

NASA CR-72262

260-SL-3 MOTOR PROGRAM

VOLUME II

GPO PRICE \$ _____

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Hard copy (HC) 3.50

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ff 653 July 85

260-SL-3 MOTOR PROPELLANT DEVELOPMENT

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NO. NAS3-7998



AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

N68-16051
(ACCESSION NUMBER)
108
(PAGES)
NASA CR #72262
(NASA CR OR TMX OR AD NUMBER)
77
(CATEGORY)
FACILITY FORM 602

PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy 096

NASA CR 72262

FINAL PHASE REPORT

260-SL-3 MOTOR PROGRAM

VOLUME II

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14 July 1967

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract No. NAS3-7998

Technical Management
NASA Lewis Research Center
Cleveland, Ohio

Report NASA CR 72262

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I. SUMMARY

The propellant formulation developed for Motor 260-SL-3 was designated ANB-3254. This formulation is similar to the ANB-3105 propellant developed for Motors 260-SL-1 and -2, but uses more active burning rate additives and a modified anhydride-free binder. The ANB-3254 formulation meets all of the ballistic, processing, and mechanical property requirements for Motor 260-SL-3.

Inert slivers for Motor 260-SL-3 were made at the Aerojet Dade County Plant from castable insulation IBC-101. Six 2500-lb vertical batch mixes of IBC-101 were prepared and cast into the sliver molds. After cure, the slivers were stripped from the molds and bonded into the chamber. After installation of the slivers, the chamber was lined with SD-850-2 material to an average thickness of 33 mils. The liner application procedure was the same as that used for Motors 260-SL-1 and -2.

Casting of Motor 260-SL-3 was initiated on 13 February and completed on 2 March 1967. A total of 333 vertical batch mixes, each consisting of 5500 lb of ANB-3254 propellant, was prepared; of these, 319 batches were qualified and cast into the motor. Motor average values for uncured propellant acceptance analyses were very close to target requirements. The average propellant initial modulus for the motor at termination of cure is expected to be approximately 430 to 440 psi, which is within the target range of 400 to 600 psi.

II. PROPELLANT TAILORING

A. OBJECTIVE

The objective of the propellant tailoring program was to modify the basic 260-in.-dia motor propellant ANB-3105 to provide a burning rate of 0.71 in./sec at 600 psia for Motor 260-SL-3. Based on the firing results of

II.A. Objective (cont)

Motors 260-SL-1 and -2, a burning-rate scale up of 6% was anticipated from 3KS-500-size motors to 260-in.-dia motors. On this basis, a 3KS-500-size-motor burning-rate target of 0.67 in./sec was established for this program.

B. PROGRAM

The propellant tailoring program was designed to define the propellant formulation requirements of Motor 260-SL-3 and consisted of the selection of (1) the burning additive type and concentration, (2) the oxidizer blend and (3) the plasticizer concentration. Formulation evaluation was conducted with small-scale batches (1, 10, and 60 lb) and the final composition selection made on the basis of burning rate, processing characteristics, and mechanical properties.

The program was planned to provide an early scale-up to full-size production mixers at the Aerojet Dade County facility. The scale-up task was scheduled so that any problems encountered in full-scale processing equipment could be resolved without compromising the motor program schedule. A raw material lot qualification task similar to that used for Motors 260-SL-1 and -2 was scheduled after the completion of scale-up. Since the oxidizer and aluminum to be used in the propellant for Motor 260-SL-3 consisted of both GFM* and residual 260-SL-2 materials, both were included in the raw material lot qualification program.

Formulations with and without the anhydride, DDS, were evaluated during propellant tailoring. The following discussion describes the evaluation of these two binder systems and the basis for selection of the anhydride-free propellant for casting of Motor 260-SL-3.

* A Glossary of Terms is included in the Appendix.

II. Propellant Tailoring (cont)

C. ANHYDRIDE-CONTAINING FORMULATION (ANB-3235)

1. Burning Rate Adjustment and Propellant Viscosity

Three basic techniques were available to modify ANB-3105 to achieve the higher propellant burning rate required for Motor 260-SL-3:

(1) adjustment of the oxidizer grind to provide a finer particle-size distribution, (2) use of more active burning-rate additives, and (3) substitution of a ballistically active plasticizer for DOA. Each of these approaches was evaluated individually and in combination to determine the effect on propellant processing characteristics as well as burning rate.

Trade-off studies between burning rate and oxidizer particle size distribution, burning rate additive, and plasticizer type were conducted in small scale (1 and 10 lb) propellant batches while maintaining the oxidizer, aluminum, and binder content of the basic ANB-3105 propellant formulation. Burning rate additives Fe_2O_3 , Iron Blue, and BRA-101 were evaluated in combination with trimodal oxidizer blends of UG/HSMP/MA and bimodal blends of UG/MA and SSMP/MA. The ballistically active plasticizer MMDPO (methoxymethyl diphenyloxide) was investigated as a replacement for DOA.

a. Evaluation of Fe_2O_3 and Fe_2O_3 /BRA-101 Burning Rate Additives

The simplest modification of ANB-3105 to increase the burning rate is an increase in the Fe_2O_3 concentration. This represents a minimum formulation change and assures the retention of all other desirable characteristics of ANB-3105. However, the data (Figure 1) indicate that Fe_2O_3 with DOA plasticizer will not provide the target burning rate of 0.67 in./sec at 600 psi. The use of MMDPO plasticizer provided an increase in

II.C. Anhydride-Containing Formulation (ANB-3235) (cont)

burning rate (Figure 1), however, the Fe_2O_3 /MMDPO combination still did not meet the target burning rate, and the MMDPO caused a significant increase in propellant viscosity.

A recently developed Aerojet burning-rate additive, BRA-101, was subsequently evaluated. The data (Figure 2) indicate a substantial increase in burning rate compared to Fe_2O_3 , but the target rate could be achieved only with MMDPO plasticizer and the processability of these formulations was fair to poor.

Since the burning rates could be achieved with Fe_2O_3 and BRA-101 only at the expense of high viscosity and poor processing, effort was made to improve the processing characteristics of the propellant and to provide further increases in burning rate through the use of high-surface trimodal oxidizer blends. The data (Figure 3) indicate that the target rate could not be achieved with Fe_2O_3 alone, and that Fe_2O_3 /BRA-101, although yielding burning rates in the required range, still exhibited poor processability with these high-surface blends.

b. Evaluation of Iron Blue and Iron Blue/BRA-101 Burning Rate Additives

Early in the 260-in.-dia motor development program, Iron Blue burning-rate additive demonstrated higher burning rates than Fe_2O_3 in PBAN propellants. The evaluation of Iron Blue with both DOA and MMDPO plasticizers (Figure 4) indicated that while Iron Blue is a more active burning-rate additive than Fe_2O_3 , the target burning rate still could not be achieved in formulations containing DOA plasticizer. The Iron Blue and MMDPO plasticizer provided the required 0.67 in./sec burning rate but processing characteristics were poor.

II.C. Anhydride-Containing Formulation (ANB-3235) (cont)

Work accomplished by Aerojet on an Independent Research and Development Program indicated that mixtures of Iron Blue and BRA-101 exhibited a synergistic effect in accelerating the burning rate of PBAN propellants. Since the poor processing of these propellants appears to be associated with the very high surface area of these additives, the synergistic effect would be valuable in reducing the total additive content while achieving high burning rates. Propellants prepared with Iron Blue/BRA-101 mixtures and with both DOA and MMDPO plasticizers indicated that this system had the capability of meeting the required burning rate with the more processable DOA plasticized propellant (Figure 5). No further work was done with MMDPO plasticizer.

To optimize processing characteristics, trade-off studies of oxidizer blends with processability and burning rate (Figure 6) indicated that although the burning rate could be achieved with approximately 1% of total burning rate additive and 30 wt% or less MA in the trimodal blends, the processing characteristics and flow properties of these propellants were marginal. Improved processability at the desired burning rate was obtained with bimodal blends (Figure 7) of either UG/MA or SSMP/MA. Propellant processability was improved when a ratio of 75/25 Iron Blue/BRA-101 at 1 wt% was used. However, the required level of the MA portion of the oxidizer blend necessary for a given burning rate was higher than that needed when a 50/50 Iron Blue/BRA-101 mixture was used. All further work was conducted at the 50/50 ratio of burning-rate additives.

Although these propellants exhibited good processing characteristics, the propellant viscosity was still appreciably higher than had been observed for ANB-3105 (29,000 vs 12,000 to 15,000 poise 10 hr after curing agent addition). To determine if further improvements in viscosity could be achieved without compromise of cure and mechanical properties the effect of plasticizer levels was determined. Batches of propellant were prepared with 30, 32.5, and 35% (of the binder) DOA plasticizer. The

II.C. Anhydride-Containing Formulation (ANB-3235) (cont)

viscosity measurements shown below indicated that 35% DOA was required to obtain propellant viscosities comparable to ANB-3105. Mechanical properties data from these batches show no significant effect due to plasticizer level.

Plasticizer Level, Wt% of Binder	10-hr Viscosity at 135°F, poise	Mechanical Properties at 77°F			
		S_{nm}' psi	m' %	b' %	E_o' psi
35	18,500	112	20	22	639
32.5	23,000	118	19	20	710
30	29,000	131	17	18	888

These formulations would exhibit essentially identical mechanical properties if adjusted to the same modulus level (through adjustment of curing agent concentration).

To confirm that the higher plasticizer level had no effect on propellant burning rate, additional batches of propellant were prepared at the 35 wt% DOA level with 0.5 and 0.7 wt% of a 50/50 Iron Blue/BRA-101 mixture and bimodal oxidizer blends ranging from 60/40 to 50/50 SSMP/MA grind ratio. The burning rate data of Figure 8 indicate that the target burning rate can be achieved with approximately 0.5 to 0.6 wt% burning rate additive and a 55/45 SSMP/MA blend with good processability.

To ensure that burning rates in the proper range could be achieved in motor firings as well as liquid strands, 60-lb batches were prepared at two burning-rate-additive levels and two plasticizer levels, and fired in 3KS-500-size motors. The following data indicate a scale-up in burning rate from LSBR to motor firing and show that the target rate is achieved with 0.5 wt% burning rate additive and 35% DOA plasticizer.

II.C. Anhydride-Containing Formulation (ANB-3235) (cont)

AP Blend SSMP/MA	DOA Level, wt% of binder	BRA Level, wt%	<u>Burning Rate, in./sec</u>	
			LSBR at 600 psig	3KS-500 at 600 psia
55/45	35	0.5	0.635	0.670
55/45	35	0.6	0.660	0.680
55/45	30	0.6	0.685	0.710

Tensile data from these 60-lb batches (Figure 9) indicate satisfactory mechanical properties and cure characteristics, although the curing agent (DER-332) concentration should be reduced from 115 to approximately 110 equivalents of DER-332 to achieve the desired 400 to 600 psi target initial modulus.

This propellant containing Iron Blue/BRA-101, a 55/45 SSMP/MA oxidizer blend ratio, and utilizing an epoxy-cured PBAN-anhydride binder plasticized 35% with DOA was designated ANB-3235.

2. ANB-3235 Premix Storage

Since the propellant premix is prepared in large batches and stored prior to use, the stability of the premix, i.e., the length of time the premix can be stored without a change in propellant characteristics, is an important processing consideration. The data obtained from storage of ANB-3235 premix (Figure 10) for up to 21 days at 135°F under agitation and N₂ blanket (standard processing conditions) indicated no change in propellant burning rate or 10-hr viscosity. However, a significant change in propellant mechanical properties is evidenced after 3 days of premix storage. On the basis of these data, the premix hold time for ANB-3235 would be limited to 3 days at 135°F.

II.C. Anhydride-Containing Formulation (ANB-3235) (cont.)

3. Propellant-To-Propellant Bonding

Delays or interruptions in the casting of Motor 260-SL-3 could result in the casting of uncured propellant onto a partially cured propellant surface which would require adequate propellant-to-propellant bonding at the batch interface to ensure grain integrity. Propellant-to-propellant bond strength of ANB-3235 was determined as a function of propellant surface age (i.e., length of time of casting interruption). Sample cartons were half-filled with ANB-3235 propellant and stored at 135°F. At intervals of 1, 2, 3, 4, and 7 days, fresh propellant was used to complete the casting of each half full carton. When the resulting interface had been cured for 28 days at 135°F, tensile specimens containing the interface were prepared and tested. The data (Figure 11) indicate that significant changes in mechanical properties occur between 3 and 4 days. On the basis of these results, if an interruption in the casting of ANB-3235 propellant exceeded three days, a preparation to re-activate the partially cured propellant surface should be used to ensure grain integrity.

4. Bonding System Characterization

The liner evaluated for use in Motor 260-SL-3 was SD-850-2, the same liner used for Motors 260-SL-1 and -2. Confirmation of the bondability of ANB-3235 propellant to this liner indicated that, as expected, the bond properties were similar to those experienced with ANB-3105, i.e., the bond exceeds the cohesive strength of the propellant. The data in Figure 12 illustrate the typically excellent bonding characteristics and storage stability of this bonding system. Bulk propellant-liner specimens stored for up to 24 days at 200°F (after 35 days cure at 135°F) show bond strengths generally exceeding the propellant cohesive strength.

The ANB-3235/SD-850-2 bonding system has also demonstrated

II.C. Anhydride-Containing Formulation (ANB-3235) (cont)

the capability of meeting the constant load bonding requirements of a 260-in.-dia motor. The data illustrated in Figure 13 indicate a constant load bond capability of approximately 32 psi in tensile and approximately 23 psi in a shear mode when extrapolated to 1-year storage at 77°F compared to calculated bond requirements of 1.1 and 7.6 psi in tensile and shear, respectively.

5. Explosive Hazard Evaluation

Explosive hazard testing of ANB-3235 propellant (Figure 14) indicates that the properties of the propellant are equivalent to those assigned I.C.C. shipping classification "B".

D. ANHYDRIDE-FREE FORMULATION (ANB-3254)

1. Comparison of Processing Characteristics

Propellant ANB-3235 met all of the propellant processing and mechanical properties requirements of a 260-in.-dia motor. However, the viscosity characteristics were marginal and the incidence of imperfections (i.e., fuel spots) in the cured propellant was higher than had been observed for ANB-3105 propellant. These considerations resulted in the investigation of an anhydride (DDS) free propellant formulation designated ANB-3254. Most of the advantages of the ANB-3254 propellant compared to ANB-3235 result from the greatly improved processing characteristics of the anhydride-free formulation. Although the exact reasons for this improvement are not known, the improvement may be the result of elimination of interactions between the polar anhydride and the thixotropic burning-rate modifiers or to the absence of hydrolysis of the anhydride by moisture present in the burning-rate additives. The extent of the improvement in processability is illustrated clearly by the photographs of samples of each propellant cast from 10-lb batches shown in Figure 15. All

II.D. Anhydride-Free Formulation (ANB-3254) (cont)

batches of DDS-containing propellants had rough surfaces and fuel spot defects; all DDS-free batches had glass-smooth surfaces and were free from defects.

The lack of surface leveling shown in the samples containing DDS is caused by the "Bingham plastic" flow characteristics exhibited by ANB-3235. A comparison of typical shear rate-vs-shear stress curves (as measured with a Rotovisko viscosimeter) for the two propellants clearly shows this characteristic (Figure 16). A shear stress of approximately 1100 dynes/cm² for the ANB-3235 propellant must be applied before any observable motion of the propellant occurs. The effect of this is to impart essentially infinite viscosity at low shear stresses (equivalent to 0.5 to 1.0 in. of propellant head).

2. Formulation Tailoring

Achievement of the required burning rate by utilizing higher burning-rate-additive levels with corresponding lower MA portions of the oxidizer blend was possible because of the improved processing characteristics of ANB-3254 propellant. The data (Figure 17) indicated that a 70/30 SSMP/MA oxidizer blend (same as ANB-3105) with 1.0 wt% of Iron Blue/BRA-101 (1:1 ratio) would provide the target burning rate of 0.67 in./sec at 600 psi.

The ability to utilize a 70/30 SSMP/MA (or even 65/35) oxidizer blend ratio at higher burning-rate-additive levels represents a highly important processing advantage in the production equipment at the Dade County facility. With the 55/45 SSMP/MA blend necessary with ANB-3235, the oxidizer Tote Bin capacity limits the maximum propellant batch size because of the lower bulk density of the final blend. Bulk density measurements indicated that with the 55/45 SSMP/MA blend the maximum propellant batch size would be less than 5000 lb compared to 5500 lb possible with 70/30 or 65/35 SSMP/MA,

II.D. Anhydride-Free Formulation (ANB-3254) (cont)

and would have represented a significant decrease in the output of the vertical mix stations with attendant important cost considerations.

The improvement in processability of the ANB-3254 formulation also enabled a reduction in DOA plasticizer level from 35 to 30 wt% of the binder. The lower plasticizer level tends to improve binder strength, bonding, and propellant and bond age stability.

Elimination of the highly reactive DDS from the propellant binder necessitates inclusion of a polymerization catalyst, ferric acetylacetonate (FeAA), to achieve a steady-state cure in a reasonable length of time. Experience with bayonet casting of ANB-3105 propellant into Motors 260-SL-1 and -2 has indicated that the propellant zero-flow time (related to bayonet submergence) and pot life are optimum with a propellant cure time of 20 to 30 days. The concentration of FeAA yielding the desired cure time was selected on the basis of propellant batches formulated with 0.005 to 0.050 wt% FeAA and tested for cure rate and viscosity buildup.

The cure data (Figure 18) indicate that an FeAA level of 0.010 to 0.015 wt% of the propellant would yield a steady state of cure within the desired 20 to 30 days. Viscosity buildup data (Figure 19) show that at this FeAA level, the viscosity characteristics of ANB-3254 are still significantly superior to either ANB-3235 or ANB-3105.

On the basis of these cure and processing data, six 60-lb batches of ANB-3254 were made to select the DER-332 curing agent levels for processing in the scale-up program at Dade County. The batches were made at DER-332 levels of 100, 105, 110, 113, 116, and 119 equivalents and a 0.01 wt% FeAA level. All of the batches (Figure 20) cured slower than expected. The propellants formulated at 116 and 119 equivalents of DER-332 reached a steady

II.D. Anhydride-Free Formulation (ANB-3254) (cont)

cure state after 30 to 35 days at 135°F while the lower DER-332 containing batches showed continued cure after 40 days at 135°F.

Since these cure rates are not compatible with motor processing requirements, propellant batches containing 0.05 and 0.02 wt% FeAA and 110 and 113 equivalents of DER-332 were prepared to re-examine the relationship between FeAA content and cure and mechanical properties in the larger batch size. Shore A hardness data obtained at 135°F for these batches (Figure 21) show that at 0.05 wt% FeAA, a steady cure state was reached at 8 to 10 days, and at 0.02 wt% FeAA cure was apparently stabilized at 20 to 25 days.

Mechanical properties data from these batches (Figure 22) confirm that steady-state cure was achieved at 10 and 20 days for the 0.05 and 0.02 wt% FeAA levels, respectively. At 113 equivalents of DER-332 and 0.02 wt% FeAA, the propellant initial modulus was 480 to 487 psi. There appeared to be an effect of FeAA level on final mechanical properties as well as cure rate, e.g., at the same 113 equivalents of curing agent, the batch containing 0.05 wt% FeAA exhibited a propellant initial modulus of 656 psi.

The constant strain capability of these propellants is excellent. Even the higher modulus batches which exhibited 18 to 21% elongation withstood greater than 15% applied strain for one week at 77°F.

E. PROPELLANT SCALE-UP AT AEROJET DADE DIVISION

1. First Scale-Up Program

The purpose of the scale-up program at the Dade County Plant was to obtain an early assessment of the processing and cure characteristics of ANB-3254 propellant in production mixing equipment. On the basis of the results of the qualification program conducted by Aerojet, Sacramento, the

II.E. Propellant Scale-Up at Aerojet Dade Division (cont)

propellant scale-up at the Dade facility was designed to evaluate the effects on propellant processing and mechanical properties of DER-332 levels of 113 ± 5 equivalents at 0.015 and 0.02 wt% FeAA. The batch mixing plan (Figure 23) was also designed to evaluate the effect of oxidizer grind ratio and burning - rate-additive level on propellant processability and burning rate.

a. Propellant Burning Rate

The propellant scale-up program at Dade County was initiated during the first week of October 1966. The liquid-strand burning rates of the first four batches (shown below) were lower than expected on the basis of the results of small-scale batches cast at the Sacramento facility.

<u>Batch</u>	<u>Oxidizer Blend</u> <u>SSMP/MA</u>	<u>BRA</u> <u>Wt%</u>	<u>Average</u> <u>LSBR at 600 psig,</u> <u>in./sec</u>
441	70/30	0.9	0.604
443	70/30	0.9	0.606
442	65/35	0.9	0.644
444	65/35	0.9	0.636

Since the vertical batch mix data indicated that the nominal target burning rate could not be achieved at reasonable BRA levels with an oxidizer blend of 70/30 SSMP/MA, the mixing plan was revised (Figure 24) and all subsequent batches were made with an oxidizer blend of 65/35 SSMP/MA. Using this blend ratio, the target burning rate was achieved with 1.3 wt% BRA. A summary of the burning rates from all batches is as follows:

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II.E. Propellant Scale-Up at Aerojet Dade Division (cont)

AP Blend	BRA Wt%	No. Batches	"Scoop" Samples From Top of Mix Bowl		Cast Samples		
			$\bar{x}$	Pot - Pot Std. Dev.	$\bar{x}$	Pot Std. Dev.	Pot - Pot Std. Dev.
70/30	0.9	2	0.604	-	0.605	0.0024	-
65/35	0.9	2	0.641	-	0.640	0.0020	-
65/35	1.3	6	0.676	0.0088	0.670	0.0020	0.0069

To minimize possible variability of burning rates caused by the use of oxidizer from two sources (GFM PEPCON and HEF residual) the decision was made to reserve the HEF material for use in the SSMP (coarser) fraction of the blend only, while the PEPCON material would be used in either fraction. However, the HEF oxidizer was used in both fractions for batches B-452 through B-454; therefore, the burning-rate data from these batches have not been included in the summary. The various lots of aluminum powder (also GFM, from Englehardt, Ind.) were blended during premix make-up by selection of the proper number of drums from each lot.

b. Premix and Uncured Propellant Analyses

The acceptance tests for the submix, premix I, and premix II are essentially the same as those for the ANB-3105 intermediates. The submix (PBAN, DOA and L-45) is tested for acid equivalents and refractive index (which serve to control the composition), moisture, and ash content. The premix I (submix and burning-rate additives) is tested for density and ash. Both tests control the BRA content with the theoretical ash content being based on composite sampling and testing of the Iron Blue and BRA-101 separately. Premix II (premix I and aluminum) is examined for density, moisture, and gas content. The premix II density is an excellent control for solids content and the gas measurement limits the amount of non-condensable gases that could be

II.E. Propellant Scale-Up at Aerojet Dade Division (cont)

liberated during vacuum mixing of the propellant and make propellant deaeration more difficult.

