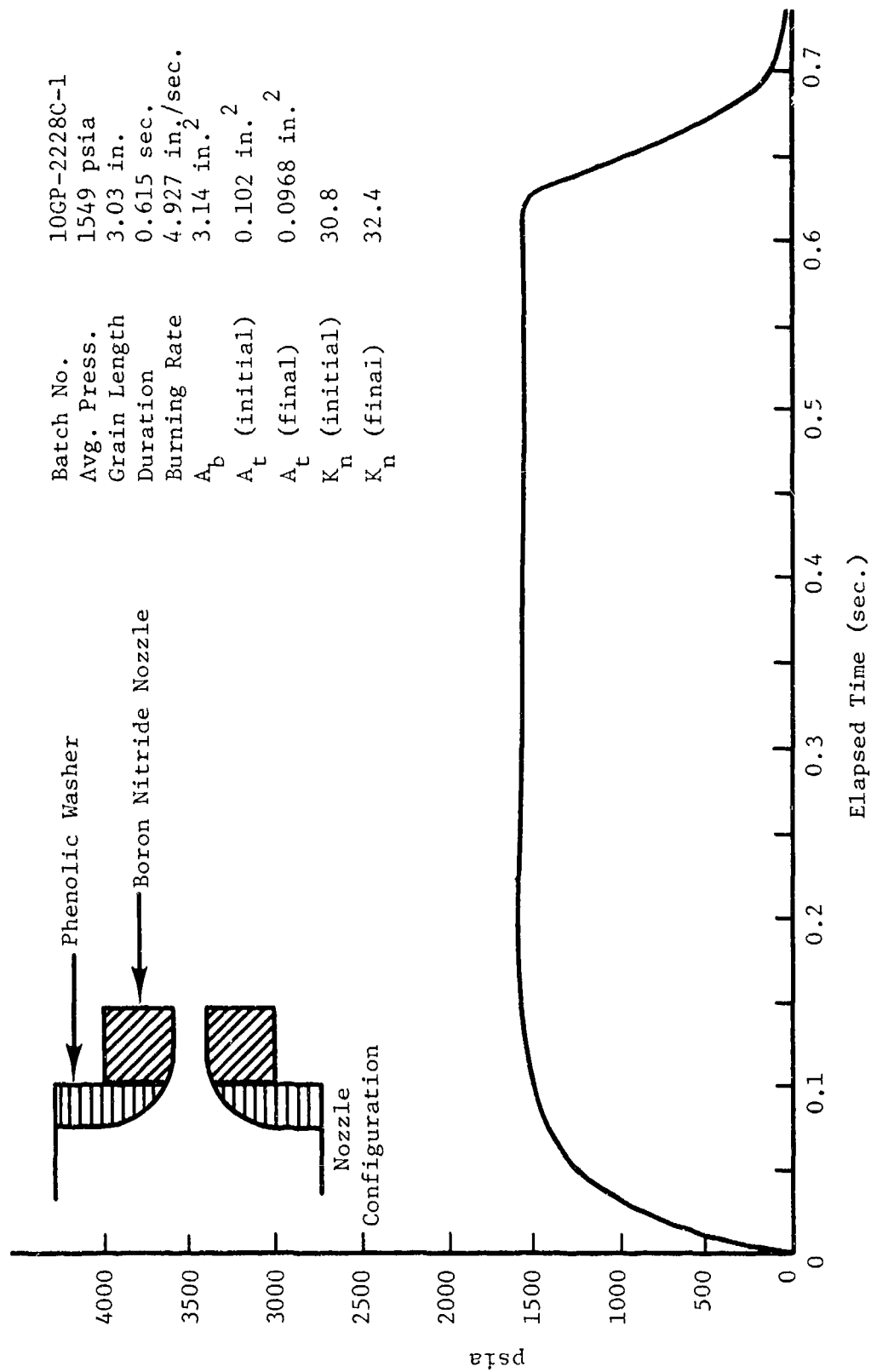


(U) FIG. 17. Pressure-Time Trace of ANB-3395-1 Motor Firing Using a Contoured Boron Nitride Nozzle. A Non-Aluminized 0.25 in. First Fire Grain was Cast onto Main Grain to Prewarm Nozzle (P-T Trace not shown).

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(U) FIG. 18. Pressure-Time Trace of ANB-3395 Motor Firing Using A Contoured Boron Nitride Nozzle.