A summary of all premix and uncured propellant acceptance analyses from the first scale-up program is presented in Figures 25 and 26. All measured values agree well with theoretical or predicted values.

c. Cure and Mechanical Properties

Shore A hardness data for the vertical mix batches (Figure 27) indicate that none of the batches reached a satisfactory state of cure within a reasonable length of time. The data also indicate a relationship between BRA level and cure behavior since all of the batches made at 0.9 wt% BRA showed a measurable Shore A hardness at 135°F while only one of the 1.3 wt% BRA batches cured sufficiently to yield a measurable hardness.

Additional small scale batches made at Aerojet, Sacramento (Figure 28) showed that at the 1.3 wt% BRA level, an FeAA concentration of 0.03 wt% was required to effect a satisfactory cure. These batches were prepared by procedures simulating as closely as possible those used at the Dade facility. A total premix was prepared containing FeAA at the 0.015% level, and increasing concentrations of FeAA (up to 0.04% total) were obtained in the propellant by adding additional FeAA (dry) directly to the batch.

2. Second Scale-Up Program

Based on the cure data from the batches made at Sacramento, additional vertical batch mixes were prepared at Dade County using FeAA concentrations of 0.03, 0.045, and 0.06 wt% total. The premix was prepared with

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II.E. Propellant Scale-Up at Aerojet Dade Division (cont)

0.03 wt% FeAA and higher levels obtained by the addition of FeAA directly to the mixer. DER-332 curing agent levels of 110 and 115 equivalents were also evaluated.

a. Propellant Burning Rate

Liquid-strand burning-rate data from five of the six vertical batch mixes were consistent with results from the 1.3 wt% BRA batches made during the first scale-up program. The first batch made in the second scale-up program exhibited an unexplained low burning rate of 0.645 in./sec. A summary of the liquid strand burning rates from the other five batches is shown below:

Ratio, SSMP/MA	Wt% BRA	No. Batches	"Scoop" Samples		Cast Samples		
			$\bar{x}$ in./sec	Pot - Pot Std. Dev.	$\bar{x}$ in./sec	Within Pot Std. Dev.	Pot - Pot Std. Dev.
65/35	1.3	5	0.674	0.0062	0.670	0.0018	0.0065

b. Premix and Uncured Propellant Analyses

A summary of all premix and uncured propellant acceptance analyses from the second scale-up program is presented in Figures 29 and 30. All measured values agree well with theoretical or predicted values.

c. Cure and Mechanical Properties

Cure data from the Dade County batches (Figure 31) showed that the batches at the two higher FeAA levels cured rapidly; however, mechanical properties tests (Figure 32) show that the state of cure stabilized at a level below the target initial modulus (500 ± 100 psi). The highest initial modulus achieved was slightly greater than 400 psi.

II.E. Propellant Scale-Up at Aerojet Dade Division (cont)

Concurrent with the second scale-up program, work was conducted at Sacramento to define the cause of this anomalous cure behavior. A possible mechanism by which FeAA could be degraded during storage in the premix is hydrolysis resulting from the relatively high concentrations of moisture brought into the premix by the burning rate additives (up to 5 wt% water is present in both Iron Blue and BRA-101 "as received"). Experimental confirmation of this was obtained by vacuumizing a premix sample to which moisture had been added and entrapping the volatiles withdrawn. Acetyl acetone, the hydrolysis product of FeAA, was positively identified among these entrapped volatiles.

The action of moisture in the propellant also explains the apparent differences in cure behavior between propellant made at Sacramento and at Dade County. The increased propellant head in the Dade County mixers also limits the amount of vacuum "seen" by the propellant in the mix bowl. As a result, moisture present in the premix (or propellant) is readily removed during the vacuum mix cycle at the Sacramento facility. Confirmation of this was obtained by actually measuring the moisture contents of propellants made at both Aerojet facilities. The data (Figure 33) show that the propellant made in Dade County retains four times as much moisture (0.048 vs 0.017 wt%) as the propellant made in Sacramento.

Drying of burning-rate additives Iron Blue and BRA-101 was considered as a possible way to eliminate this problem, but unlike Fe_2O_3 (used in ANB-3105), these materials contain a large amount of water (up to 5 wt%) which could be removed only by severe drying conditions (Figure 34). Furthermore, as shown, both compounds rapidly regain moisture even under conditions of low relative humidity. For these reasons, this approach was considered impractical.

II.E. Propellant Scale-Up at Aerojet Dade Division (cont)

Addition of FeAA dry to the mixer could not be a satisfactory production process. In addition to introducing quality control problems, dry addition was completely incompatible with the continuous mix process which was being planned as a backup to the vertical mixers for casting of Motor 260-SL-3.

The most desirable alternative method of FeAA addition was in solution with the DER-332 curing agent. The FeAA is readily soluble in DER-332 and extensive peripheral tests indicated that no degradation of either material occurred during storage of the solution. Furthermore, a simple colorimetric test was developed which accurately measured the concentration of FeAA in DER-332 and provided adequate in-process control of this important parameter.

A series of small-scale propellant batches was made in which the FeAA was added in solution with the DER-332 curing agent. The data (Figures 35 and 36) indicate that reliable and reproducible cures, which are not affected by premix storage time or by storage of the DER-332/FeAA solution, are obtained.

F. RAW MATERIAL LOT QUALIFICATION AT AEROJET DADE DIVISION

1. Lot 4 Pre-Qualification Program

To provide an early confirmation of the alternative method of FeAA addition in production equipment, and to define the relationship between FeAA concentration and curing agent level a pre-qualification program was undertaken at the Dade County facility. Six vertical mix batches prepared during the week of 21 November 1966 at Dade County confirmed that addition of the FeAA cure catalyst in solution with the DER-332 curing agent was effective in eliminating the possibility of catalyst degradation and also provide

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II.F. Raw Material Lot Qualification at Aerojet Dade Division (cont)

improved control of FeAA concentration. The batches (batch numbers are shown) were prepared according to the following mix plan:

DER-332 Equivalents	FeAA Concentration, Wt%		
	<u>0.02</u>	<u>0.032</u>	<u>0.045</u>
115			B-461
120		B-463	B-462
125	B-465	B-464	
130	B-466		

Confirmation of the colorimetric method for determination of FeAA concentration in the DER-332 solution was obtained, and analyses of each solution made up for the pre-qualification batches (Figure 37) indicate close agreement with theoretical values.

a. Propellant Burning Rate

Liquid-stand burning rates from the six vertical batch mixes averaged slightly higher than those obtained in the scale-up programs. Burning-rate variability was also somewhat greater. It is possible that both effects were due to small oxidizer agglomerates which were observed in the propellant. The presence of these agglomerates was attributed to exceeding the storage life of the ground and blended oxidizer. A summary of the burning-rate data is shown below:

Blend SSMP/MA	Wt% BRA	No. Batches	"Scoop" Samples		Cast Samples		
			$\bar{x}$ in./sec	Pot - Pot Std. Dev.	$\bar{x}$ in./sec	Within Pot Std. Dev.	Pot - Pot Std. Dev.
65/35	1.3	6	0.686	0.0117	0.683	0.0020	0.0089

II.F. Raw Material Lot Qualification at Aerojet Dade Division (cont)

b. Premix and Uncured Propellant Analyses

A summary of all premix and uncured propellant acceptance analyses from the pre-qualification batches is given in Figures 38 and 39. All measured values agree well with theoretical or predicted values.

c. Cure and Mechanical Properties

The mechanical properties of these batches as a function of cure time at 135°F (Figure 40) show that one batch at each FeAA level achieved the target 500 ± 100 psi initial modulus. The constant strain capability of these propellant batches (Figure 41) continued to be greater than observed for ANB-3105. All batches (tested after 24-day cure) exhibited a minimum constant strain capability of 20% compared to approximately 12% for ANB-3105. Based on 20 to 24 day cure data for these batches, the formulation selected for processing in the Lot 4 Raw Material Qualification Program at Dade County was based on a DER-332 curing agent equivalents level of 130 with an FeAA concentration of 0.032 wt%.

d. Bond to SD-850-2 Liner

Bond tests of these batches of ANB-3254 propellant to SD-850-2 liner show excellent bonding characteristics (Figure 42). All bond specimens, both tensile and shear, failed at random within the propellant, indicating bond strength in excess of the cohesive strength of the propellant.

e. Pre-Qualification, Aerojet Solid Rocket Operations

To establish a correlation between cure of propellant made at Sacramento and Dade County, four 60-lb propellant batches were made at Sacramento to duplicate the lower (0.020 and 0.032 wt%) FeAA levels of the

II.F. Raw Material Lot Qualification at Aerojet Dade Division (cont)

Dade facility pre-qualification batches. The mechanical properties of these batches (Figure 43) indicated that the properties of the propellant made by the Sacramento facility were in better agreement with the propellant made by the Dade facility as a result of using the FeAA/DER-332 solution addition method. Although the data from one of these batches (66-969 at 0.02% FeAA and 130 equivalent DER-332) appear to be anomalous (possibly an undetected dispensing error), the remaining batches, within normal batch-to-batch variations, appeared to approach the same moduli as the corresponding Dade County batches.

2. Lot 4 Raw Material Qualification Program

The Lot 4 Raw Material Qualification Program was conducted at the Dade facility during the last two weeks of December 1966. The objective of the program was to provide data to select the specific formulation to be cast into Motor 260-SL-3. Although it was planned to use only the vertical batch mixers to cast the motor, the continuous mix facility was also to be qualified with the ANB-3254 formulation to provide standby mixing capability in the event that both vertical mixers went off stream simultaneously.

a. Qualification in Vertical Batch Mixers

The mixing plan for the vertical mix Raw Material Qualification program at Dade County is shown below:

<u>Oxidizer Blend Storage Time, Days</u>	<u>Oxidizer Source</u>	
	<u>All PEPCON</u>	<u>HEF (SSMP only)</u>
1	B-468*, B-469*	B-467, B-470
5	B-471	B-472

* Batches B-468 and B-469 used to cast 44-in.-dia subscale motor.

II.F. Raw Material Lot Qualification at Aerojet Dade Division (cont)

In addition to obtaining ANB-3254 reproducibility data, a determination of the effect on burning rate of the useage of residual HEF oxidizer in the SSMP fraction was obtained. The effect of oxidizer blend storage time was evaluated because a number of small oxidizer agglomerates had been observed in the pre-qualification propellant batches which were made with oxidizer blends stored approximately 5 to 6 days.

(1) Propellant Burning Rate

The comparison of the liquid-strand burning rates of propellants made with HEF and PEPCON oxidizers (Figure 44) shows that statistically the burning rates are not significantly different, and that HEF and PEPCON ammonium perchlorate can be used interchangeably in the SSMP fraction of the oxidizer blend. The batch-to-batch variation of the burning rates are consistent with previous experience.

Visual observation of the propellant indicated that the occurrence of oxidizer agglomerates was significantly reduced by the use of fresher oxidizer blends and by heat tracing of the oxidizer feed chute.

A summary of the liquid-strand burning-rate data from all Dade County batches is given in Figure 45. The data show that the "scoop" samples to be used for batch qualification during the motor casting are statistically representative of the entire batch. Based on these data, the target mean LSBR for the motor was set at 0.680 in./sec at 600 psig with a tolerance of ± 0.03 in./sec.

A summary of all burning rates from Dade County batches for which 3KS-500 size and Crawford Bomb motor data are available (Figure 46) shows good agreement between LSBR and 3KS-500 motor data (0.684 vs

II.F. Raw Material Lot Qualification at Aerojet Dade Division (cont)

0.690 in./sec, respectively) for the 1.3 wt% BRA batches. Crawford Bomb motor data appear to be more consistent with 3KS-500 data over the entire range of burning rates.

(2) Premix and Uncured Propellant Analyses

A summary of the premix and uncured propellant acceptance analyses from the qualification program is shown in Figures 47 and 48. All measurements agree well with theoretical or predicted values.

(3) Cure and Mechanical Properties

Mechanical properties data from the vertical batch mixes of qualification propellant (Figure 49) indicate that the DER-332 curing agent level used was slightly high. Based on these data as well as additional cure data subsequently available from the pre-qualification program, the formulation selected for casting into Motor 260-SL-3 was based on 125 equivalents of DER-332 with 0.032 wt% FeAA.

(4) Bond Strength of Qualification Propellant to SD-850-2 Liner

The bond strength to SD-850-2 liner of ANB-3254 propellant prepared from each of the six batches of qualification batches is given in Figure 50. All samples failed at random within the propellant indicating a bond strength in excess of the cohesive strength of the propellant. These results are similar to those obtained with the ANB-3105 propellant used in Motors 260-SL-1 and -2.

II.F. Raw Material Lot Qualification at Aerojet Dade Division (cont)

b. Qualification of the Continuous Mixer at Dade County

Efforts were made to qualify the continuous mix facility at Dade County during the week of 26 December with a planned 9 to 10 hour run. The attempt was unsuccessful because of the excessive thixotropy of the ANB-3254 propellant before deaeration. In the UK-200 continuous mixer, the mixed (but unvacuumized) propellant discharges from the mixer outlet into a surge pot which is open to the atmosphere. Normally the propellant feeds by gravity (and vacuum) into a Rotofeed deaerator where it is thoroughly degassed and pumped into the loading area. The mixed (but unvacuumized) ANB-3254 would not flow properly from the surge pot to the Rotofeed. Channeling occurred continually through the pot and Rotofeed inlet line which degraded the vacuum in the Rotofeed and prevented further flow. This problem was attributed to the large amount of very high surface burning rate additives in the formulation which do not become wetted (with binder) until the propellant is deaerated.

III. PROCESSING STUDIES

A. PROPELLANT

1. Propellant-To-Propellant Bond

To ensure that an unavoidable interruption in the casting of Motor 260-SL-3 would not result in a propellant-to-propellant bond problem when casting was resumed, an interrupted casting situation was simulated during the qualification program at the Dade facility. Sample cartons were cast half-full from each of the first two batches (B-467 and B-468) and held at 135°F for three days. The cartons were then filled with propellant from the last two batches (B-471 and B-472) and cured for 24 days at 135°F. Mechanical properties specimens from each carton containing the batch-to-batch

III.A. Propellant (cont)

interface were prepared and tested at 77°F. The data (Figure 51) indicate that a slight reduction in elongation results. It is not expected that this change would have any effect on the motor grain integrity.

2. Zero-Flow Time

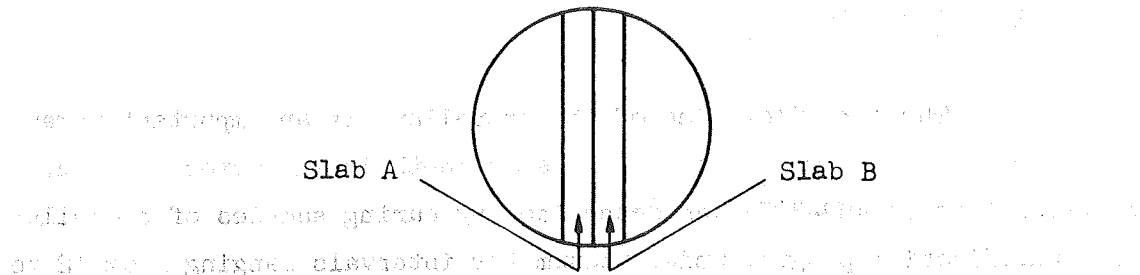
The zero-flow time of the propellant is an important parameter in establishing maximum bayonet immersion depth during motor casting. The zero-flow time of ANB-3254 was determined by curing samples of propellant from the qualification program under vacuum for intervals ranging from 12 to 120 hours followed by a normal ambient pressure cure of 24 days. By sectioning the cured propellant and examining the void content, it can be determined at what length of time the voids formed by the vacuum environment fail to collapse when the vacuum is removed (zero-flow time). Two sets of sample cartons were tested in this manner. One set was bayonet cast (standard technique) and the other set was "ribbon" cast to intentionally introduce voids. After cure, the cartons were sectioned and examined for void content. The zero-flow time was clearly established as 72 to 96 hours for both sets of cartons. This compares with approximately 84 hours for ANB-3105. On the basis of these data and on experience in casting Motors 260-SL-1 and -2, the bayonet immersion depth for Motor 260-SL-3 has been limited to 48 in. or 24 hours, whichever occurs first.

3. Mechanical Properties Variability

Mechanical properties data from the scale-up and Qualification Program at the Dade facility showed significantly higher variability, both within carton and carton-to-carton, than had been observed for ANB-3105 propellant. The cause of this variability in ANB-3254 propellant appears to be the location of the tensile specimens in the one-half gallon sample cartons of cured propellant. Sample cartons from each of the eight batches of

III.A. Propellant (cont)

propellant made at Dade County during the pre-qualification program were tested to determine the profile of tensile properties from one edge of the carton to the other. Two 1-in.-thick slabs were cut from the cartons longitudinally as close to the center of the carton as possible:



Each slab was then cut into Instron tensile specimens (seven per slab) and tested to establish the profile. Of the eight cartons tested, only two showed equivalent mechanical properties from one edge of the slab to the other. The remaining cartons showed significantly lower moduli at the center of the carton than at the edges. A typical profile of this type is shown in Figure 52. Development work conducted on ANB-3105 propellant under Contract NAS3-6284 and development work on other propellant formulations indicated that flow orientation might affect tensile properties. Therefore, it is probable that the phenomenon illustrated in Figure 52 is directly related to flow orientation effects introduced during bayonet casting of the carton. To minimize this source of variability of measured properties, the Instron specimens were taken from the center of the carton for mechanical properties tests of propellant cast into Motor 260-SL-3.

4. Explosive Hazard Classification

A summary of the I.C.C. hazard classification tests of ANB-3254 propellant is presented in Figure 53. In addition to the test performed at Aerojet, Sacramento, samples of propellant made at the Dade facility were shipped to the Bureau of Explosives for testing. On the basis of these tests, the Bureau assigned an I.C.C. shipping classification of "B" to ANB-3254 propellant.

III.A. Propellant (cont)

5. Effect of Ambient Temperature Storage

To confirm that continued cure of ANB-3254 does not occur after the propellant is cooled to ambient temperature from the 135°F cure condition, samples from Batch B-473 were stored at +77°F for 8 to 16 days after a 26-day cure at 135°F. The data (Figure 54) show that no change in propellant mechanical properties occurred during this ambient temperature storage period.

B. BONDING SYSTEM

1. Liner Bonding Life

To confirm that the bonding life (length of time liner may be held prior to cast) of the ANB-3254/SD-850-2 bonding system was adequate for the expected storage time of the lined 260-SL-3 chamber, propellant from Batch B-469 was cast against samples of SD-850-2 liner which had been stored for up to 35 days at 135°F. The bond tensile and shear strengths measured on these samples are shown below:

<u>Liner Storage Time at 135°F, days</u>	<u>Bond Strength at 77°F, psi</u>	
	<u>Tensile</u>	<u>Shear</u>
15	138	112
30	147	102
35	136	92

The majority of the samples failed within the propellant (cohesive failure). These data are similar to the ANB-3105 results and indicate the bonding life of the liner is satisfactory for the intended storage period of the motor after lining.

III.B. Bonding System (cont)

2. Effect of Propellant Surface Age on Bond Strength

During bayonet casting of Motor 260-SL-3, the age of the propellant surface contacting the liner varies depending on casting rate and bayonet submergence. To determine if propellant age (up to 24 hours, which corresponds to the maximum time between bayonet changes) would affect bonding, an experiment was conducted to evaluate the effect of propellant surface age on bond strength. Propellant was cast into a shallow box and allowed to stand undisturbed at 135°F for up to three days. At intervals of 0, 1, and 3 days, the box was inverted over a piece of V-44 rubber lined with SD-850-2 and cured in this position for 24 days. The results of this experiment are shown below:

<u>Propellant Surface Age, days</u>	<u>Bond Strength at 77°F, psi</u>	
	<u>Tensile</u>	<u>Shear</u>
0	132	101
1	108	-
3	101	-

All failures were cohesive within the propellant. On the sample aged for 3 days there was evidence of incomplete wetting of the liner by the propellant. Since this test is more severe than would be expected in the motor where the propellant actually flows outward and upward against a vertical liner surface, it appears that the bondability of the liner-propellant system under these conditions is compatible with the 24-hour limitation on bayonet change.

IV. MECHANICAL PROPERTIES CHARACTERIZATION

To provide engineering data for comparison of the mechanical properties of ANB-3254 propellant with the stress analysis of the 260-SL-3 motor grain design, mechanical properties characterization tests were conducted on

IV. Mechanical Properties Characterization (cont)

representative samples of ANB-325⁴ propellant. The data (Figure 55) compare favorably with results of similar tests of ANB-3105, and indicate that all motor requirements are easily achieved.

V. PROCESSING OF MOTOR 260-SL-3

A. PREPARATION OF INERT SLIVERS

The inert slivers used in Motor 260-SL-3 to provide improved tail-off characteristics were made from a castable insulation recently developed by Aerojet. This material, designated IBC-101, is a PBAN-epoxy material (similar to SD-850-2) filled with asbestos, Sb_2O_3 , and carbon black. The proposed process for sliver preparation was demonstrated at Sacramento using a short length of a simulated full-scale cross-section mold. A 300-lb vertical batch mix of IBC-101 was prepared and cast into the mold, cured, stripped, and sectioned. Mold filling was complete and the cured insulation showed a negligible void content. The selected mold release, a silicone polymer, performed satisfactorily.

A total of six 2500-lb vertical mix batches of castable insulation IBC-101 was successfully mixed at the Dade facility and cast into molds to fabricate the inert slivers for Motor 260-SL-3. All batches cured normally and stripped easily from the molds. Uncured insulation acceptance data from each of these batches (Figure 56) show that all measured values were well within specification limits.

B. LINING OF MOTOR 260-SL-3

The 260-SL-3 chamber was lined on 16 and 17 January 1967. The liner application procedure was identical to that used on Motors 260-SL-1 and -2. The liner was spread using a specially designed trowel with thickness

V.B. Lining of Motor 260-SL-3 (cont)

controlling wire spacers. The marks left by the spacers were then brushed out leaving a smooth surface. A total of 933 lb of SD-850-2 liner was applied to the interior of the chamber including the inert slivers. This compares to approximately 910 lb of liner material applied to each of the first two 260-in.-dia chambers. On the basis of chamber area the liner weight corresponds to an average thickness of 33 mils compared to the target requirement of 35 ± 10 mils.

Three 420-lb batches of liner were prepared and qualified for use. A summary of the uncured liner acceptance tests of these batches (Figure 57) shows that each batch was well within specification limits.

C. CASTING OF MOTOR 260-SL-3

Casting of the 260-SL-3 propellant grain was initiated at the Dade facility 13 February 1967, and operations were continued on a 3-shift 7-day basis until the casting was completed on 2 March. A total of 319 vertical mixer batches, each containing 5500 lb of ANB-3254 propellant, was qualified and cast into the motor. Fourteen batches failed to meet acceptance criteria and were scrapped. The motor average values for propellant burning rate, density, and DER-332 curing agent content (presented below) were very close to target requirements:

	<u>Motor Average</u>	<u>Target Mean and Specification Limits</u>
Liquid Strand Burning Rate at 600 psig, in./sec	0.682	0.680 ± 0.030
Liquid Density, gm/ml	1.746	1.747 ± 0.007
DER-332 Content, wt%	1.20	1.19 ± 0.12

V.C. Casting of Motor 260-SL-3 (cont)

The initial propellant production rate was below normal because of excessive oxidizer addition times on several of the first batches. This problem was caused by improperly installed vibrators in the oxidizer addition system on both vertical batch mixers. Correction of the vibrator installation problem resulted in achievement of normal batch-cycle times.

The overall 260-SL-3 casting operation was smooth and uneventful. The flow characteristics of ANB-3254 propellant during bayonet casting were comparable with those of the ANB-3105 propellant cast into Motors 260-SL-1 and -2. The propellant-to-liner contact in 260-SL-3 appeared to be excellent, and should result in high bond strengths. Summary plots of propellant liquid-strand burning rate, density, and DER-332 content as well as the ten-pot running average LSBR are presented in Figure 58.

1. Propellant Burning Rate

During the early portion of the propellant mixing run, the average batch burning rate was close to the desired mean value of 0.680 in./sec. However, after about 45 batches had been mixed, the batch burning rates began to increase. After 76 batches had been qualified, the burning rates had increased to a point where the 10-batch running average was outside the prescribed range of 0.665 to 0.695 in./sec. Since it was apparent that a shift in the mean propellant burning rate had occurred, the burning rate was reduced by adjusting the burning-rate additive concentration from 1.3 to 1.2 wt%. The 10-batch running average returned to within the target range after six batches; however, the burning rate continued to fluctuate in a random cyclic manner. Although the lower additive level was in usage, the 10-batch average burning rate drifted out of range on two occasions during the next 35 batches. Since the response of propellant burning rate to changes in BRA content was slow due to the large (12,000 lb) premix batch size, it was decided to adjust the oxidizer blend ratio on a batch-to-batch basis to maintain

V.C. Casting of Motor 260-SL-3 (cont)

the propellant burning rate in the required range for the remainder of the run. By varying the oxidizer blend ratio (as necessary) between 65/35 and 70/30 SMP/MA, fluctuations in the burning rate trend were compensated. After this control was initiated, the 10-batch running-average burning rate was outside of the desired range only twice.

Although the 260-SL-3 propellant burning rate variability is greater than that obtained in Motors 260-SL-1 and -2, the 10-batch running-average burning rate in Motor 260-SL-3 was within the target range for more than 95% of the run.

The cause of these unexpected burning rate fluctuations is not definitely known; however, the nature of the problem indicates that blending of the unground PEPCON oxidizer was nonhomogeneous. Statistical analyses of the ground and unground oxidizer acceptance test data indicate that this should, in fact, represent a source of variability. Despite burning-rate data obtained during the Raw Material Qualification Program (Figure 44), which indicated no difference between HEF and PEPCON oxidizer, statistical examination of the screen analyses (Figure 59) shows that significant differences exist in both the ground and unground materials. Furthermore, the SSMP ground PEPCON oxidizer shows a marked difference in fines content (-325 mesh screen) between the first 135 grinds and the last 167 grinds.

Limited data (Figure 60) suggest that a possible reason for these effects is the increased friability of the PEPCON oxidizer, i.e., fracturing of the crystal during grinding may be more variable as well as produce a different particle size distribution when compared with oxidizer from another source.

One possible source of LSBR variability in any propellant containing a burning rate additive is variability in the amount of the

V.C. Casting of Motor 260-SL-3 (cont)

additive. An examination of the measured variability of the premix I density (the best available measure of BRA concentration) during the casting of 260-SL-3 and correlation with the maximum resultant variation in BRA concentration (Figure 61) indicates that the maximum LSBR variability attributable to this source is only ± 0.01 in./sec. Since the actual LSBR variability was greater than ± 0.03 in./sec, it appears that BRA concentration is not a major factor in the observed burning rate fluctuation. The Iron Blue and BRA-101 used in the propellant for Motor 260-SL-3 were received as several lots but were blended prior to or during premix make-up. This would appear to eliminate lot-to-lot variability of catalytic activity as being responsible for burning-rate variability.

2. Premix and Uncured Propellant Analyses

A summary of the premix and uncured propellant acceptance analyses is presented in Figure 62. Forty-seven 12,000-lb premix batches were prepared, 14 at the 1.3 wt% BRA level and 33 at the 1.2 wt% BRA level. All premix batches were qualified for use.

3. Cure and Mechanical Properties

Mechanical properties tests are in process on samples from every sixth propellant pot mixed for Motor 260-SL-3. This represents a total of 56 batches being tested for tensile properties after 12, 16, 20, 24, 28, 32, and 40 days of cure at 135°F. The testing is complete through 32 days with partial results at 36 and 40 days. The data (Figure 63) indicate a slightly slower propellant cure rate than had been anticipated. Selection of tensile bar specimens from the center of the sample carton for the reasons discussed in Section III, A, 3, may have contributed to the apparent lower propellant modulus. It was shown that this practice should yield more uniform results but a somewhat lower modulus.

V.C. Casting of Motor 260-SL-3 (cont)

A graph of propellant initial modulus as a function of cure time (Figure 64) indicates that the cure has started to stabilize and will probably be terminated when the last batch cast has been cured for 36 days. This would yield an overall motor average propellant modulus of about 440 to 450 psi.

4. Liner Bond Data

SD-850-2 liner bond test specimens (prepared from the same material used to line Motor 260-SL-3) were cast with ANB-3254 propellant from every twelfth batch prepared for the motor. Cure times on these samples ranged from 24 to 40 days at 135°F. The test results were as expected, i.e., all samples failed at random within the propellant indicating a bond strength in excess of the cohesive strength of the propellant:

	<u>Bond Strength at 77°F, psi</u>	
	<u>Tensile</u>	<u>Shear</u>
Mean (n = 28)	158	104
Std. Dev.	17.5	11.5

VI. CONCLUSIONS

The objectives of the propellant tailoring program for Motor 260-SL-3 were achieved with propellant formulation ANB-3254. Propellant ANB-3254 exhibits adequate mechanical and bonding properties margins compared to the calculated structural requirements for the 260-in.-dia-motor grain. The suitability of the propellant processing characteristics was confirmed during the successful casting of Motor 260-SL-3. Although the propellant burning-rate variability for Motor 260-SL-3 is greater than that of Motors 260-SL-1 and -2, the 10-batch running-average burning rate of Motor 260-SL-3 was within

VI. Conclusions (cont)

the target range for more than 95% of the casting process. While this variability will be considered in the prediction of motor performance, the effects will be minor. The higher burning rate variability is attributed to within-lot oxidizer variability. Preliminary data indicate that cure of the Motor 260-SL-3 grain is normal and that the average propellant initial modulus will be well within the target range of 400 to 600 psi.

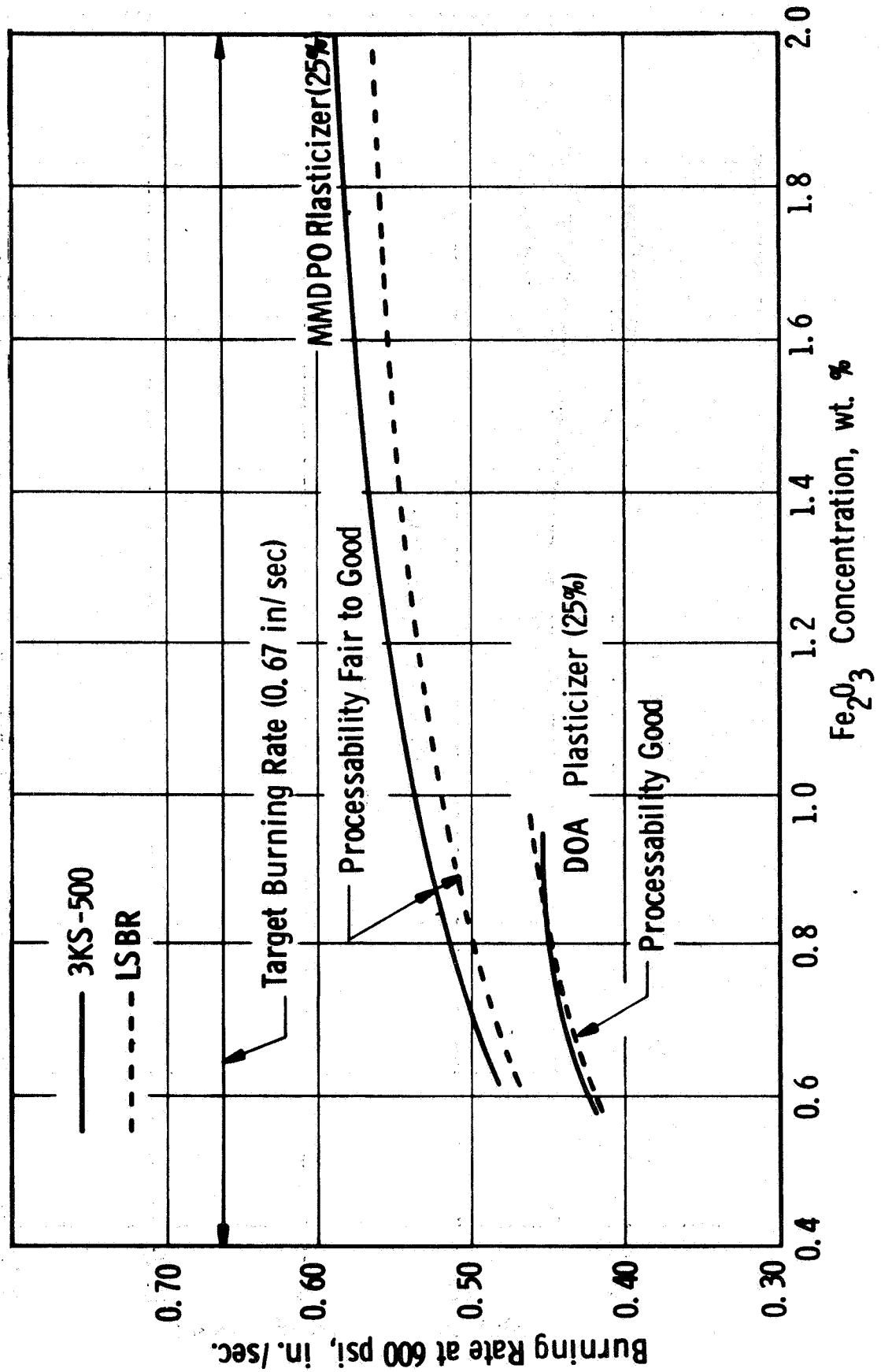
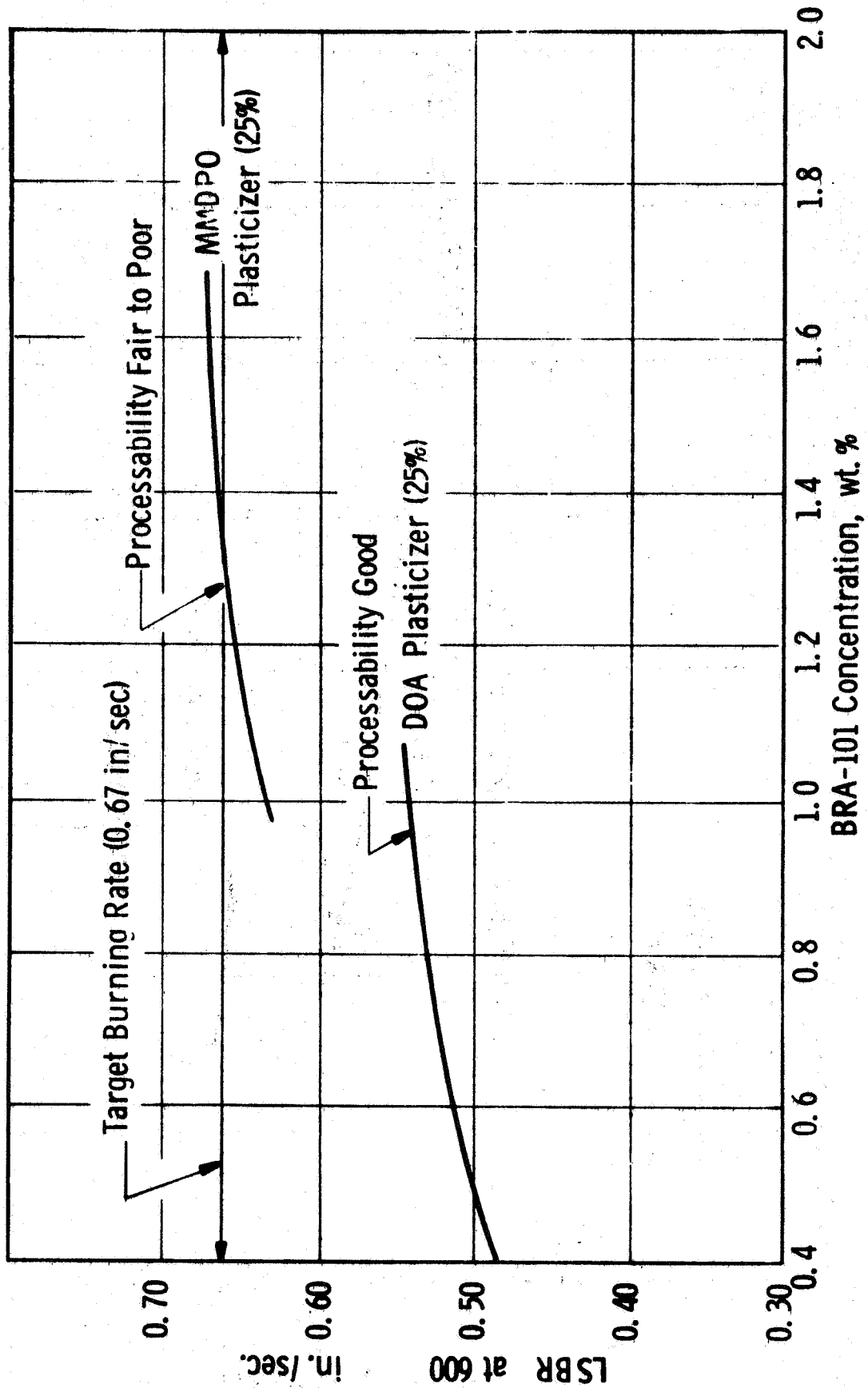


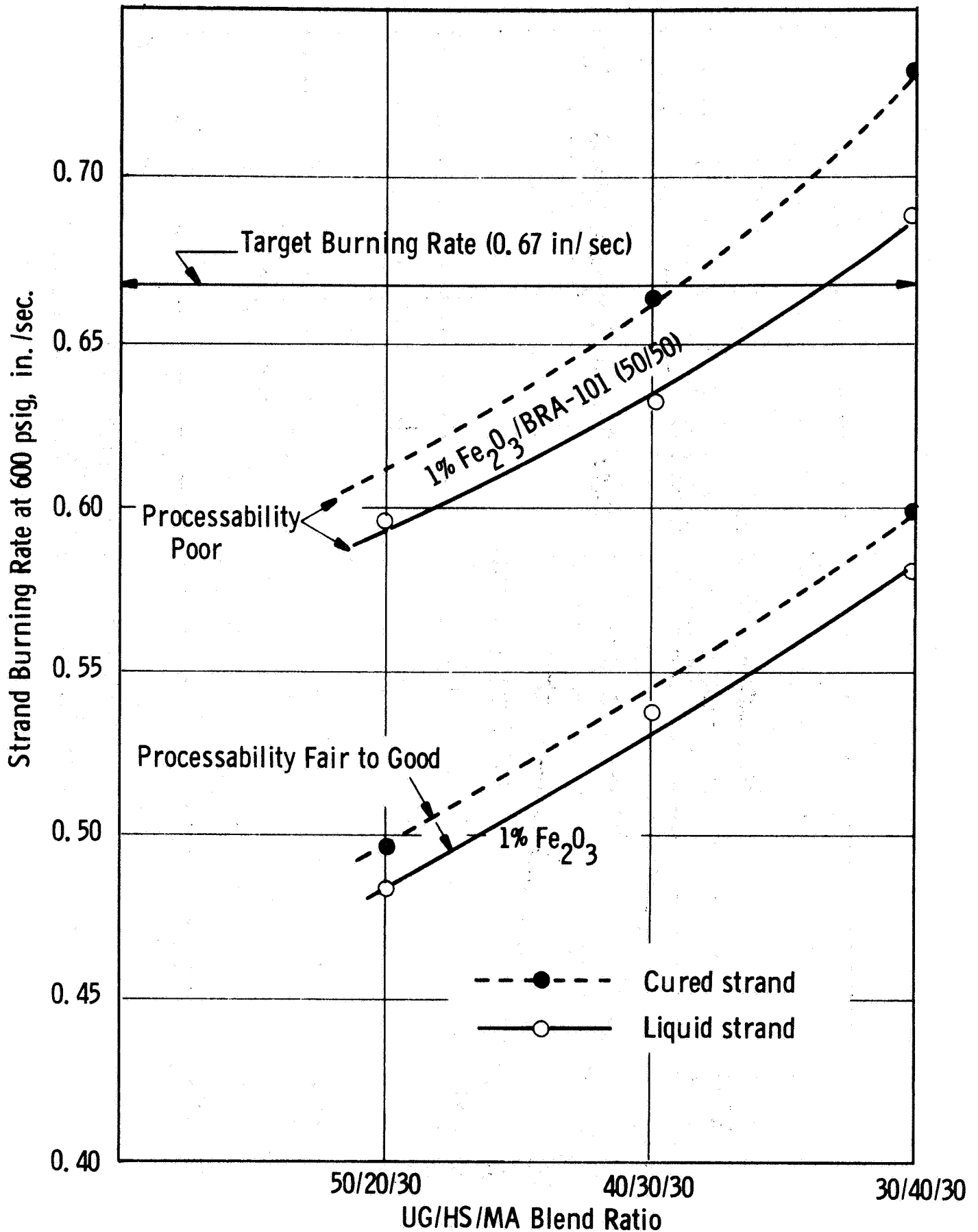
Figure 1

Effect of Fe_2O_3 Concentration and Plasticizer Type on Burning Rate of ANB-3105 Type Propellant

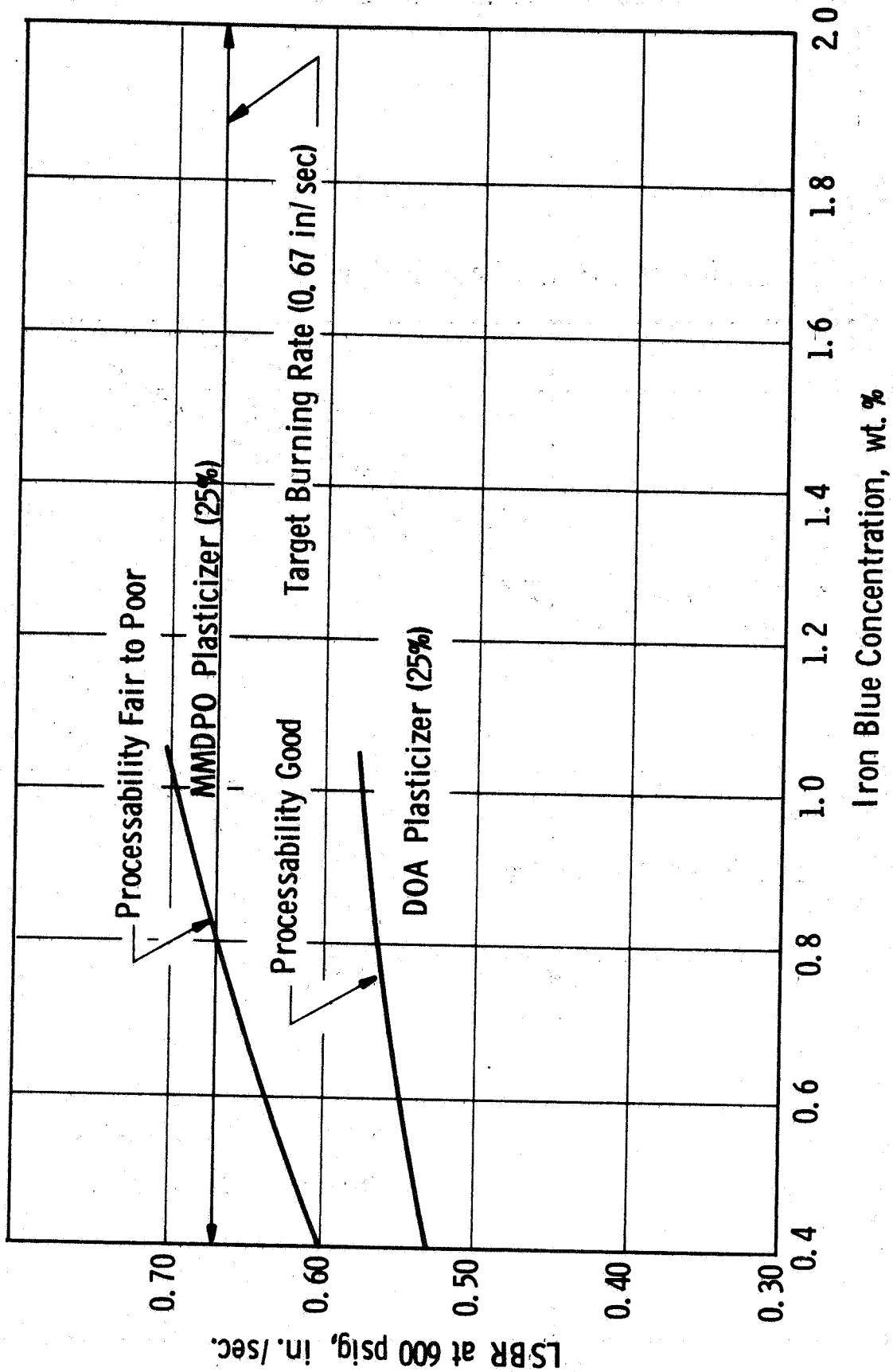


Effect of BRA-101 Concentration and Plasticizer Type on LSBR of ANB-3105

Figure 2

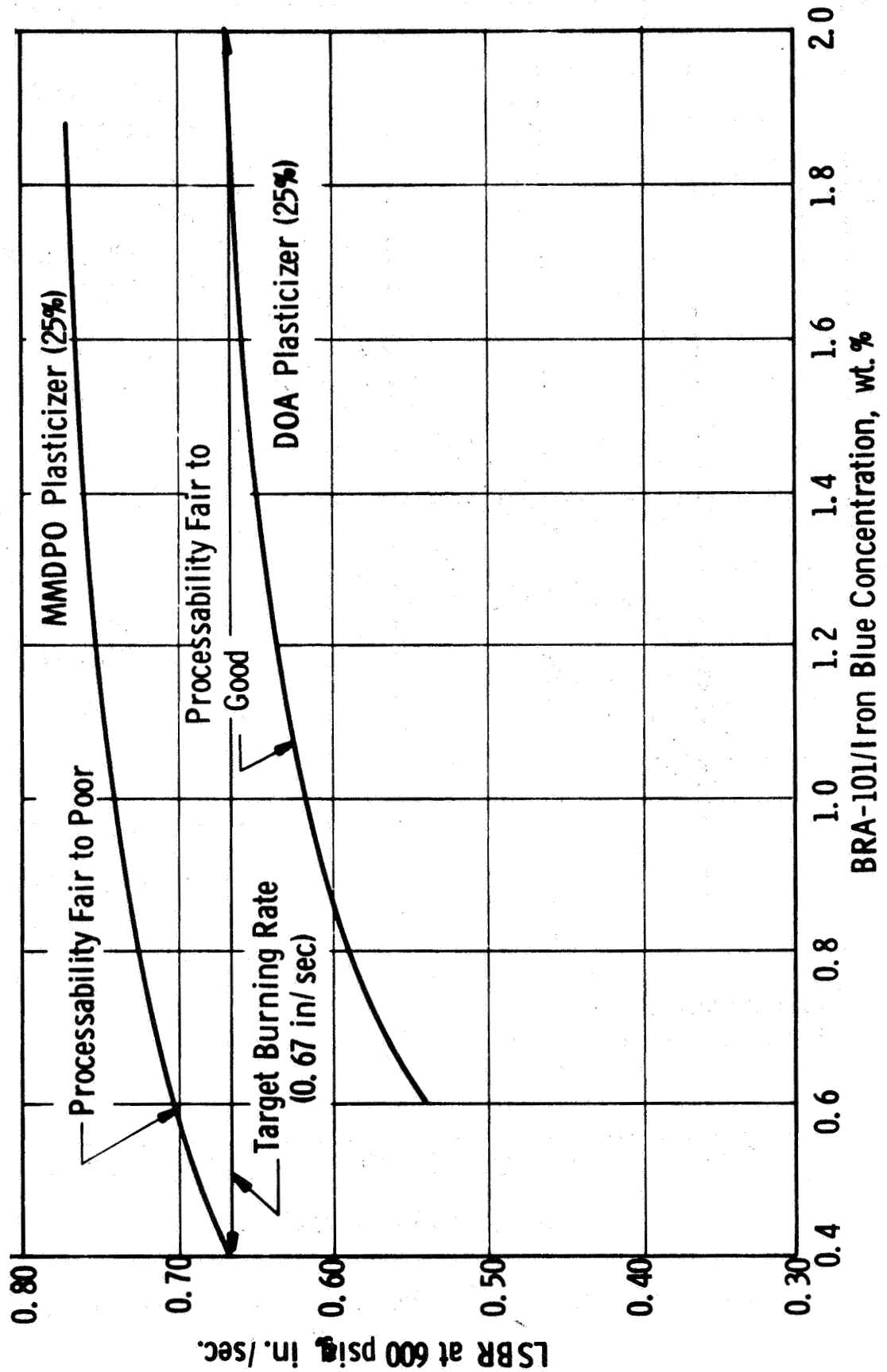


Effect of UG/HS/MA Ratio on Strand Burning Rate
(1% Burning Rate Additive, DOA Plasticizer)