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(U) TABLE 19. Summary of Initial and Aged Properties of ANB-3394

Processing and Cure Properties

	Initial	Aged 1 Month @ 135°F
Potlife, hrs.	3.0	...
Shore "A" Hardness	45	52
Density, g/cm ³	...	1.719

Mechanical Properties

	Initial				Aged 1 Month @ 135°F			
	160°F	77°F	0°F	-40°F	160°F	77°F	0°F	-40°F
σ_m , psi	43.3	72.5	131	270	59.5	90.2	177	329
ϵ_m , %	18.5	20.8	18.3	14.8	13.2	14.4	14.7	13.0
E_o , psi	275	453	956	2836	477	704	1490	3606

Ballistic Properties

	Initial	Aged 1 Month @ 135°F
R_B , in/sec		
500 psia	1.21	1.16
1000 psia	2.06	2.00
2000 psia	3.42	3.30
n (500-2000)	0.77	0.77

Liner/Propellant Bond Properties

	Initial	Aged 1 Month @ 135°F
DPT, psi	69.5 (P_2 break)	92.4 (P_2 break)

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(U) TABLE 20. Summary of Initial and Aged Properties of ANB-3395-1

Processing and Cure Properties

	Initial	Aged 1 Month @ 135°F
Potlife, hrs.	3.0	...
Shore "A" Hardness	43	47
Density, gm	...	1.729

Mechanical Properties

	Initial				Aged 1 Month @ 135°F			
	160°F	77°F	0°F	-40°F	160°F	77°F	0°F	-40°F
σ_m , psi	48.5	73.7	151	367	62.9	88.1	192	469
ϵ_m , %	24.7	25.5	22.8	16.5	23.7	22.8	19.8	14.0
E_m , psi	257	383	967	3650	337	528	1435	5123

Ballistic Properties

	Initial	Aged 1 Month @ 135°F
R_B , in/sec		
500 psia	2.18	2.13
1000 psia	3.55	3.49
2000 psia	6.80	6.81
n (500-1000)	0.71	0.72
n (1000-2000)	0.92	0.94