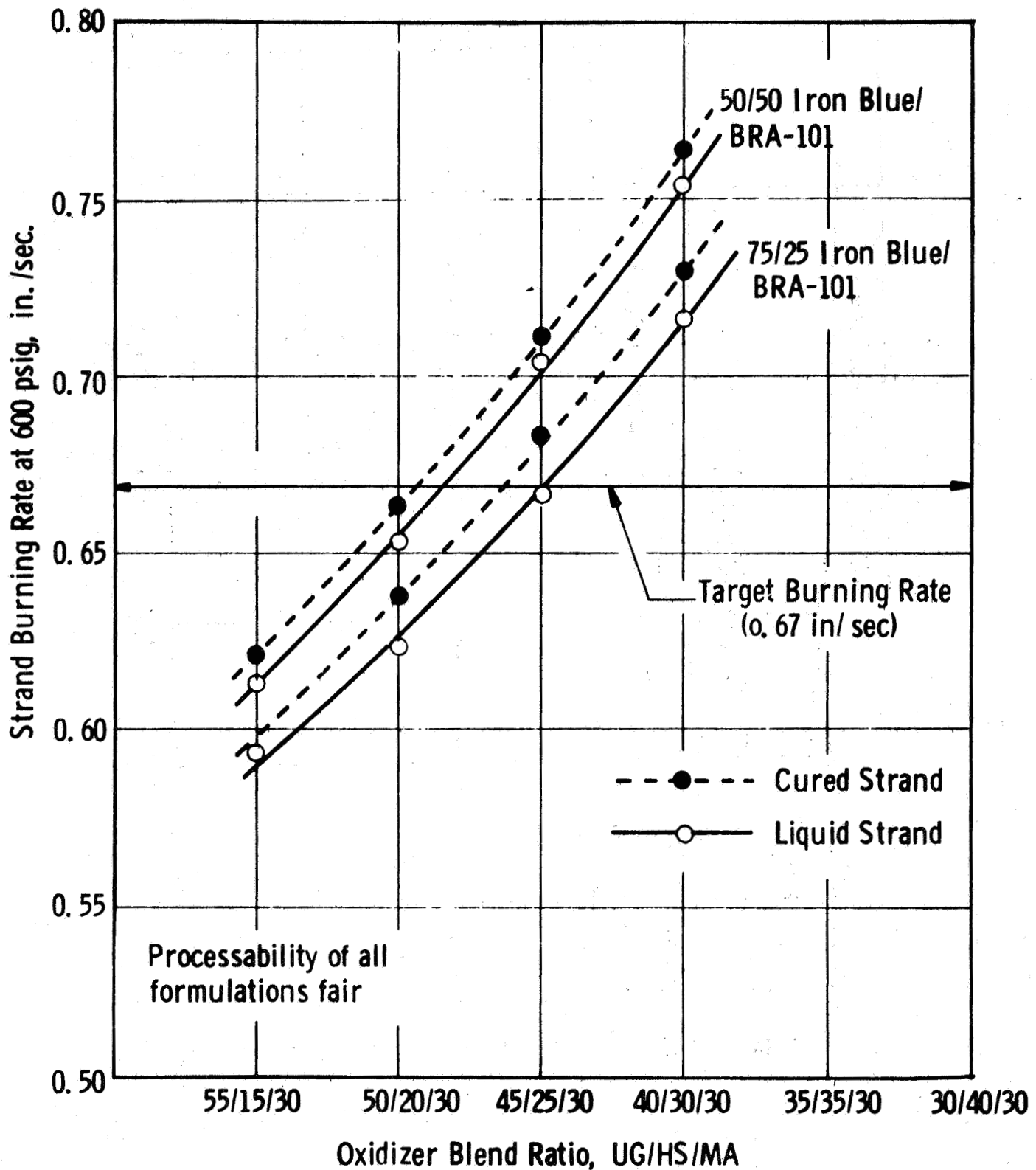
Effect of Iron Blue Concentration and Plasticizer Type on LSBR of ANB-3105

Figure 4



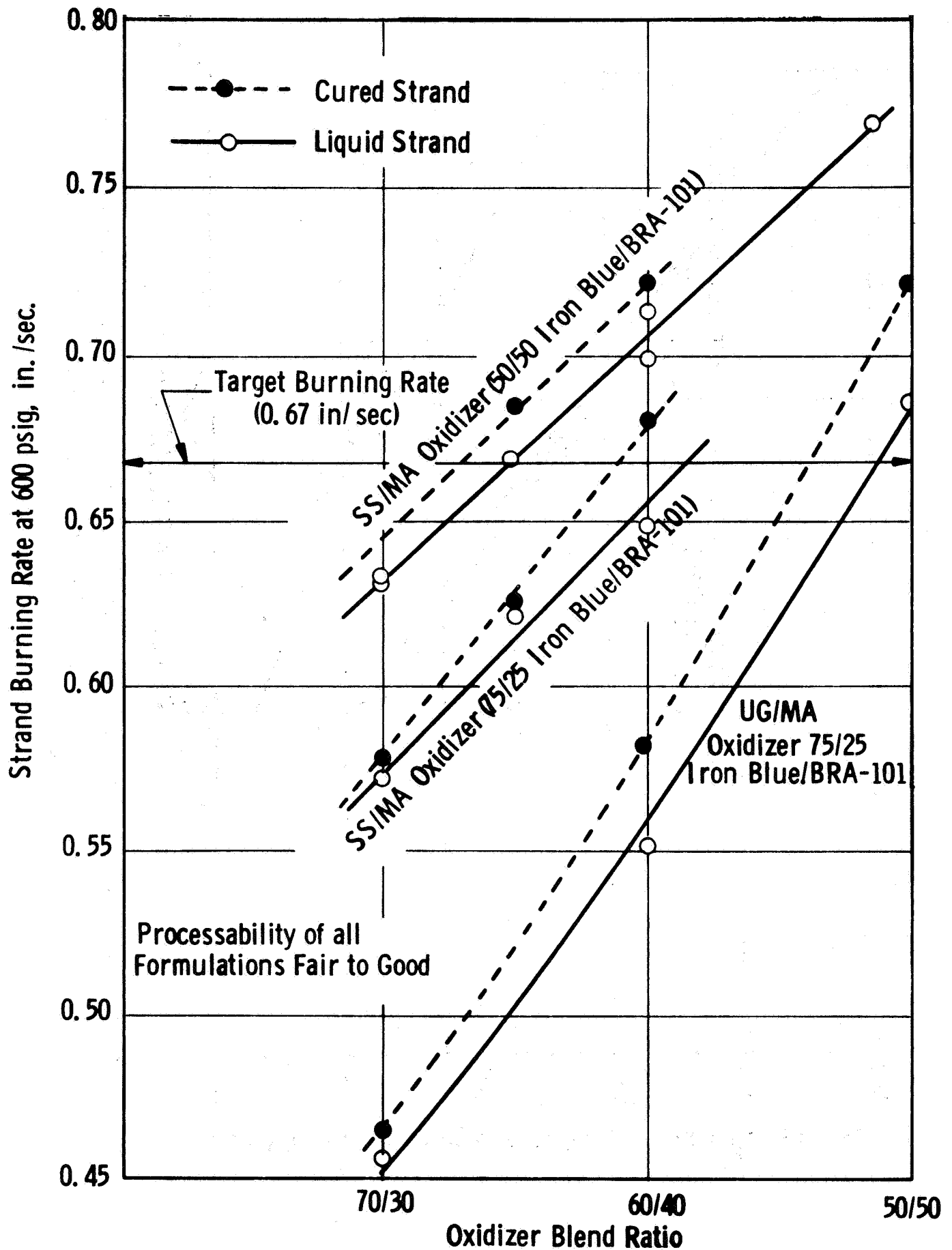
Effect of BRA-101/Iron Blue Concentration and Plasticizer Type on LSBR of ANB-3105

Figure 5



Effect of Trimodal Oxidizer Blend Ratio on Strand Burning Rate
(1% Iron Blue/BRA-101)

Figure 6



Effect of Bimodal Oxidizer Blend Ratio on Strand Burning Rate
(1% Iron Blue/BRA-101)

Figure 7

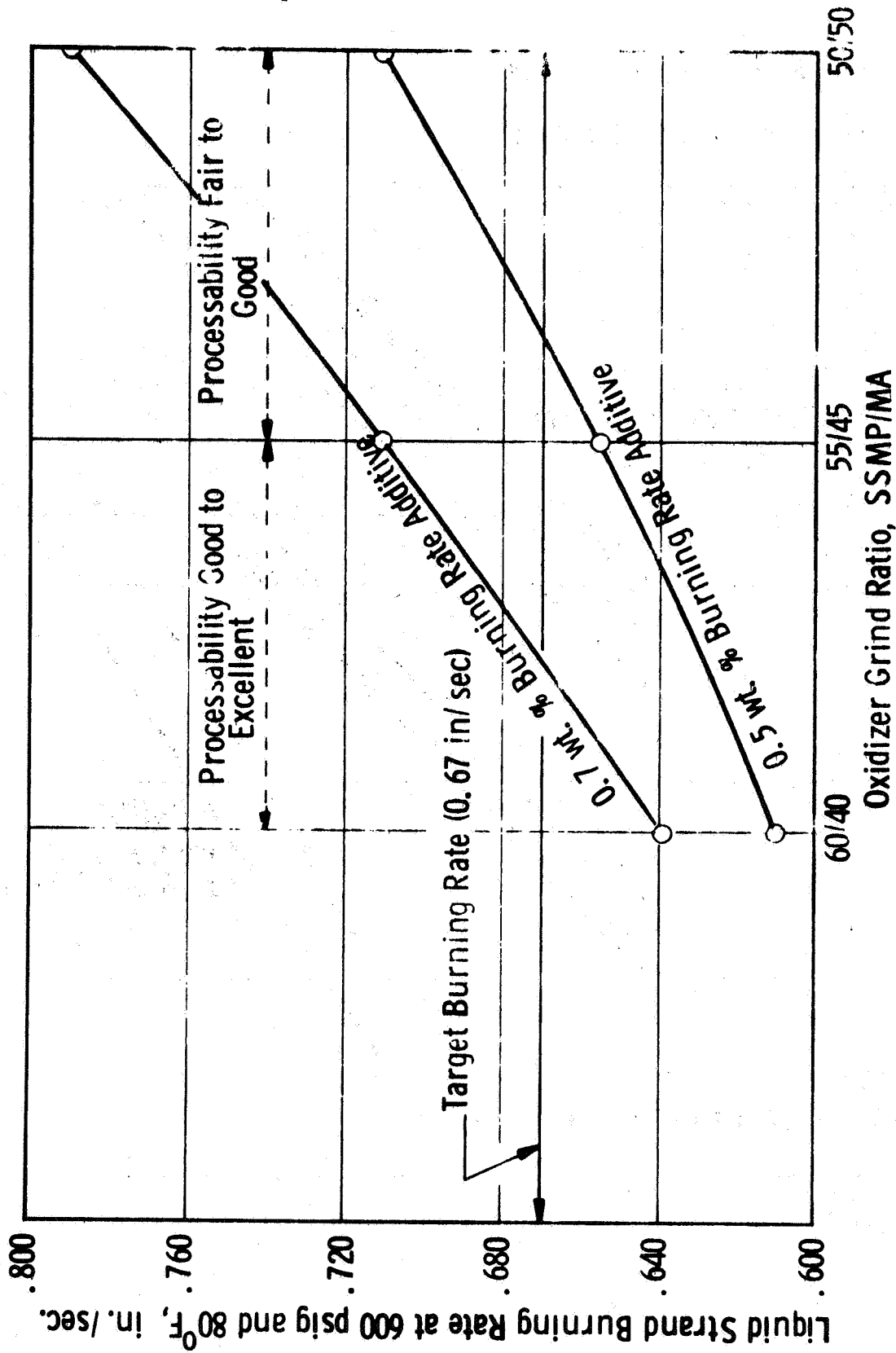


Figure 8

Effect of Oxidizer Blend Ratio and Burning Rate Additive Level on Liquid Strand Burning Rate of ANB-3235
 (3% DOA Plasticizer, 50/50 Ratio of Iron Blue/BRA 101)

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<u>Batch No.</u>	<u>Cure Time at 135°F</u>	<u>BRA Level wt%</u>	<u>Mechanical Properties at 77°F</u>			
			<u>S_{nm}, psi</u>	<u>γ_m, %</u>	<u>γ_b, %</u>	<u>F_o, psi</u>
66-269	27	0.5	129	22	22	719
		(35% DOA)	148	22	24	804
291	27	0.6	119	20	21	710
		(35% DOA)	146	22	23	838
297	27	0.6	131	18	19	872
		(30% DOA)	145	18	20	934

Preliminary Mechanical Properties of ANB-3235
 (60-lb Batches)
 (115 Equiv. DER-332)

Figure 9

Premix Storage Time, Days	Propellant Cure Time at 135°F, Days	LSBR @ 600 psig, in./sec	Viscosity @ 10 hr poise	Mechanical Properties at 77°F			
				S_{nm} psi	γ_m %	γ_b %	E_o psi
0	21	.667	8900	85	24	26	413
	28			108	22	24	568
	35			100	23	24	515
3	21	.700	9500	92	23	25	464
	28			99	22	25	464
	35			101	21	23	553
7	21	.680	7500	104	22	26	569
	25			106	20	22	634
	28			114	20	23	683
14	21	.691	8100	107	22	24	604
	28			110	20	22	677
	35			115	20	23	758
21	21	.691	-	147	18	20	921
	28			138	15	16	989
	35			172	16	17	1161

Effect of Premix Storage Time on Properties of ANB-3235

Figure 10

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Age of Surface at Cast, Days	Mechanical Properties at 77°F				Location of Failure
	S_{nm} , psi	γ_m , %	γ_b , %	E_o , psi	
Control	66	33	41	266	-
1	62	29	30	273	Top Batch
2	60	26	27	261	Top Batch
3	66	30	34	275	Interface
4	57	18	19	328	Interface
7	56	20	21	293	Interface

Note: Tested when interface had reached 28 days cure at 135°F

Effect of Surface Age on Propellant-to-Propellant Bond
ANB-3235

Figure 11

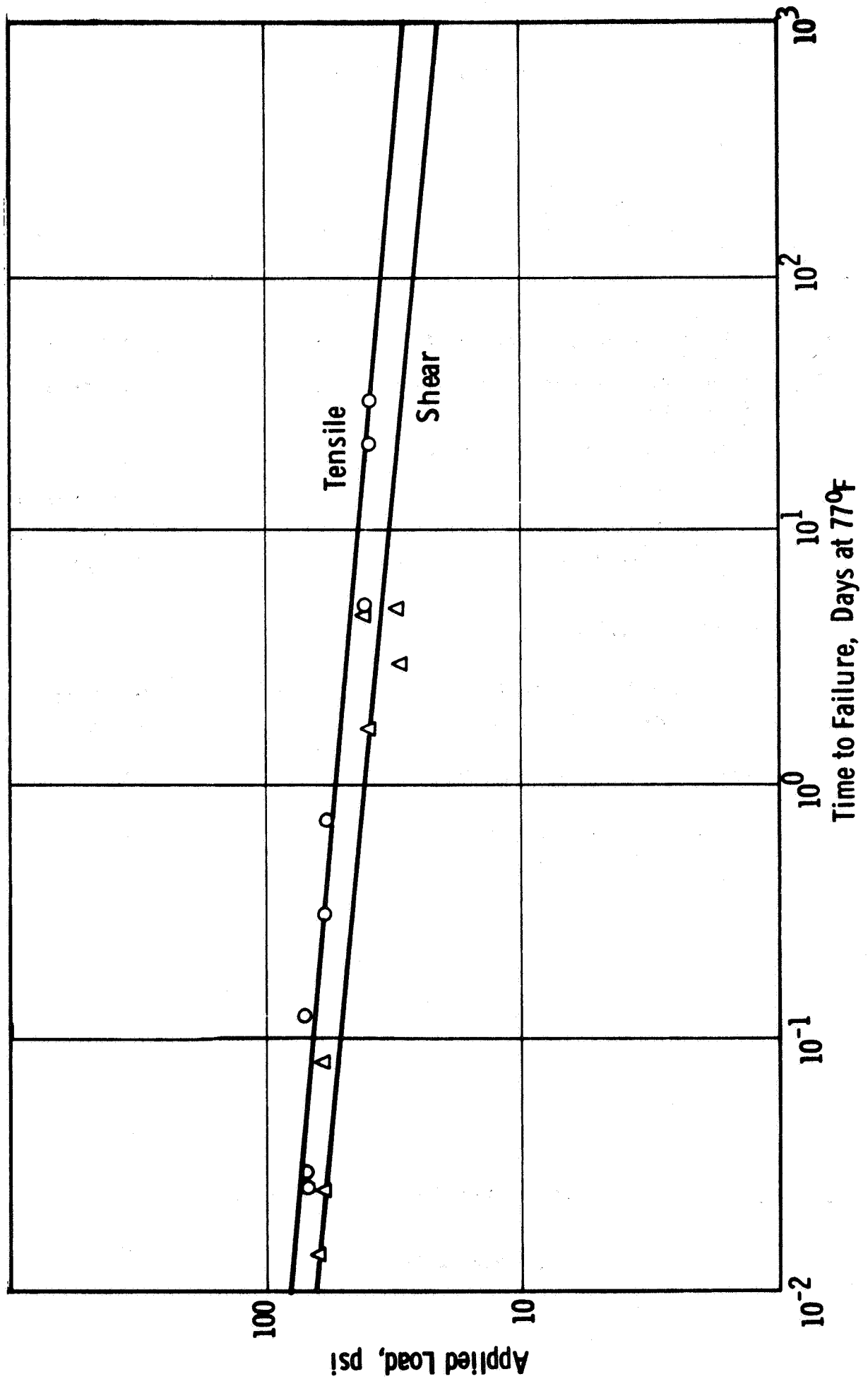
Report NASA CR 72262

<u>Cure and Storage Conditions</u>	<u>Bond Strength at 77°F, psi</u>	
	<u>Tensile</u>	<u>Shear</u>
27 Days at 135°F	174	112
35 Days at 135°F	99	77*
35 Days at 135°F plus 17 Days at 200°F	116	148
35 Days at 135°F plus 24 Days at 200°F	118*	63*

* Sample failed between propellant and steel test plate, i.e., these represent minimum values of liner-propellant bond. All other samples failed at random within propellant.

Bond Strength of ANB-3235 Propellant to SD-850-2 Liner

Figure 12



Constant Load Capability of the ANB-3235/SD-850-2 Liner Bond System

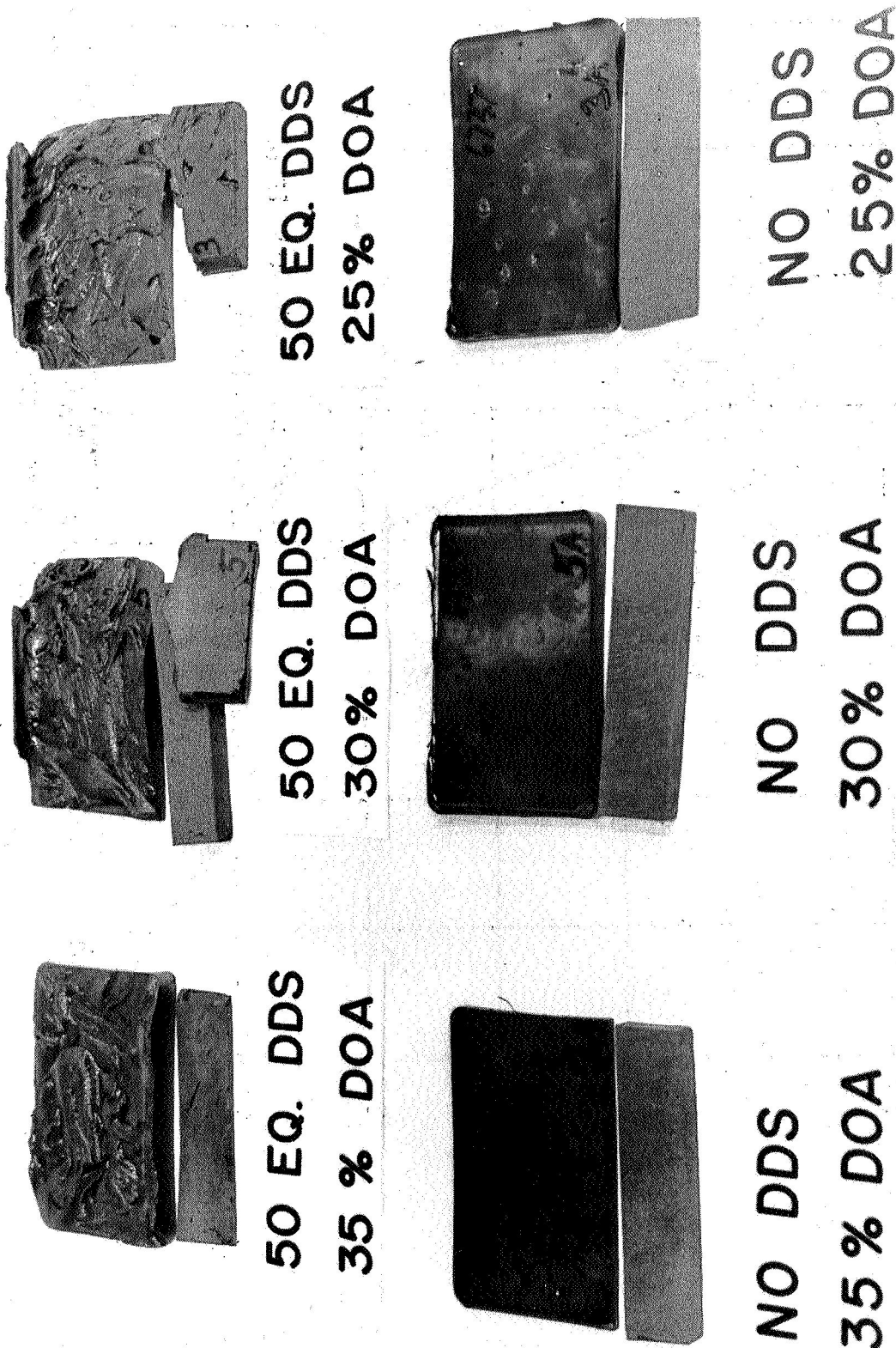
Figure 13

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- | | | |
|----|--|----------------|
| A. | 2" Cube with No. 8 Blasting Cap (5 tests) | Negative |
| B. | 2" Cube with Engineer's Special Blasting Cap (5 tests) | Negative |
| C. | Ignition and Unconfined Burning Tests: | |
| | 1-in. cube (1 test) | Burned 10 sec. |
| | 2-in. cube (2 test) | Burned 14 sec. |
| | Four 2-in. cubes (1 test) | Burned 20 sec. |
| D. | Thermal Stability Test (48 hours at 75°C): | |
| | 1-in. cube (1 test) | No change |
| | 2-in. cube (1 test) | No change |
| E. | Autoignition Temperature, °F | 480 |
| F. | Recommended Classification | "B" |

I.C.C. Classification Testing for ANB-3235

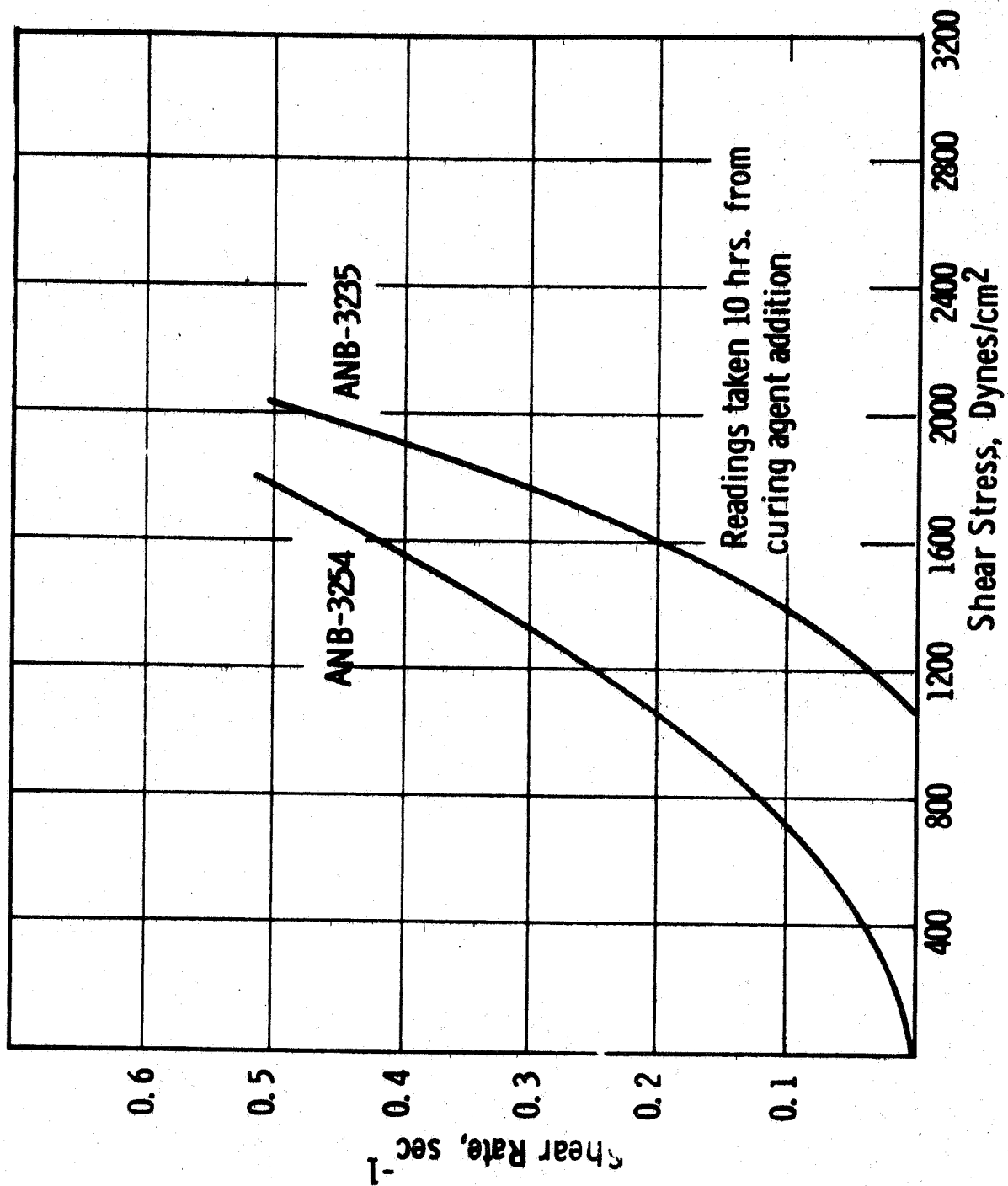
Figure 14



PLS 12-1-66 (22)

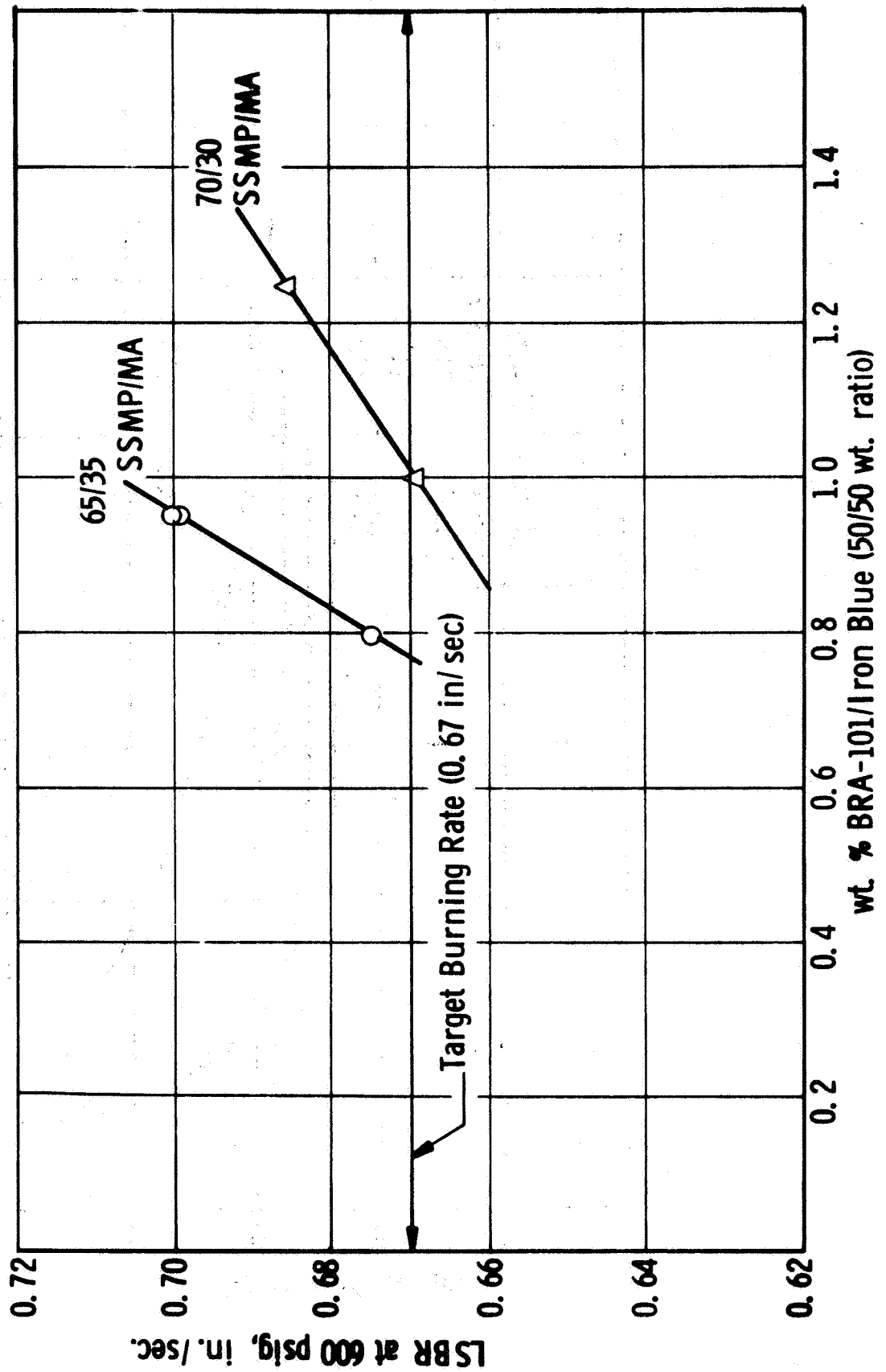
Effect of DOA Plasticizer and DDS Anhydride Content on Surface
Leveling and Fuel Spot Defects in PBAN Propellants

Figure 15



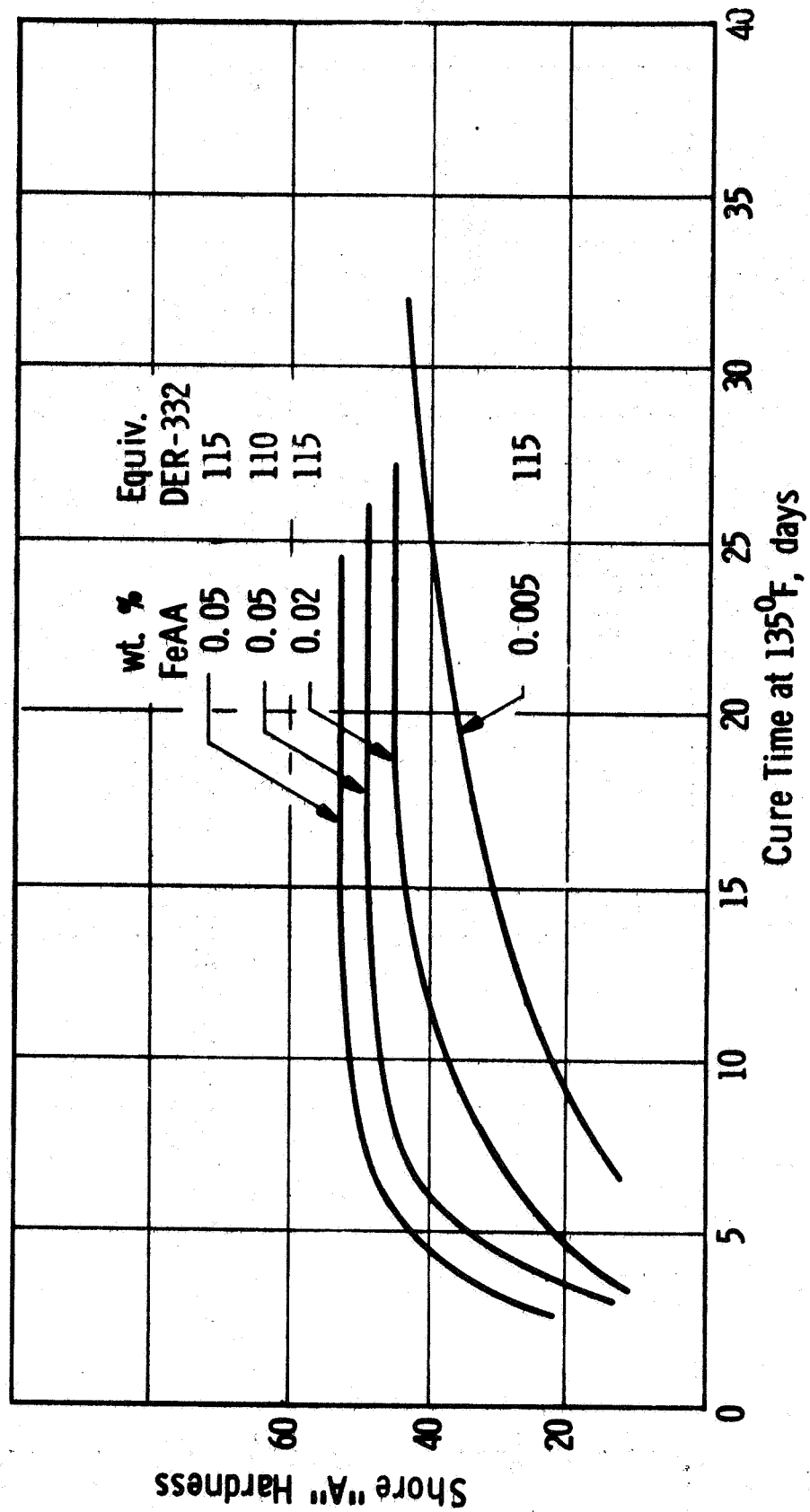
Comparison of Bingham Plastic Flow Characteristics of ANB-3235 and ANB-3254

Figure 16



Effect of Burning Rate Additive Level and Oxidizer Grind Ratio
on Liquid Strand Burning Rate of ANB-3254 Propellant

Figure 17



Effect of FeAA and DER-332 Concentrations on Cure Rate of ANB-3254 Propellant

Figure 18

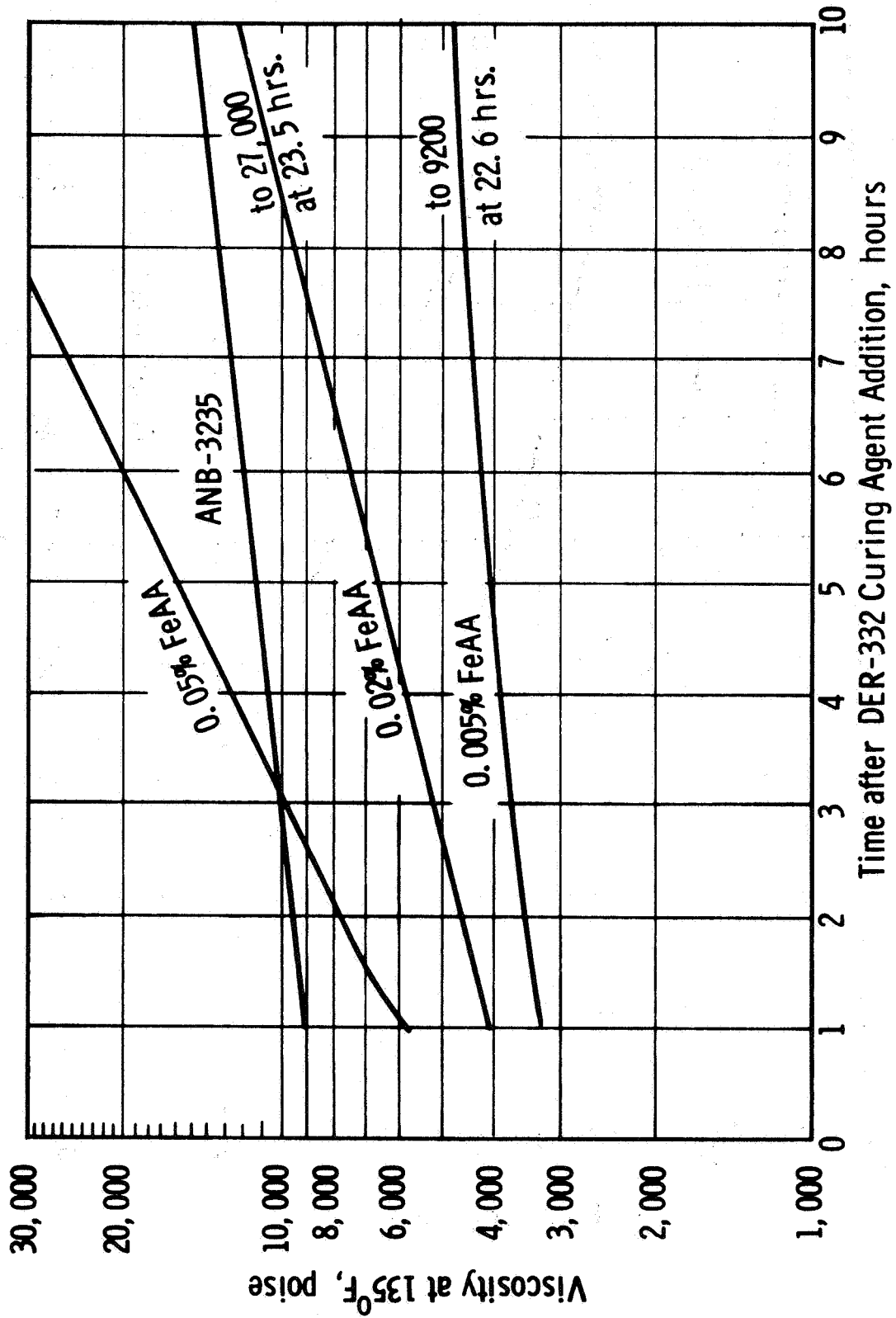
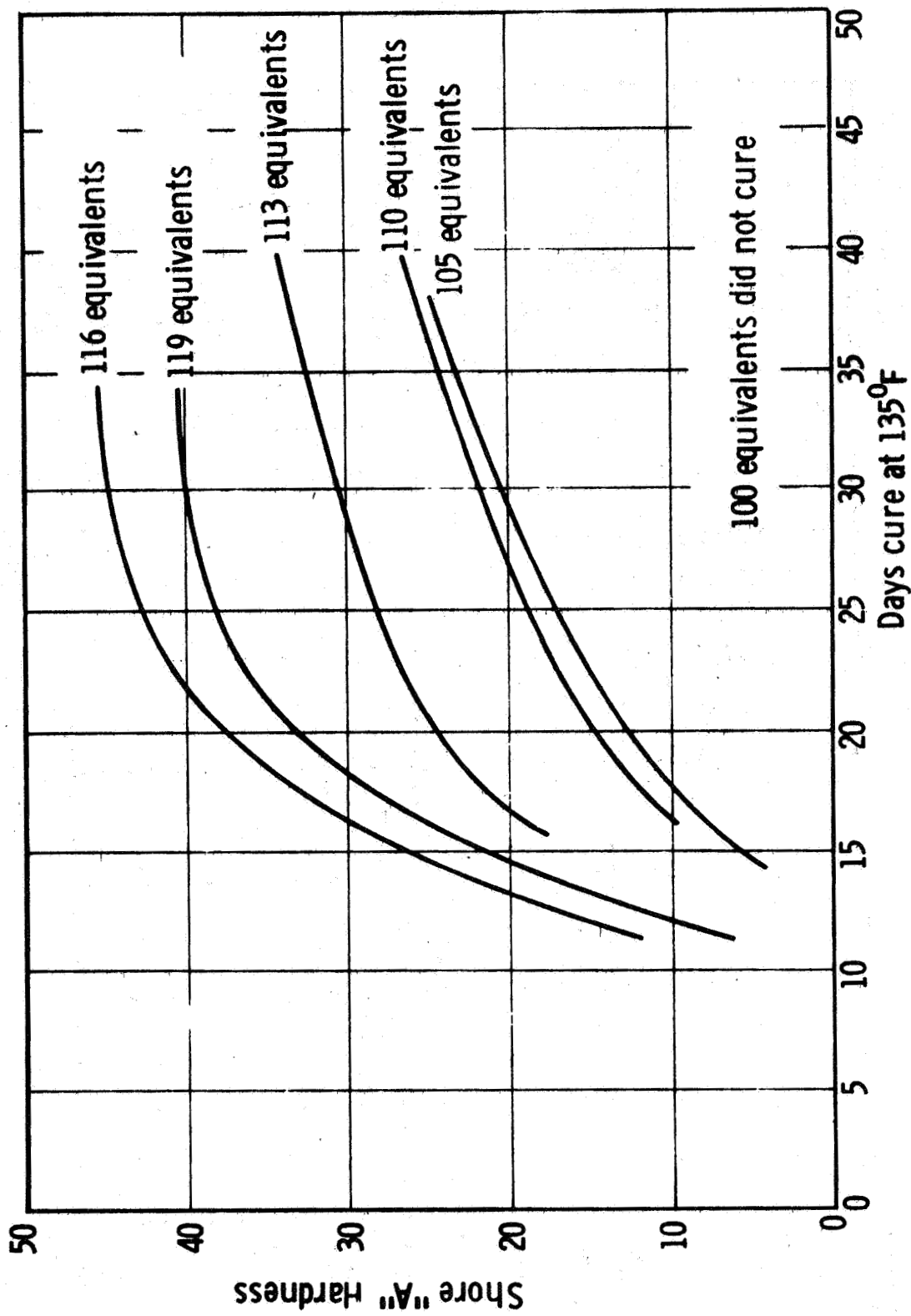