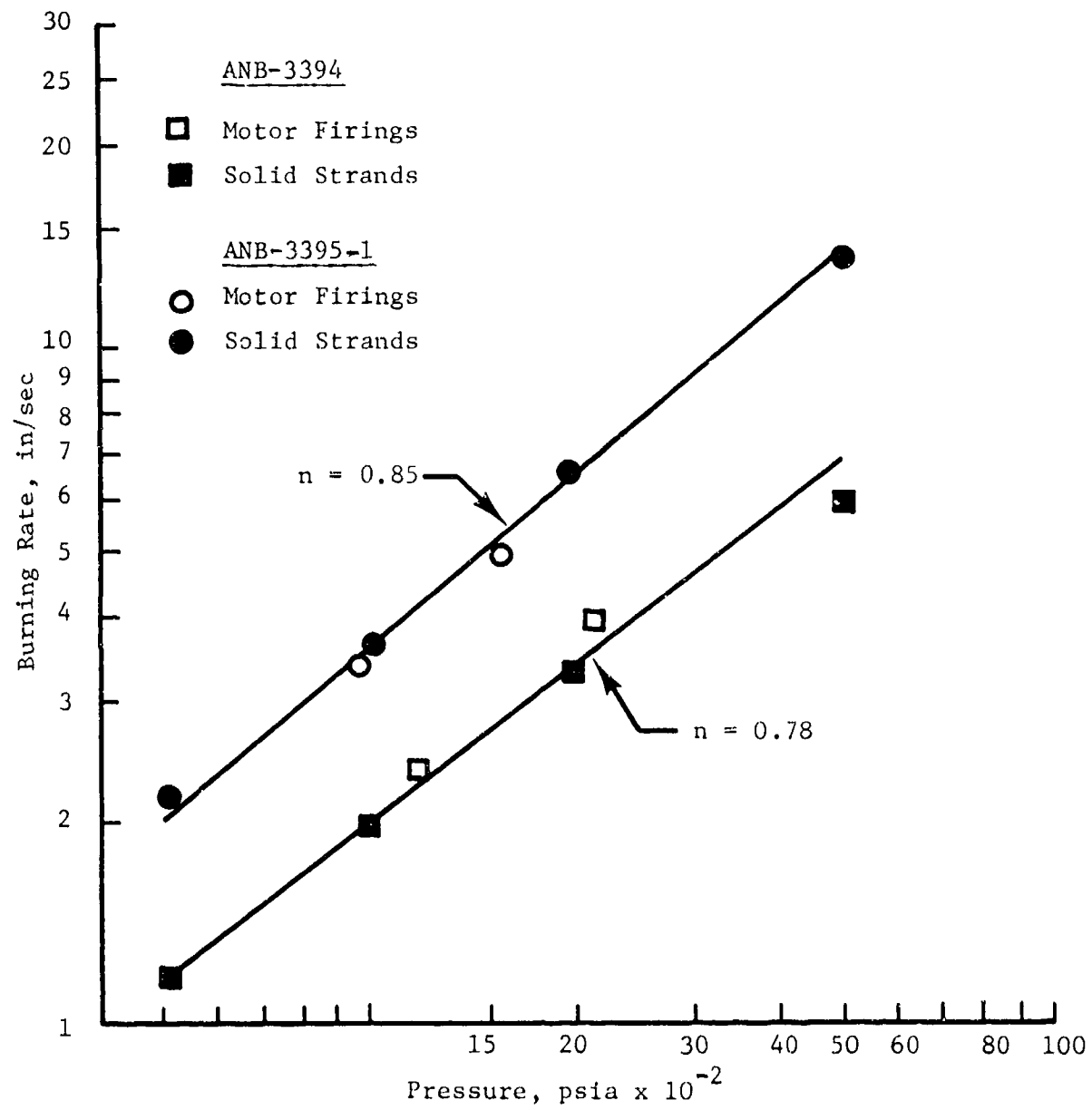
Liner/Propellant Bond Properties

	Initial	Aged 1 Month @ 135°F
DPT, psi	85.3 (P_2 break)	106.7 (P_2 break)

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(U) FIG. 19. Burning Rate Curves from Solid Strand and Motor Rate Data for ANB-3394 and ANB-3395.

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Glossary of Terms and Abbreviations

Agerite White	Antioxidant
AO-2246	Antioxidant
AP	Ammonium Perchlorate
BDB	Aerojet proprietary coating agent
BRA-99	Aerojet proprietary combustion catalyst
BRA-101	Aerojet proprietary combustion catalyst
CTPB	Carboxy terminated polybutadiene
DEO	Hydroxy functional wetting agent
DOA	Diethyladipate
EDB	Aerojet proprietary fuel component
ERL-4205	Bis(2-3-epoxycyclopentyl)ether
ERL-4221	3,4-Epoxycyclohexylmethyl-(3,4-epoxy) cyclohexane carboxylate
FC-155	Aerojet proprietary fuel component
Freon-113	1,1,2 Trifluoro-1,2,2 Trifluoro-1,2,2 Trichloroethane
HC-434	Carboxy-terminated polybutadiene (Thiokol Chemical Co.)
HDI	Hexamethylene diisocyanate
HTPB	Hydroxy terminated polybutadiene
Hycat-6	A non-volatile liquid ferrocene derivative
IDP	Isodecyl pelargonate plasticizer
IPDI	Isophorone diisocyanate
Isonol	Phosphorous containing polyol
MA	Mikro-atomizer ground ammonium perchlorate
MSA	Mine Safety Appliances Co., particle size measuring apparatus, a liquid sedimentation technique
nBF	n-Butylferrocene
P-33	Thermal carbon black
PAP	Porous Ammonium Perchlorate
Plastinox 711	Antioxidant
R-45M	Free radical initiated HTPB
Refrasil	Silica Fiber
SS-AP	Slow-speed mikro-pulverized ground ammonium perchlorate

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Glossary of Terms and Abbreviations (Cont'd)

SURFAC OS	Carboxy functional wetting agent
TEA	Triethanol amine
TEHOS	2-Ethylhexylorthosilicate
Thixcin E	Modified 1-hydroxy stearin
UFAP	Ultra-fine ammonium perchlorate (<5μ)
VEM	Vibro-energy mill

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13. ABSTRACT			
<p>(U) Two candidate propellant formulations, ANB-3394 and ANB-3395-1, were developed that satisfied all the technical goals. Additionally, these propellants were successfully test fired in small scale motors verifying propellant ballistic properties, excellent liner propellant bonds, and propellant processability adequate for good grains.</p>			

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Propellant High Burn Rate Ferrocene Ultra Fine Ammonium Perchlorate Porous Ammonium Perchlorate HTPB						

ABSTRACT CARD

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