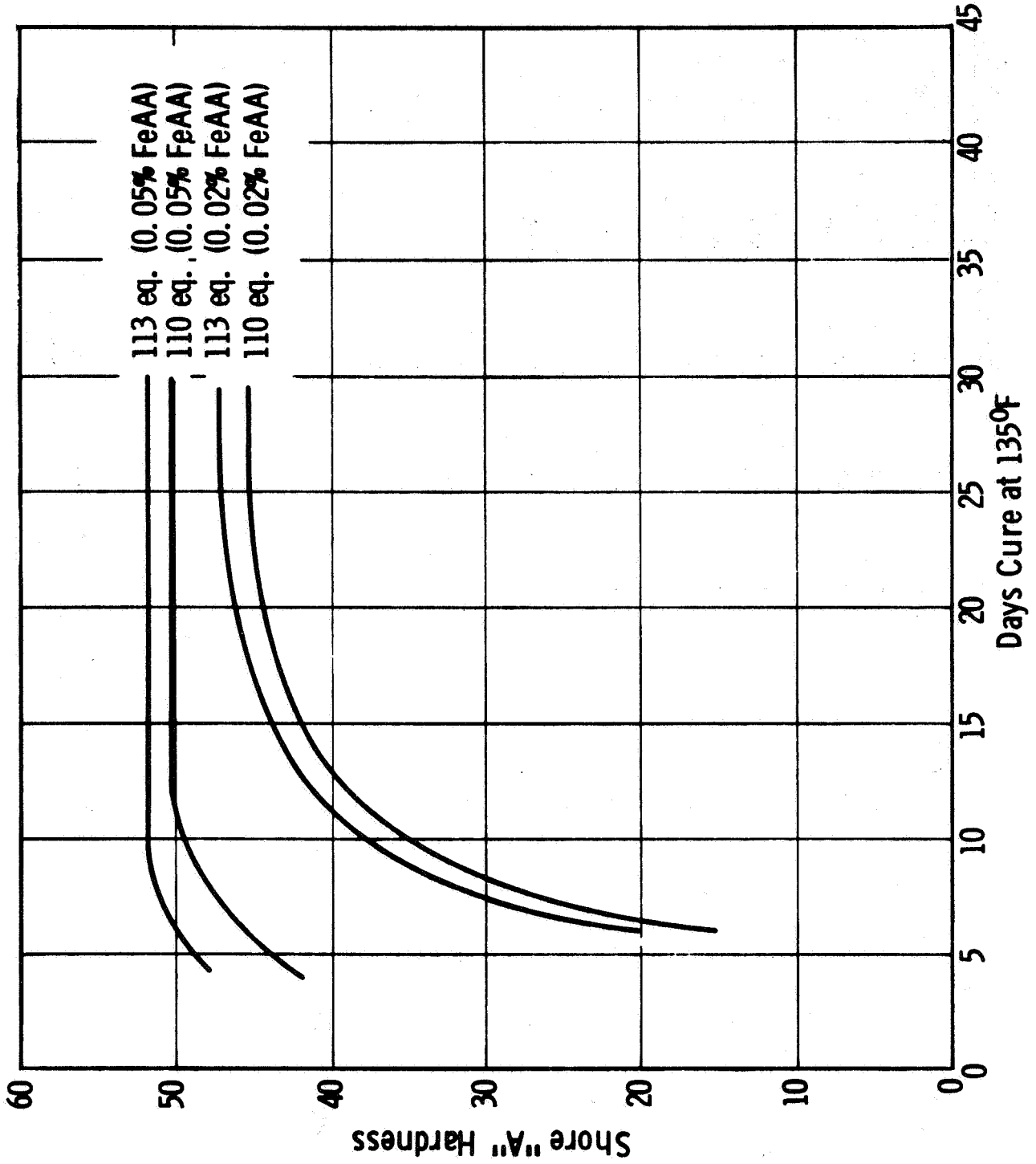
Figure 19

Effect of FEAA Level on Viscosity Buildup Characteristics of ANB-3254
(Compared with ANB-3235)



Effect of DER-332 Curative Level on the Cure Rate of ANB-3254 Propellant
(0.01 wt% FeAA)

Figure 20



Effect of FeAA Level and DER-332 Equivalents on the Cure of ANB-3254 Propellant

Figure 21

DER-332 Equivalents	FeAA, Wt %	Days Cure at 135°F	Mechanical Properties at 77°F				
			S_{mm} psi	γ_m %	γ_b %	E_o psi	Constant Strain *
							10% 15% 20%
110	0.02	12	88	28	29	389	- - -
		21	93	27	28	442	2/2 2/2 2/2
113	0.02	12	97	27	28	451	- - -
		21	94	23	23	480	2/2 - 1/2
		30	102	22	28	487	- - -
110	0.05	5	92	24	27	475	- - -
		10	94	19	21	584	2/2 2/2 1/2
		30	97	18	19	586	- - -
113	0.05	5	91	20	22	534	- - -
		10	95	17	18	664	2/2 2/2 2/2
		30	95	17	18	656	- - -

* No. bars holding/No. bars tested

Effect of FeAA and DER-332 Concentrations on the Cure Rate and
Mechanical Properties of ANB-3254

Figure 22

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<u>DER-332</u> <u>Equiv.</u>	<u>Wt% FeAA = 0.015</u>		<u>Wt% FeAA = 0.020</u>	
	<u>65/35</u> <u>SS/MA</u>	<u>70/30</u> <u>SS/MA</u>	<u>65/35</u> <u>SS/MA</u>	<u>70/30</u> <u>SS/MA</u>
108	BRA ₂ ⁽⁸⁾	BRA ₁ ⁽¹⁾	BRA ₂ ⁽¹⁰⁾	BRA ₁ ⁽⁵⁾
113	BRA ₁ ⁽²⁾	BRA ₂ ⁽⁷⁾	BRA ₁ ⁽⁴⁾	BRA ₂ ⁽¹²⁾
118	BRA ₂ ⁽⁹⁾	BRA ₁ ⁽³⁾	BRA ₂ ⁽¹¹⁾	BRA ₁ ⁽⁶⁾

BRA = Burning rate additive levels (2) - Based on SRO data

BRA₁ = 0.90% of propellant

BRA₂ to be selected after mixing Batch No. (3).

Batch mixing order indicated in upper right hand corner of box.

Proposed Mixing Plan for Propellant Scale-Up at A-DD

Figure 23

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DER-332 Level	wt% FeAA - 0.015			wt% FeAA - 0.020	
	70/30 SS/MA (PEPCON)	65/35 SS/MA (PEPCON)	65/35 SS/MA (HEF)	55/35 SS/MA (PEPCON)	70/30 SS/MA (PEPCON)
108	BRA ₁ ⁽¹⁾	BRA ₂ ⁽⁸⁾	BRA ₂ ⁽¹²⁾	BRA ₂ ⁽⁶⁾	-
113	-	BRA ₁ ⁽²⁾ BRA ₂ ⁽⁵⁾	BRA ₂ ⁽¹¹⁾	BRA ₂ ⁽¹⁰⁾	BRA ₁ ⁽⁴⁾
118	BRA ₁ ⁽³⁾	BRA ₂ ⁽⁹⁾	BRA ₂ ⁽¹³⁾	BRA ₂ ⁽⁷⁾	-

BRA₁ - 0.90 wt% of propellant

BRA₂ - 1.30 wt% of propellant

Batch mixing order indicated by superscript numbers in parenthesis

Batches 1 thru 4 made from 12,000-lb premix batch

Batches 5 thru 7 made from 6,000-lb premix batch

Batches 8 thru 13 made from 12,000-lb premix batch

All batches 5500-lb

Actual Mixing Plan for Propellant Scale-Up at A-DD

Figure 24

Component	Test	Premix Batch No. (0.9 wt% BRA)		Premix Batch No. (1.3 wt% BRA)		Theoretical
		PM0138	PM0139	PM0140	PM0141	
Submix	Liquid density at 25°C g/cc	0.930	0.932	0.931	0.933	0.930
	Acid equivalents/100g	0.0416	0.0414	0.0414	0.0404	0.0412
	Refractive index at 25°F	1.4910	1.4915	0.062	0.080	
	H ₂ O content, %	0.055	0.056	0.062	0.080	
	Ash content, %	0.09	0.52	0.38	0.43	
Premix I	Liquid density at 25°C g/cc	0.959	0.960	0.971	0.972	0.970
	Ash content, %	3.75	3.38	5.46	5.36	5.45
Premix II	Liquid density at 25°C g/cc	1.422	1.414	1.427	1.424	1.429
	H ₂ O content, %	0.067	0.091	0.134	0.137	
	Gas content, %	-	0.059	0.049	0.050	

Submix and Premix Acceptance Analyses, First Scale-Up Program at A-DD

Figure 25

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Batch No.	Location	Uncured Density, g/ml	Wt% DER-332	Burning Rate at 600 psig, in./sec	Oxidizer Grind Ratio SSMP/MA
441	Scoop	1.739	1.11	0.603	70/30
0.015% FeAA	Bottom	1.740	1.10	0.605	
108 eq	Middle	1.741	1.14	0.605	
(1)	Top	1.741	1.10	0.602	
	Theo.	(1.742)	(1.07)		
442	Scoop	1.739	1.15	0.643	65/35
0.015% FeAA	Bottom	1.740	1.12	0.645	
113 eq	Middle	1.739	1.10	0.643	
(2)	Top	1.740	1.12	0.644	
	Theo.	(1.740)	(1.12)		
444	Scoop	1.738	1.23	0.639	65/35
0.015% FeAA	Bottom	1.739	1.18	0.636	
118 eq	Middle	1.739	1.19	0.633	
(3)	Top	1.739	1.18	0.636	
	Theo.	(1.739)	(1.17)		
443	Scoop	1.738	1.21	0.606	70/30
0.020% FeAA	Bottom	1.740	1.18	0.609	
113 eq	Middle	1.740	1.22	0.605	
(4)	Top	1.740	1.21	0.603	
	Theo.	(1.740)	(1.12)		
446	Scoop	1.747	1.10	0.680	65/35
0.015% FeAA	Bottom	1.746	1.10	0.669	
113 eq	Middle	1.746	1.08	0.670	
(5)	Top	1.746	1.10	0.670	
	Theo.	(1.746)	(1.09)		
447	Scoop	1.746	1.11	0.684	65/35
0.020% FeAA	Bottom	1.745	1.09	0.673	
108 eq	Middle	1.746	1.10	0.677	
(5)	Top	1.746	1.16	0.758	
	Theo.	(1.747)	(1.05)		
448	Scoop	1.745	1.14	0.680	65/35
0.020% FeAA	Bottom	1.746	1.20	0.673	
118 eq	Middle	1.746	1.10	0.673	
(7)	Top	1.746	1.20	0.667	
	Theo.	(1.745)	(1.14)		
449	Scoop	1.744	1.01	0.661	65/35
0.015% FeAA	Bottom	1.745	1.01	0.660	
108 eq	Middle	1.745	1.04	0.659	
(8)	Top	1.744		0.660	
	Theo.	(1.747)	(1.05)		

Uncured Propellant Acceptance Data, First Scale-Up Program at A-DD

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Batch No.	Location	Uncured Density, g/ml	Wt% DER-332	Burning Rate at 600 psig, in./sec	Oxidizer Grind Ratio SEMP/MA
450	Scoop	1.744	1.16	0.669	65/35
0.015% FeAA 118 eq (9)	Bottom	1.745	1.18	0.664	
	Middle	1.744	1.12	0.671	
	Top	1.745	1.13	0.669	
	Theo.	(1.745)	(1.14)		
451	Scoop	1.745	1.05	0.681	65/35
0.020% FeAA 113 eq (10)	Bottom	1.746	1.07	0.674	
	Middle	1.746	1.08	0.675	
	Top	1.746	1.08	0.678	
	Theo.	(1.746)	(1.09)		
452	Scoop	1.744	1.07	0.679	65/35 (HEF Oxidizer)
0.015% FeAA 113 eq (11)	Bottom	1.744	1.13	0.674	
	Middle	1.744	1.09	0.674	
	Top	1.743	1.07	0.674	
	Theo.	(1.746)	(1.09)		
453	Scoop	1.744	1.02	0.723	65/35 (HEF Oxidizer)
0.015% FeAA 108 eq (12)	Bottom	1.744	1.00	0.709	
	Middle	1.745	1.02	0.707	
	Top	1.744	0.98	0.708	
	Theo.	(1.747)	(1.05)		
454	Scoop	1.744	1.08	0.697	65/35 (HEF Oxidizer)
0.015% FeAA 118 eq (13)	Bottom	1.745	1.11	0.688	
	Middle	1.744	1.10	0.687	
	Top	1.744	1.09	0.684	
	Theo.	(1.745)	(1.09)		

Uncured Propellant Acceptance Data, First Scale-Up Program at A-DD

Batch No.	Blend Ratio SSMP/MA	DER-332 Equiv.	FeAA ⁽¹⁾ Wt%	BRA Wt%	Shore "A" Hardness at 135°F ⁽²⁾															34
					Cure Time at 135°F, Days															
					12	13	14	15	16	17	18	19	20	21	22	23	24	25		
441	70/30	108	0.015	0.9	-	-	-	-	-	-	-	-	0	-	-	0	-	-	3 (7)	4
442	65/35	113	0.015	0.9	-	0	-	2	-	-	4	-	7	-	-	7	-	-	7 (15)	12
443	70/30	113	0.020	0.9	3	7	-	8	-	-	10	-	13	-	-	14	-	-	16 (22)	17
444	65/35	113	0.015	0.9	-	0	-	1	-	-	8	-	10	-	-	10	-	-	11 (17)	13
446	65/35	113	0.015	1.3	-	-	-	-	-	-	0	-	0	-	-	-	0 (0)	-	-	
447	65/35	108	0.020	1.3	-	-	-	-	-	-	0	-	0	-	-	-	0 (0)	-	-	
448	65/35	118	0.020	1.3	-	-	-	-	-	-	0	-	0	-	-	-	2 (13)	-	-	
449	65/35	108	0.015	1.3	-	-	-	-	0	-	0	-	0	0 (0)	-	-	-	-	-	
450	65/35	118	0.015	1.3	-	-	-	-	0	-	0	-	-	0 (2)	-	-	-	-	-	
451	65/35	113	0.020	1.13	-	-	-	-	0	-	0	-	-	0 (0)	-	-	-	-	-	
452	65/35 ⁽³⁾	113	0.015	1.3	-	-	0	-	0	-	-	0 (0)	-	-	-	-	-	-	-	
453	65/35 ⁽³⁾	108	0.015	1.3	-	-	0	-	0	-	-	0 (0)	-	-	-	-	-	-	-	
454	65/35 ⁽³⁾	118	0.015	1.3	-	-	0	-	0	-	-	0 (5)	-	-	-	-	-	-	-	

(1) Premix contained 0.015 wt FeAA

(2) Values in parentheses were measured at 77°F

(3) HEF oxidizer

Shore "A" Hardness as a Function of Cure Time at 135°F for Vertical Batch Mixes
Made During First Scale-Up Program at A-DD

Batch No.	Premix Storage	Wt% FeAA in Premix	Wt% FeAA Dry	Total Wt% FeAA	Shore "A" Hardness at 77°F																
					Cure Time at 135°F, Days																
					6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	27
8150	24 hrs, 77°F	0.015	0.00	0.015	0	0	-	1	-	-	-	2	-	7	-	7	-	-	10	-	10
8151	24 hrs, 77°F	0.015	0.005	0.02	0	0	-	2	-	-	-	9	-	8	-	5	-	-	-	-	11
8152	24 hrs, 77°F	0.015	0.015	0.03	22	28	-	32	-	-	-	39	-	40	-	37	-	-	42	-	41
8153	24 hrs, 77°F	0.015	0.025	0.04	41	40	-	45	-	-	-	46	-	50	-	45	-	-	46	-	48

* 115 DEN-332 equivalents, 1.3 wt% BRA

Effect of FeAA Concentration and Addition Method on the Cure Behavior of ANB-3254, (SRO)*

Figure 28

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<u>Compound</u>	<u>Test</u>	<u>Batch No.</u> <u>PM0142</u>	<u>Theoretical</u>
Submix	Liquid Density at 25°C, g/cc	0.929	0.930
	Acid Equivalents/100g	0.0414	0.0412
	Refractive Index at 25°C	1.4914	1.4916
	H ₂ O Content, %	0.083	
	Ash Content, %	0.11	
Premix I	Liquid Density at 25°C, g/cc	0.971	0.970
	Ash Content, %	5.33	5.45
	H ₂ O Content, %	0.230	
Premix II	Liquid Density at 25°C, g/cc	1.427	1.429
	H ₂ O Content, %	0.103	
	Gas Content, %	0.108	

Submix and Premix Acceptance Analyses,
Second Scale-Up Program at A-DD

Figure 29

Report NASA CR 72262

<u>Batch No.</u>	<u>Sample Location</u>	<u>DER-332 Level</u>	<u>FeAA Level</u>	<u>Uncured Density, gm/ml</u>	<u>Wt% DER-332</u>	<u>LSBR at 600 psig, in./sec</u>
455	Scoop	115	0.06	1.745	1.04	0.646
	Bottom			1.745	1.05	0.647
	Middle			1.745	1.02	0.646
	Top			1.746	1.05	0.645
				Theo. (1.745)	(1.11)	
456	Scoop	110	0.03	1.746	1.01	0.673
	Bottom			1.746	0.99	0.665
	Middle			1.746	0.97	0.667
	Top			1.747	1.00	0.667
				Theo. (1.746)	(1.07)	
457	Scoop	110	0.06	1.745	1.00	0.674
	Bottom			1.746	1.05	0.671
	Middle			1.746	1.03	0.669
	Top			1.746	1.07	0.674
				Theo. (1.746)	(1.07)	
458	Scoop	115	0.045	1.746	1.11	0.684
	Bottom			1.746	1.09	0.683
	Middle			1.746	1.10	0.677
	Top			1.747	1.07	0.684
				Theo. (1.745)	(1.11)	
459	Scoop	110	0.045	1.746	1.02	0.672
	Bottom			1.746	1.05	0.667
	Middle			1.747	1.05	0.668
	Top			1.747	1.01	0.669
				Theo. (1.746)	(1.07)	
460	Scoop	115	0.03	1.745	1.09	0.667
	Bottom			1.746	1.10	0.665
	Middle			1.747	1.06	0.666
	Top			1.746	1.07	0.665
				Theo. (1.745)	(1.11)	

Uncured Propellant Analyses,
Second Scale-Up Program at A-DD

Figure 30

Batch No.	A-DD DER-332 Level	Wt% FeAA in Premix	Wt% FeAA Dry	Wt% FeAA Total	Shore "A" Hardness at 77°F																		
					Days Cure at 135°F																		
					7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
460	115	0.03	0.00	0.03	8	-	-	-	14	-	17	-	19	-	-	-	23	-	-	-	-	25	
456	110	0.03	0.00	0.03	5	-	-	-	-	9	-	10	15	-	-	-	16	-	-	-	-	19	
458	115	0.03	0.015	0.045	26	-	-	-	29	-	32	-	35	-	-	-	36	-	-	-	-	39	
459	110	0.03	0.015	0.045	20	-	-	-	23	-	23	-	27	-	-	-	30	-	-	-	-	33	
455	115	0.03	0.03	0.060	31	-	-	-	-	33	-	32	-	37	-	-	38	-	-	-	-	40	
457	110	0.03	0.03	0.060	21	-	-	-	-	29	-	25	-	29	-	-	35	-	-	-	-	35	

Figure 31

Cure Behavior of A-DD Vertical Batch Mixer, Second Scale-Up

Batch No.	DER-332 Equiv.	FeAA Wt%	Cure Time at 135°F, Days	Mechanical Properties at 77°F				
				S _{nm} psi	Y _m %	Y _b %	E _o psi	
455	115	0.06	14	67	31	37	290	
			16	72	29	33	333	
			20	78	26	32	405	
			24	79	25	30	417	
			28	78	26	35	404	
			40	77	25	29	400	
457	110	0.06	14	57	32	37	233	
			16	58	29	31	258	
			20	66	25	28	336	
			24	64	29	33	303	
			28	68	26	29	344	
			40	66	24	26	345	
458	115	0.045	13	64	27	29	295	
			15	70	28	30	321	
			20	77	28	30	352	
			24	75	29	31	372	
			28	76	27	29	344	
			40	85	22	24	472	
459	110	0.045	15	53	29	33	231	
			20	59	30	33	264	
			24	59	30	34	272	
			28	59	30	33	264	
			40	68	25	28	350	
460	115	0.03	15	40	36	46	161	
			20	43	34	43	177	
			24	45	33	40	193	
			28	47	31	39	209	
			40	54	31	36	235	

Mechanical Properties of A-DD Vertical Batch Mixes of ANB-3254, Second Scale-Up

Batch No.	DER-332 Equiv.	FeAA Wt%	Cure Time at 135°F, Days	Mechanical Properties at 77°F			
				S _{nm} , psi	γ _m , %	γ _b , %	E _o , psi
456	110	0.03	15	33	41	57	114
			20	37	36	46	139
			24	37	35	41	152
			28	41	33	42	169
			40	44	34	42	177

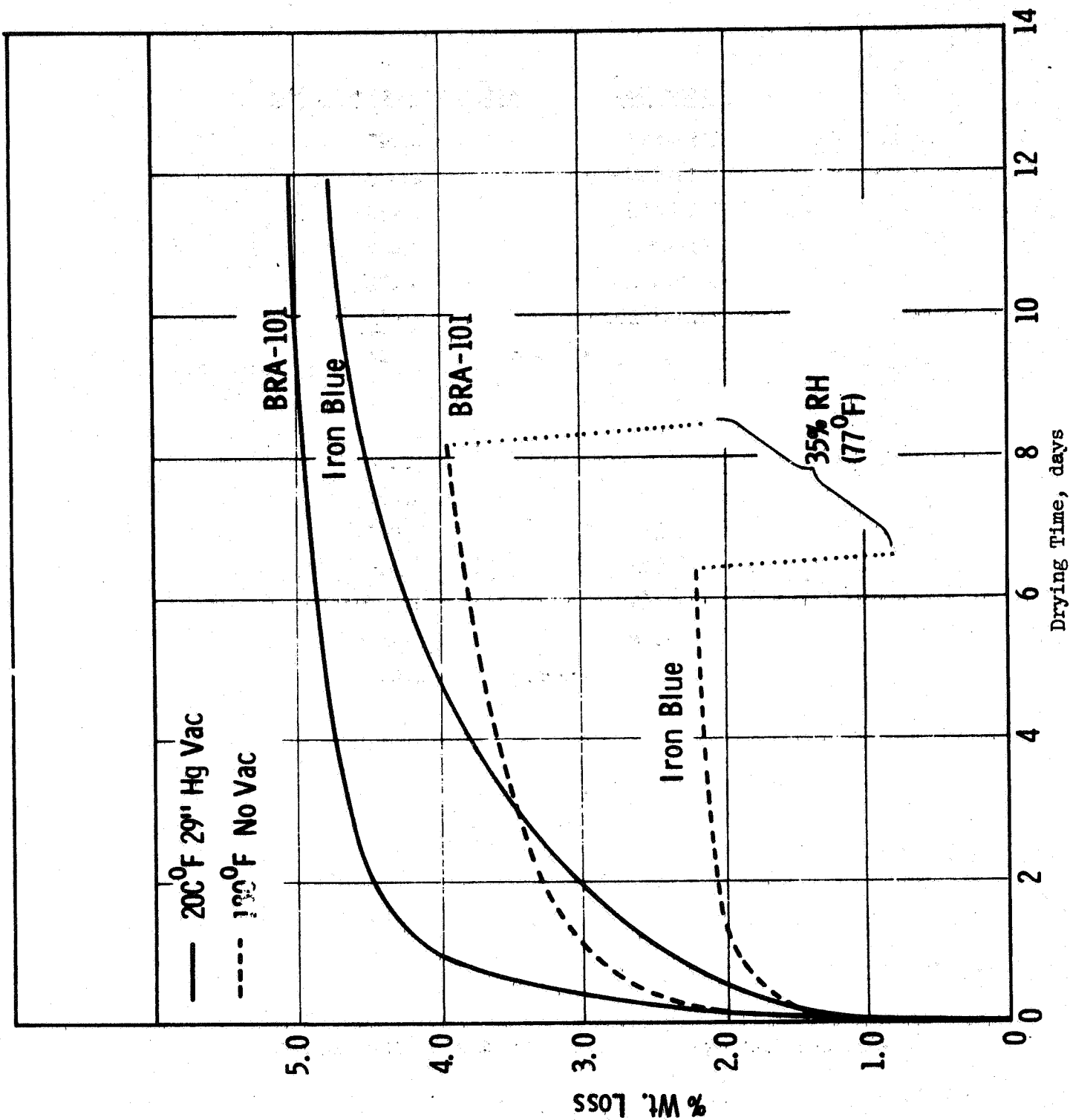
Mechanical Properties of A-DD Vertical Batch Mixes of ANB-3254, Second Scale-Up

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	<u>Batch No.</u>	<u>Moisture Content, Wt%</u>
I. <u>SRO</u>	10LR-8538	0.022
	10LR-8540	0.013
	10LR-8541	0.013
	10LR-8542	0.016
	10LR-8543	0.012
	10LR-8544	<u>0.019</u>
	Average	0.016
II. <u>A-DD</u>	B-461	0.054
	B-462	0.048
	B-463	0.050
	B-464	0.045
	B-465	0.048
	B-466	<u>0.041</u>
	Average	0.048

Moisture Contents of Propellants Made at SRO and A-DD

Figure 33



Effect of Drying Time, Temperature, and Vacuum on Wt Loss of Iron Blue and BRA-101

Figure 34

Batch No.	Wt% FeAA in DER-332	Shore "A" Hardness at 77°F Cure Time at 135°F, Days																		
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
8305	0.02	S	-	-	-	S	-	S	15	9	-	-	18	-	-	-	-	-	-	29
8306	0.03	S	-	-	-	28	-	32	-	35	-	-	38	-	-	-	-	-	-	46
8307	0.045	0	-	-	-	40	-	45	-	45	-	-	47	-	-	-	-	-	-	50
8308	0.060	20	-	-	-	45	-	48	-	46	-	-	49	-	-	-	-	-	-	54
8352	0.02(1)	-	-	-	S	-	21	29	12	-	-	26	-	-	-	-	-	-	35	
8354	0.045(1)	-	-	-	44	-	44	46	45	-	-	47	-	-	-	-	-	-	49	
8352R	0.02(2)	-	-	S	-	-	7	-	-	-	-	-	-	17						
8354R	0.045(2)	-	-	27	-	-	38	-	-	-	-	-	-	43						

(1) DER-332/FeAA solution stored 24 hrs at 180°F
 (2) DER-332/FeAA solutions stored 5 days at 180°F

Effect of FeAA Concentration and Addition Method on the Cure Behavior of ANB-3254, (SRO)

Figure 35

Batch No.	Wt% FeAA in Premix	Wt% FeAA in DER-332	Premix Storage Time, Days	After Days Cure at 135°F			
				8	12	16	20
8302	0.03	-	1	13	22	24	27
8306	-	0.03	1	32	36	42	46
8302R	0.03	-	6	6	10	14	-
8306R	-	0.03	6	30	40	42	-

Figure 36

Effect of Premix Storage Time on Cure Behavior of ANB-3254

<u>Batch No.</u>	<u>Measured FeAA Content, Wt-%</u>	<u>Theoretical FeAA Content, Wt-%</u>
461	3.92/3.91	3.91
462	3.76/3.72	3.75
463	2.62/2.68	2.70
464	2.61/2.61	2.59
465	1.64/1.64	1.64
466	1.54/1.54	1.57

Analyses of DER-332/FeAA Solutions Used in
Prequalification Vertical Batch Mixes

Figure 37

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<u>Compound</u>	<u>Test</u>	<u>Batch No.</u> <u>FM01143</u>	<u>Theoretical</u>
Submix	Liquid Density at 25°C, g/cc	0.930	0.930
	Acid Equivalents/100g	0.0412	0.0412
	Refractive Index at 25°C	1.4914	1.4916
	H ₂ O Content, %	0.073	
	Ash Content, %	0.29	
Premix I	Liquid Density at 25°C, g/cc	0.971	0.970
	Ash Content, %	5.67	5.45
	H ₂ O Content, %	-	
Premix II	Liquid Density at 25°C, g/cc	1.426	1.429
	H ₂ O Content, %	0.140	
	Gas Content, %	0.057	

Submix and Premix Acceptance Analyses
Prequalification Program at A-DD

Figure 38

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<u>Batch No.</u>	<u>Sample Location</u>	<u>DER-332 Level</u>	<u>FeAA Level</u>	<u>Uncured Density, g/ml</u>	<u>Wt% DER-332</u>	<u>LSBR at 600 psig, in./sec</u>
461	Scoop	115	0.045	1.745	1.05	0.667
	Bottom			1.747	1.12	0.669
	Middle			1.746	1.12	0.668
	Top			1.747	1.05	0.668
				Theo. (1.746)	(1.11)	
462	Scoop	120	0.045	1.746	1.18	0.696
	Bottom			1.748	1.08	0.694
	Middle			1.746	1.10	0.692
	Top			1.747	1.10	0.698
				Theo. (1.746)	(1.15)	
463	Scoop	120	0.032	1.744	1.15	0.680
	Bottom			1.746	1.11	0.676
	Middle			1.745	1.10	0.678
	Top			1.745	1.10	0.682
				Theo. (1.746)	(1.15)	
464	Scoop	125	0.032	1.746	1.115	0.683
	Bottom			1.746	1.20	0.682
	Middle			1.746	1.20	0.683
	Top			1.747	1.19	0.683
				Theo. (1.745)	(1.20)	
465	Scoop	125	0.020	1.744	1.20	0.698
	Bottom			1.746	1.22	0.684
	Middle			1.746	1.18	0.690
	Top			1.746	1.27	0.691
				Theo. (1.745)	(1.20)	
466	Scoop	130	0.020	1.744	1.27	0.690
	Bottom			1.745	1.26	0.688
	Middle			1.746	1.25	0.683
	Top			1.745	1.25	0.683
				Theo. (1.745)	(1.25)	

Uncured Propellant Analyses Prequalification Program at A-DD

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Batch No.	DER-352 Equiv. Level	FeAA Conc., Wt%	Days Cure at 135°F	Mechanical Properties at 77°F			
				S _{nm} , psi	γ _m , %	γ _b , %	E _o , psi
B-461	115	0.045	12	59	31	34	260
			16	62	32	34	260
			20	63	28	31	279
			24	69	27	29	331
			28	70	25	27	344
			31	73	24	26	376
			40	73	23	25	398
			50	83	25	27	435
B-462	120	0.045	60	74	22	23	405
			12	74	26	27	347
			16	80	25	26	387
			20	80	24	26	408
			24	85	22	24	451
			28	84	22	23	446
			31	90	21	22	504
			40	86	19	20	531
B-463	120	0.032	50	93	18	19	589
			60	87	19	20	534
			12	68	28	29	312
			16	72	23	24	382
			20	73	24	25	360
			23	83	26	29	406
			28	76	21	22	428
			31	89	25	26	455
B-464	125	0.032	40	83	21	22	460
			50	98	22	23	539
			60	94	22	23	532
			12	72	24	26	356
			16	80	24	26	407
			20	84	24	26	417
			23	83	21	22	458
			28	86	21	22	474
B-465	125	0.020	31	87	20	22	501
			40	92	20	21	546
			50	100	20	20	562
			60	108	23	24	584
			11	48	31	37	207
			16	65	26	28	318
			20	71	26	30	351
			24	74	26	29	361
B-466	130	0.020	28	80	26	28	398
			30	76	23	25	398
			40	81	24	26	419
			50	94	21	22	533
			60	98	24	26	507
			12	57	25	26	283
			16	70	25	27	351
			20	77	24	27	396
			24	81	23	24	421
			28	88	23	25	471
			30	86	23	24	449
			40	98	24	26	523
			50	115	23	25	636
			60	112	24	25	577

Mechanical Properties of Prequalification Propellant
(A-DD) as a Function of Cure Time

Figure 40

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Batch No.	DER-332 Equiv. Level	FeAA Conc., Wt%	Applied Strain Level 77°F, 30% RH*			
			10%	15%	20%	25%
B-461	115	0.045	2/2	2/2	2/2	1/1
B-462	120	0.045	2/2	2/2	2/2	0/1
B-463	120	0.032	2/2	2/2	1/1	-
B-464	125	0.032	2/2	1/1	2/2	1/2
B-465	125	0.020	2/2	2/2	2/2	2/2
B-466	130	0.020	2/2	2/2	2/2	2/2

* Propellant cured 24 days at 135°F; figures represent number bars passing/number bars tested

Constant Strain Capability of Prequalification (A-DD) Propellant

Figure 41

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Batch No.	DER-332 Equiv. Level	FeAA Conc., Wt%	Bond Strength* at 77°F	
			Tensile psi	Shear psi
B-461	115	0.045	143	91
B-462	120	0.045	153	108
B-463	120	0.032	161	101
B-464	125	0.032	156	99
B-465	125	0.020	130	77
B-466	130	0.020	147	94

* Cured 24 days at 135°F; all samples failed at random within propellant

Bond Strength of Prequalification Propellant (A-DD) to SD-850-2 Liner

Figure 42

Report NASA CR 72262

Batch No.	DER-332 Equiv. Level	FeAA Conc., Wt%	Days Cure at 135°F	Mechanical Properties at 77°F			
				S _{nm} , psi	Y _m , %	Y _b , %	E _o , psi
66-968	125	0.020	12	61	29	33	280
			16	74	25	27	398
			20	76	26	29	383
			27	81	26	29	407
66-969	130	0.020	12	137	22	23	760
			16	159	22	23	909
			20	161	22	22	963
			27	165	20	21	1005
66-971	120	0.032	12	84	30	32	380
			16	85	28	32	400
			22	89	26	28	429
			29	99	25	27	514
66-972	125	0.032	12	100	26	28	520
			16	103	24	25	542
			22	112	23	24	616
			29	113	23	24	642

Mechanical Properties of Prequalification Propellant (SRO)
As a Function of Cure Time

Figure 43

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PEPCON		HEF	
Batch No.	LSBR at 600 psig, in./sec	Batch No.	LSBR at 600 psig, in./sec
<u>"Scoop" Samples</u>			
468	0.680	467	0.678
469	0.700	470	0.692
471	0.694	472	0.680
$\bar{x}$	0.691	$\bar{x}$	0.683
s	0.0102	s	0.0076
<u>Bottom Cast Samples</u>			
468	0.681	467	0.676
469	0.697	470	0.694
471	0.693	472	0.672
$\bar{x}$	0.690	$\bar{x}$	0.681
s	0.0083	s	0.0117
<u>Combined Samples</u>			
$\bar{x}$	0.691	$\bar{x}$	0.682
s	0.0084	s	0.0089

Comparison of Effect of HEF and PEPCON Oxidizer on
LSBR of ANB-3254 Propellant

Figure 44

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AP Blend	Wt% BRA	No. Batches	"Scoop" Samples From Top Of Mix Bowl		Cast Samples Within		
			$\bar{x}$	Pot - Pot Std. Dev.	$\bar{x}$	Pot Std. Dev.	Pot - Pot Std. Dev.
SCALE-UP I							
70/30	0.9	2	0.604	-	0.605	0.0024	-
65/35	0.9	2	0.641	-	0.640	0.0020	-
65/35	1.3	6	0.676	0.0088	0.670	0.0020	0.0069
SCALE-UP II							
65/35	1.3	5*	0.674	0.0062	0.670	0.0018	0.0065
PRE-QUALIFICATION							
65/35	1.3	6	0.686	0.0117	0.683	0.0020	0.0089
QUALIFICATION							
65/35	1.3	6	0.684	0.0096	-	-	-
COMBINED**							
65/35	1.3	17*	0.681	0.0102	0.676	0.0019	0.0093

* Batch No. 455 (Avg LSBR - 0.646) not included

** All 65/35 SSMP/MA, 1.3 wt% BRA batches

Summary of Burning Rates of A-DD Vertical Mixed Batches of ANB-3254

Figure 45

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	Batch No.	Wt% BRA	SS/MA Ratio	LSBR in./sec at 600 psig	C.P. Motor in./sec at 600 psig	3KS-500 Motor in./sec at 600 psia
<u>First Scale-Up</u>	442	0.90	65/35	0.643	0.635	0.605
	444	0.90	65/35	0.639	0.620	0.600
			Avg.	0.641	0.628	0.602
	443	0.90	70/30	0.606	0.570	0.570
<u>Second Scale-Up</u>	457	1.30	65/35	0.674	0.710	0.690
	458	1.30	65/35	0.684	0.730	0.670
	459	1.30	65/35	0.672	0.700	0.670
			Avg.	0.677	0.713	0.677
<u>Pre-Qualification</u>	461	1.3	65/35	0.667	0.662	0.640
	462	1.3	65/35	0.696	0.690	0.681
	463	1.3	65/35	0.680	0.675	0.695
	464	1.3	65/35	0.683	0.687	0.682
	465	1.3	65/35	0.698	0.710	0.708
	466	1.3	65/35	0.690	0.685	0.689
			Avg.	0.686	0.685	0.682
<u>Qualification</u>	467	1.3	65/35	0.678	0.685	0.700
	468	1.3	65/35	0.680	0.685	0.696
	469	1.3	65/35	0.700	0.730	0.711
	471	1.3	65/35	0.694	0.712	0.740
	472	1.3	65/35	0.680	0.700	0.690
			Avg.	0.686	0.702	0.707
<u>Combined</u>		1.3	65/35	0.684	0.697	0.690

Comparison of Liquid Strand and Motor Burning Rates of
Vertical Mix Batches of ANB-3254

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Compound	Test	Batch No.		Theo.
		PM0144	PM0145	
Submix	Acid Equivalents/100g	0.0409	0.0408	0.0412
	Refractive Index at 25°C	1.4911	1.4911	1.4912
	H ₂ O Content, %	0.082	0.068	
	Ash Content, %	0.12	0.46	
Premix I	Liquid Density at 25°C, g/cc	0.971	0.972	0.970
	Ash Content, %	5.45	5.28	5.45
Premix II	Liquid Density at 25°C, g/cc	1.433	1.431	1.433
	H ₂ O Content, %	0.174	0.166	
	Gas Content, %	0.040	0.051	

Submix and Premix Analyses for Lot 4
Raw Material Qualification Program

Figure 47

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<u>Batch No.</u>	<u>Sample Location</u>	<u>Oxidizer Blend Composition, SS/MA</u>	<u>Uncured Density g/ml</u>	<u>Wt% DER-332</u>	<u>LSBR at 600 psig in./sec</u>
467	Scoop Bottom	HEF/PEPCON	1.748	1.27	0.678
			1.748	1.16	0.676
468	Scoop Bottom	PEPCON/PEPCON	1.749	1.27	0.680
			1.750	1.30	0.681
469	Scoop Bottom	PEPCON/PEPCON	1.748	1.18	0.700
			1.748	1.25	0.697
470	Scoop Bottom	HEF/PEPCON	1.748	1.28	0.692
			1.748	1.24	0.694
471	Scoop Bottom	PEPCON/PEPCON	1.748	1.25	0.694
			1.749	1.18	0.693
472	Scoop Bottom	HEF/PEPCON	1.748	1.28	0.680
			1.748	1.26	0.672
Summary ("Scoop" Samples)	Average, $\bar{x}$		1.748	1.26	0.684
	Standard Deviation, s		0.00045	0.039	0.0096
	Theoretical or Predicted		1.749	1.23	0.679

Uncured Propellant Analyses
Vertical Mixer Lot 4 Raw Material Qualification Program at A-DD

Figure 48

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Batch No.	Cure Time Days	Mechanical Properties at 77°F			
		S_{nm} , psi	γ_m , %	γ_b , %	E_o , psi
467	12	93	24	25	488
	16	94	22	23	505
	20	105	22	23	580
	24	105	21	22	591
	28	111	22	24	624
	32	113	22	23	622
	40	118	21	22	659
	60	138	20	20	872
	90				
468	12	85	24	25	421
	16	101	26	28	509
	20	103	23	25	564
	24	108	24	26	582
	28	111	24	25	619
	32	112	22	24	631
	40	117	22	23	650
	60	130	23	25	737
469	12	92	23	24	506
	16	112	25	26	520
	20	101	21	22	565
	24	116	21	22	681
	28	112	22	22	642
	32	116	22	24	647
	40	124	18	19	780
	60	129	20	21	808
470	12	92	21	23	525
	16	103	23	24	579
	20	104	23	24	560
	24	113	22	23	667
	28	110	22	22	636
	32	113	20	21	696
	40	116	19	20	750
	60	127	20	22	760
471	12	93	24	26	500
	16	107	24	26	560
	20	112	24	25	601
	24	108	24	26	581
	28	118	20	21	720
	32	116	22	24	656
	40	120	21	22	710
	60	136	19	20	830

Mechanical Properties of Qualification Propellant
(130 equiv DER-332, 0.03 wt% FeAA)

Batch No.	Cure Time Days	Mechanical Properties at 77°F			
		S_{nm} psi	γ_m %	γ_b %	E_o psi
472	12	107	23	24	598
	16	115	23	25	647
	20	121	22	24	728
	24	122	23	24	696
	28	120	21	23	698
	32	121	22	24	697
	40	142	23	25	800
	60	134	19	19	822
473	12	84	29	34	387
	16	89	27	30	448
	20	100	24	27	534
	24	104	23	26	581
	28	99	24	26	542
	32	113	22	24	652
	40	109	24	26	583
	60	124	24	25	698

Mechanical Properties of Qualification Propellant
(130 equiv DER-332, 0.03 wt% FeAA)

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<u>Batch No.</u>	<u>Bond Strength at 77°F, psi</u>	
	<u>Tensile</u>	<u>Shear</u>
467	218	125
468	198	134
469	232	156
470	215	140
471	173	126
472	231	140

NOTE: All samples failed at random within propellant

Bond Strength to SD-850-2 Liner of ANB-3254 Propellant Prepared
in the A-DD Qualification Program

Figure 50

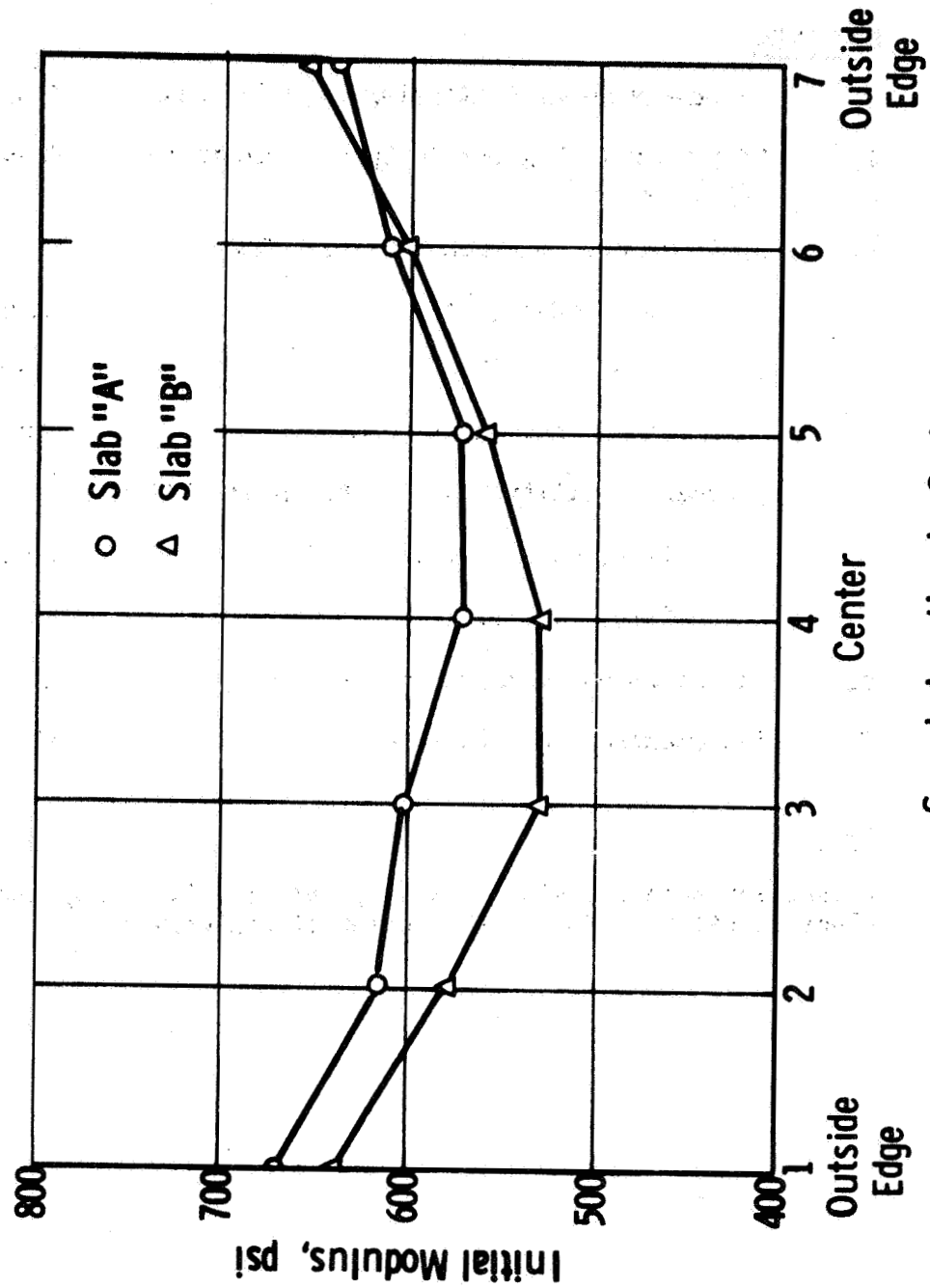
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<u>Batch Numbers (Top/Bottom)</u>	<u>Carton No.</u>	<u>Mechanical Properties at 77°F</u>			
		<u>S_{nm}, psi</u>	<u>γ_m, %</u>	<u>γ_b, %</u>	<u>E_o, psi</u>
471/468	E-1	100	17	18	629
471/468	E-2	95	19	19	542
472/467	E-1	99	17	17	635
472/467	E-2	101	17	18	621

Note: All specimens failed at propellant/propellant interface. Age of surface of first batch was 72 hours at time of casting second batch. Interface cured for 24 days at 135°F.

Mechanical Properties of Propellant-to-Propellant
Bond Test Specimens

Figure 51



Sample Location in Carton

Effect of Specimen Location in One-Half Gallon Carton on Initial Modulus of ANB-3254 Propellant (Batch B-463)

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I. SRO DATA

A.	2" Cube with N. 8 Blasting Cap (5 tests)	Negative
B.	2" Cube with Engineer's Special Blasting Cap (5 tests)	Negative
C.	Ignition and Unconfined Burning Tests:	
	1-in. cube (1 test)	Burned 7 sec.
	2-in. cube (2 tests)	Burned 15 sec.
	Four 2-in. cubes (1 test)	Burned 14 sec.
D.	Thermal Stability Test (48 hours at 75°C):	
	1-in. cube (1 test)	No change
	2-in. cube (1 test)	No change
E.	Autoignition Temperature, °F	495
F.	Recommended Classification	"B"

II. A-DD

Propellant made at A-DD has been given an I.C.C. shipping classification of "B" by the Bureau of Explosives

I.C.C. Classification Testing of ANB-3254

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Cure Time at 135°F, Days	Cure Time at Ambient, Days	Mechanical Properties at 77°F			
		S_{nm} , psi	γ_m , %	γ_p , %	E_o , psi
24	0	104	23	26	581
28	0	99	24	26	542
26	8	107	26	28	543
26	16	102	25	28	522

Effect of Ambient Temperature Storage on Mechanical
Properties of ANB-3254 (Batch B-473)

Figure 54

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Condition	Calculated Maximum	Allowable*	
		ANB-3254	ANB-3105
Interfacial Shear, ** psi			
Storage (1 yr)	4.9	9.8***	20
Firing (0.04 sec)	34.4	385	385
Interfacial Tensile, ** psi			
Storage (1 yr)	0.7	16***	27
Tensile Strain, %			
Storage (1 yr)	5.4	18	10
Firing (0.04 sec)	9.6	22	36

* This allowable value is the measured mean property, adjusted statistically to a probable minimum value, divided by an uncertainty factor of 1.2 and, where applicable, a biaxiality correction factor of 1.2.

** Propellant bonded to SD-850-2 liner.

*** Estimate based on two stress levels; test still in progress.

Comparison of Propellant and Propellant-Liner Bond Properties
for ANB-3105 and ANB-3254 with Motor Requirements

Figure 55

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	Batch Number						
	<u>S0001</u>	<u>S0002</u>	<u>S0003</u>	<u>S0004</u>	<u>S0005</u>	<u>S0006</u>	<u>Theo.</u>
<u>Premix</u>							
PBAN/P-33 density, gm/ml	1.110	1.110	1.109	1.108	1.108	1.108	1.109
<u>Insulation</u>							
MNA, wt%	11.4	12.0	10.2	10.0	9.38	8.16	12.9
PBAN, wt%	21.0	20.4	20.9	18.4	21.2	20.6	20.9
DER-332, wt%	29.8	27.0	30.0	28.4	30.0	30.1	29.7
Density, gm/ml	1.316	1.319	1.318	1.315	1.318	1.320	1.317
Final Shore "A"	55	54	65	63	61	61	

Acceptance Analysis of IBC-101 Castable Insulation
Used for Inert Slivers

Figure 56

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	Analyses			Specification Limits
	<u>Batch 10020</u>	<u>Batch 10021</u>	<u>Batch 10022</u>	
<u>Submix</u>				
Wt% Moisture	0.046	0.051	0.050	0.12 max
Wt% PBAN	52.2	51.8	50.9	52.5 $\pm$ 10
Wt% MNA	31.0	30.9	31.0	32.4 $\pm$ 8
Density, g/ml	1.020	1.021	1.020	1.020 (info.)
<u>Premix</u>				
Density, g/ml	1.053	1.049	1.054	1.054 $\pm$ 0.005
Wt% FeAA	1.66	1.67	1.72	1.84 $\pm$ 0.5
<u>Uncured Liner</u>				
Wt% PBAN	27.0	26.7	28.2	27.0 $\pm$ 10
Wt% DER-332	41.8	44.6	43.1	41.0 $\pm$ 8
Density, g/ml	1.124	1.127	1.124	1.124 $\pm$ 0.007

Acceptance Analyses of SD-850-2 Liner Used in Motor 260-SL-3

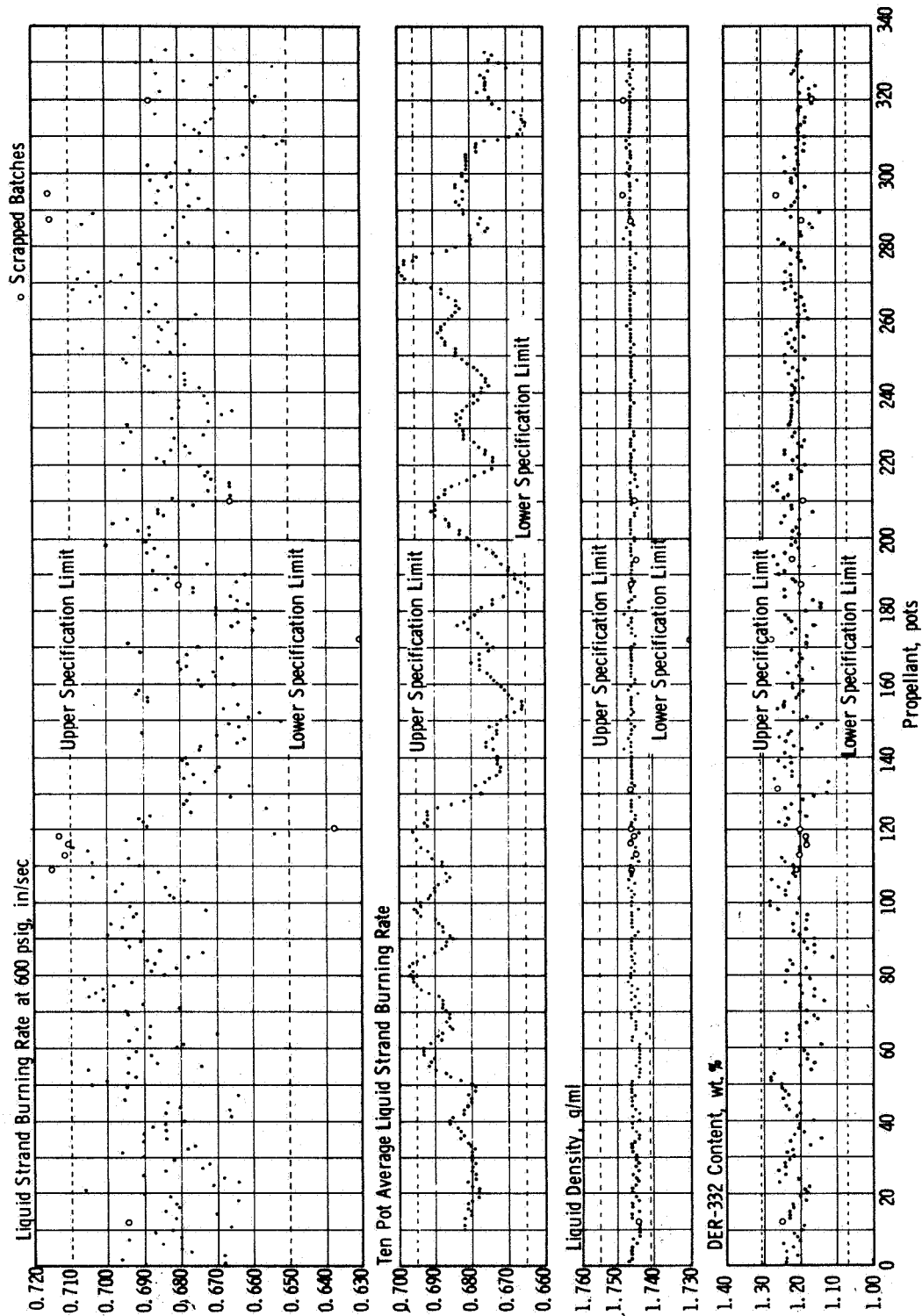


Figure 58

Precast Qualification Data for ANB-3254 Propellant Batches
Prepared for Motor 260-SL-3

Vendor	Screen Size, Mesh					
	48	65	100	150	200	325
I. UNGROUND						
HEF						
n - 20	$\bar{x}$: 92.1	59.9	29.7	11.9	-	0.9
	S.D.: 0.8	1.4	1.6	1.2	-	0.6
PEPCON						
n - 222	$\bar{x}$: 94.3	70.9	32.6	8.7	-	1.0
	S.D.: 0.7	2.0	2.1	1.3	-	0
Are differences significant?						
	$\bar{x}$: yes	yes	yes	yes	-	-
Variance:	no	no	no	no	-	-
II. SLOW-SPEED MIKROPULVERIZER GROUND						
HEF						
n - 80	$\bar{x}$: -	79.5	54.1	32.9	19.7	10.5
	S.D.: -	1.4	2.3	2.2	2.1	1.5
PEPCON						
n - 384	$\bar{x}$: -	88.1	61.6	32.4	18.8	9.0
	S.D.: -	1.0	1.6	1.6	1.6	1.7
Are differences significant?						
	$\bar{x}$: -	yes	yes	yes	yes	yes
Variance:	-	yes	yes	yes	yes	yes
PEPCON Grinds 1115-1256						
n - 135	$\bar{x}$: -	-	-	-	-	9.6
	S.D.: -	-	-	-	-	1.1
PEPCON Grinds 1257-1426						
n - 167	$\bar{x}$: -	-	-	-	-	8.6
	S.D.: -	-	-	-	-	2.0
Are differences significant						
	$\bar{x}$: -	-	-	-	-	yes
Variance	-	-	-	-	-	yes

Analysis of Oxidizer Particle Size

Figure 59

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Ammonium Perchlorate

<u>Vendor</u>	<u>Lot</u>	<u>Friability, %</u>
Ampot	5170	5.5
Ampot	5152	3.0
Ampot	5165	3.0
Pepcon	64007	8.7
Pepcon	64016	7.8
Pepcon	64002	4.1
Pepcon	64008	7.6
Pennsalt	1438	6.0
Pennsalt	1347C	3.2

Friability of Class I Ammonium Perchlorate

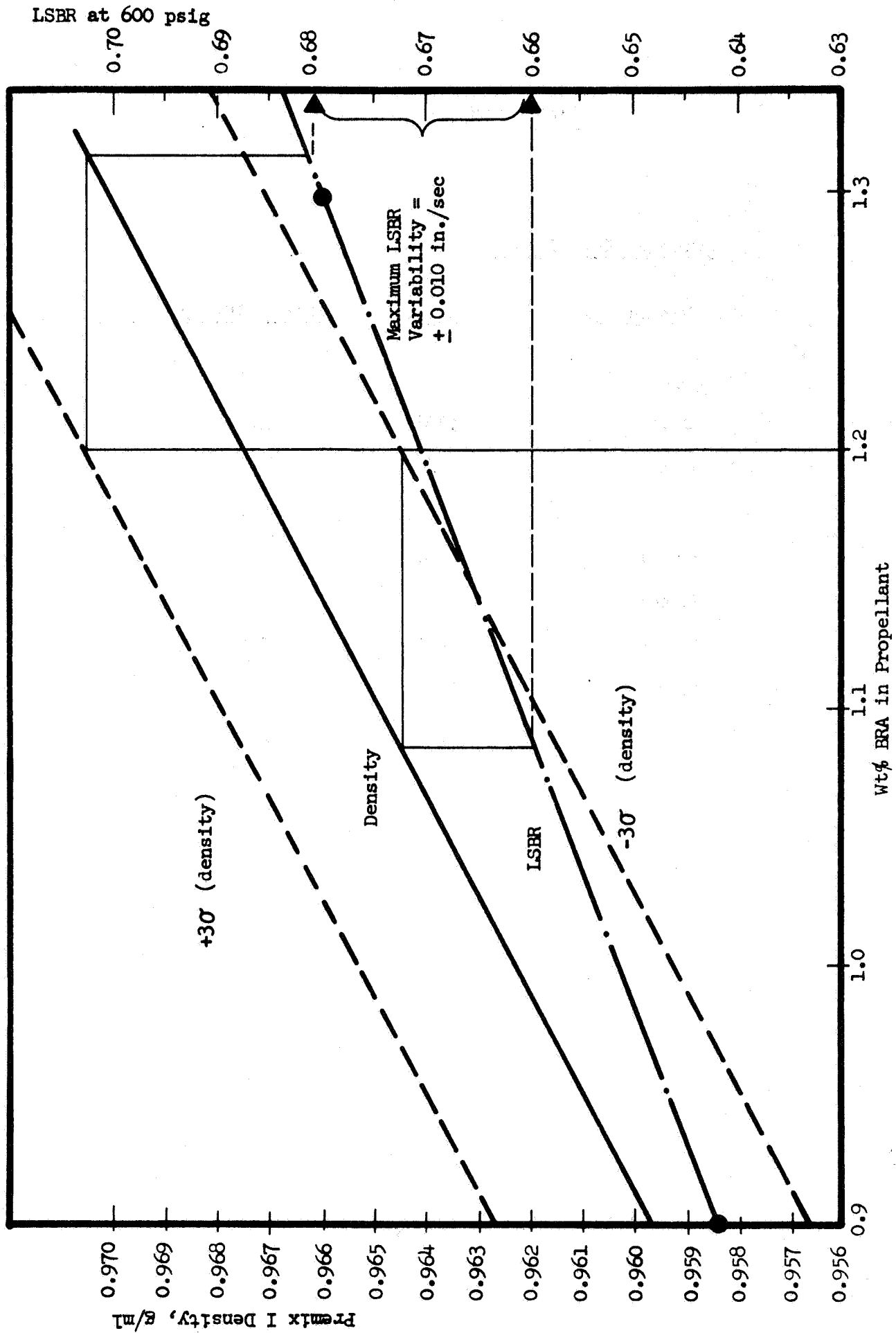


Figure 61

Effect of Measured Variability of Premix I Density on Expected Variability of LSBR

	1.3 Wt% BRA (n = 14)			1.2 Wt% BRA (n = 33)		
	$\bar{x}$	s	Limits	$\bar{x}$	s	Limits
Submix						
Wt% H ₂ O	0.048	0.0098	0.20 Max	0.056	0.0067	0.20 Max
Acid Equiv/100g	0.0409	0.0003	0.0410 $\pm$ 0.005	0.0409	0.0004	0.0410 $\pm$ 0.005
Ref. Index	0.4911	0.00006	0.4911 $\pm$ 0.002	0.4910	0.00009	0.4911 $\pm$ 0.002
Premix I						
Density, g/ml	0.970	0.0011	0.972 $\pm$ 0.007	0.968	0.0007	0.968 $\pm$ 0.007
Wt% Ash	5.25	0.133	5.37 $\pm$ 0.50	4.89	0.151	5.05 $\pm$ 0.50
Premix II						
LSHR, in./sec	0.685	0.0103	0.680 $\pm$ 0.030	0.680	0.0127	0.680 $\pm$ 0.030
Density, g/ml	1.745	0.009	1.748 $\pm$ 0.007	1.746	0.0006	1.748 $\pm$ 0.007
Motor Averages						
	$\bar{x}$	s	Limits			
LSHR, in./sec	0.682	0.0143	0.680 $\pm$ 0.030			
Density, g/ml	1.746	0.0007	1.748 $\pm$ 0.0007			
Wt% DER-332 in Uncured Propellant	1.20	0.0307	1.19 $\pm$ 0.12			
Wt% DER-332 in Final Fuel	2.64	0.003	2.62 $\pm$ 0.10			

Submix, Premix, and Uncured Propellant Acceptance Data, Motor 260-SL-3

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<u>Cure Time at 135°F, days</u>	<u>Mechanical Properties at 77°F/Std. Deviation</u>			
	<u>S_{nm}, psi</u>	<u>γ_m, %</u>	<u>γ_b, %</u>	<u>E_o, psi</u>
12	72/9.3	29/2.3	33/3.7	325/44.8
16	77/8.7	29/2.1	32/3.4	352/53.5
20	80/8.4	28/2.0	30/2.5	372/51.9
24	84/8.4	27/2.6	29/3.4	395/51.0
28	87/8.9	27/2.3	30/3.4	411/54.4
32	90/9.1	27/2.0	29/2.7	429/57.8

NOTE: Data obtained from every sixth batch (total of 56)
cast into 260-SL-3.

Mechanical Properties of ANB-325⁴ Propellant Cast into Motor 260-SL-3

Figure 63

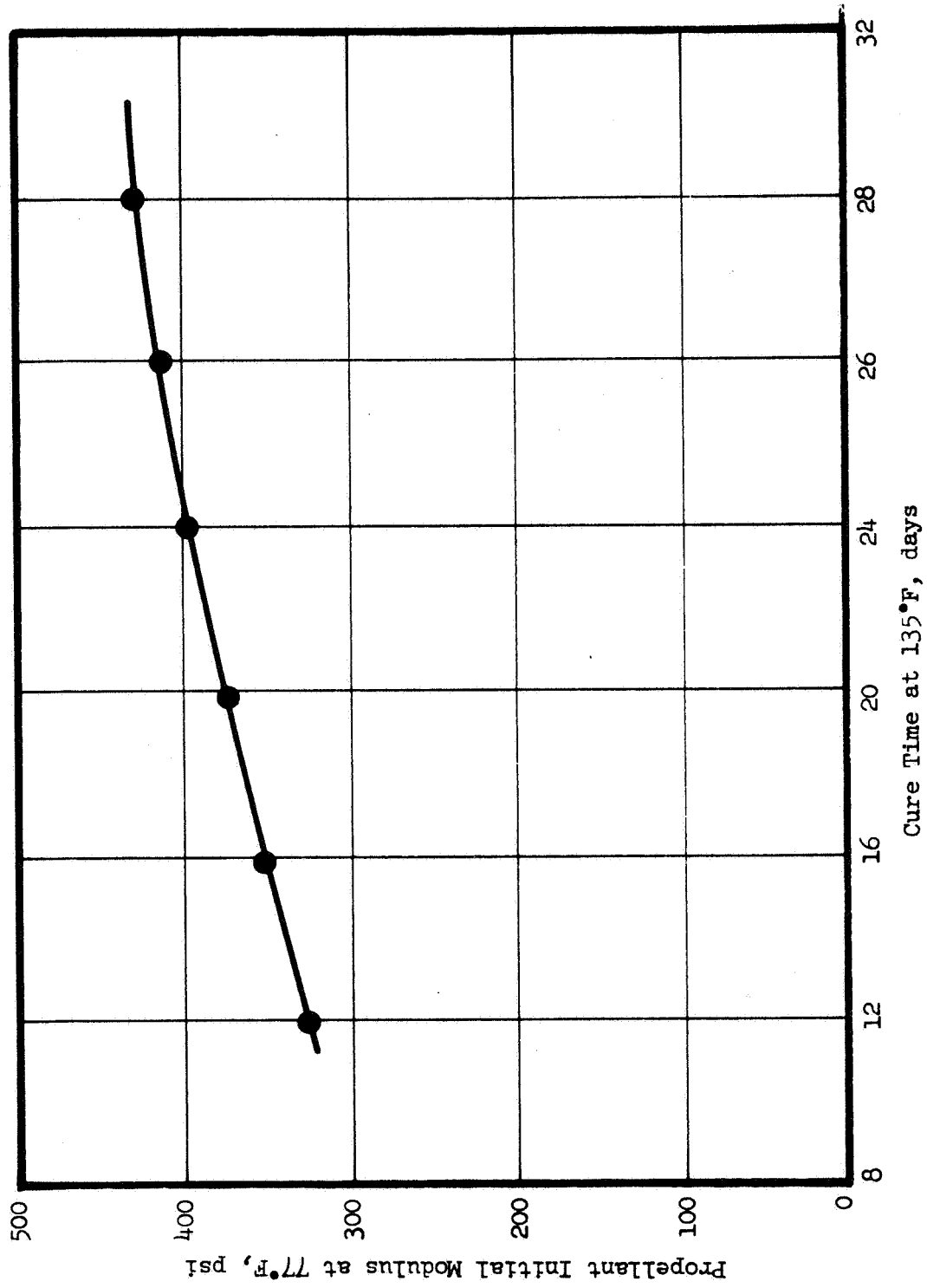


Figure 64

Effect of Cure Time at 135°F on Initial Modulus of ANB-3254 Propellant Cast into Motor 260-SL-3

APPENDIX

Glossary of Terms

A-DD	Aerojet Dade Division
AP	Ammonium perchlorate; NH_4ClO_4 ; oxidizer
BRA	Burning-rate additive
BRA-101	Aerojet proprietary compound; burning-rate additive
DDS	Dodecenylsuccinic anhydride; chain extender
DER-332	Diglycidyl ether of Bisphenol A; diepoxide curing agent
DOA	Di(2-ethylhexyl)adipate; plasticizer
E_o	Initial modulus of elasticity
FeAA	Ferric acetylacetonate; curing catalyst
Fe_2O_3	Ferric oxide powder; burning-rate modifier
GFM	Government furnished material
HEF	H.E.F., a division of Hooker Chemical Corp.; oxidizer vendor
HSMP	High-Speed Mikro-Pulverizer ground oxidizer
Iron Blue	Iron Blue pigment; burning-rate modifier
L-45	Silicone fluid, polydimethyl siloxane; anti-foam agent
LSBR	Liquid-strand burning rate
MA	Mikro-Atomizer ground oxidizer
MMDPO	Methoxymethyl diphenyloxide; ballistically active plasticizer
MNA	Methylnadic anhydride; chain extender
PEPCON	Pacific Engineering and Production Co. of Nevada; oxidizer vendor
PBAN	Terpolymer of polybutadiene, acrylic acid and acrylonitrile; binder component
Sb_2O_3	Antimony oxide; insulation filler material
S_{nm}	Nominal maximum tensile stress, psi
SRO	Aerojet Solid Rocket Operations
SSMP	Slow-Speed Mikro-Pulverizer ground oxidizer
UG	Unground oxidizer
γ_m	Elongation at nominal maximum tensile stress, %
γ_b	Elongation at break, %