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MEMORANDUM REPORT ARBRL-MR-03096

BURNING RATE OF PRESSED STRANDS OF A
STOICHIOMETRIC MAGNESIUM-SODIUM NITRATE MIX

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March 1981



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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I. INTRODUCTION

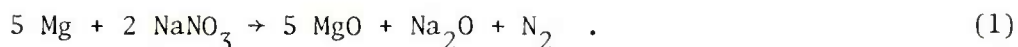
Pyrotechnics see frequent military use because they offer light (tracer and illuminating rounds), heat (incendiary rounds), and smoke (obscurants and signaling devices).¹ Although pyrotechnics have recently been tested as propellants (fuel-rich pyrotechnics burn to produce reactive metal vapors),²⁻⁷ studies of their combustion lag far behind conventional propellants.

The studies performed have also focused on the behavior of pyrotechnics near atmospheric pressure. The new role for pyrotechnics as fuel-rich propellants requires higher pressure combustion data starting with burning rates of binary magnesium-sodium nitrate pressed strands. The customary binder was eliminated to simplify interpretation of results, and to provide further data for understanding combustion of propellant candidates. Without the binder, though, burning rate reproducibility suffered.

II. EXPERIMENTAL

Starting mix for the samples was made from 24.9894g of sodium nitrate (oven-dried and pulverized) and 17.8739g of magnesium (50 mesh, atomized). The ratio of sodium nitrate to magnesium corresponded to a stoichiometric mix according to

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- ¹*"Military Pyrotechnic Series, Part Four, Design of Ammunition for Pyrotechnic Effects," AMC Pamphlet AMCP 706-188, March 1974.*
 - ²*J.R. Ward, F.P. Baltakis, and S.W. Fronchick, "Wind Tunnel Study of Base Drag Reduction by Combustion of Pyrotechnics," BRL Report No. 1745, October 1974. (AD #C016949L)*
 - ³*K. Anderson, N.E. Gunners, and R. Hellgren, "Swedish Base Bleed-Increasing the Range of Artillery Projectiles Through Base Flow," Propellants and Explosives, 1, 69 (1976).*
 - ⁴*K.C. Schadow, "Base Drag Reduction by Combined External Burning/Base Burning," Proceedings of the 1980 JANNAF Propulsion Meeting Vol. I, p. 353, CPIA Publication 315, March 1980.*
 - ⁵*M.K. King and L.B. Childs, "Development of Highly-Magnesium Loaded Fuel-Rich Propellants," 12th JANNAF Combustion Meeting Proceedings, Vol. III, 201, CPIA Publication 273, December 1975.*
 - ⁶*M.K. King and J.L. Fields, "Combustion of Highly-Magnesium Loaded Fuel-Rich Propellants," 13th JANNAF Combustion Meeting Proceedings, Vol. IV, 85, CPIA Publication 281, December 1976.*
 - ⁷*M.K. King, "Combustion Studies of Fuel-Rich Propellants, Atlantic Research Final Report TR-PL-5520, AFOSR Contract No. F44629-71-C00124, August 1976.*



The sodium nitrate and magnesium was stirred thoroughly with mortar and pestle.

Pressed strands of magnesium and sodium nitrate for the burning rate determinations were made with a Baird pellet press. Sample preparation started by placing a weighed amount of igniter ("eimite") in one end of the pellet press. A weighed portion of the magnesium-sodium nitrate mix was added and a 33.5 Kn force applied to the mixture for at least two minutes. Considerable trial-and-error was necessary to find force and holding time which would produce strands with uniform density. The pressed strand was removed from the pellet press, weighed, and the dimensions taken. The strands were approximately 4mm x 4mm x 22mm, formed by a pressing pressure of 380 MPa on the strand (88mm² pressing area).

The strands were inhibited with a thick coat of DUCO cement. As with the pressing technique, considerable trial-and-error was spent finding a suitable inhibitor. A thick paste made from DUCO cement and a one-to-one magnesium-sodium nitrate mix was applied to the end of the strand with the igniter. A coil of nichrome wire was included in the paste leaving two 10mm long leads protruding from the paste. The DUCO cement hardened overnight after which the strands were baked at 373K to complete drying. Failure to dry the cement led to uneven burning along the sides of the strands. The strands were conditioned at 294K for the burning rate determinations.

Burning rates were measured in a gas cylinder equipped with two directly opposed viewing ports. The sample was clamped into place on a tray in the gas cylinder and the ignition wires glued to the sample were clamped to wires leading from the ignition power supply. A ruler and an ID card were placed before the sample and photographed with a HYCAM high-speed camera. The ruler and ID card were removed and the sample repositioned if necessary. The gas cylinder was sealed, evacuated, and nitrogen pressuring gas added after the cylinder was isolated from the vacuum line. In one run oxygen was the pressurizing gas. The ignition power supply ignited the sample and turned on the HYCAM camera to photograph the burning strand. The HYCAM camera reaches desired frame speed in four to five milliseconds. Upon completion of the run, the cylinder is depressurized through a "bleed-off" valve and the strand burner readied for the next run.

After the film was developed, the burning rate was determined with a Vanguard motion analyzer. From the picture of the ruler, a correlation between film distance and actual distance was established. Time was determined from timing light exposures focused on the edge of the film. The total distance burned was measured at seven or eight times. The burning rate was taken as the slope of the line drawn through a plot of distance burned versus time.

III. RESULTS AND DISCUSSION

Table 1 summarizes the mean burning rates and sample standard deviations at the various pressures tested. Table 2 provides the burning rates and dimensions for the individual strands.

TABLE 1. SUMMARY OF BURNING RATES AT VARIOUS PRESURES

<u>Pressure, MPa</u>	<u>Number of Samples</u>	<u>Burning Rate*, g/cm²-s</u>
0.10	3	1.9 ± 0.6
.69	3	3.4 ± 0.5
1.72	3	5.7 ± 1.0
3.45	7	5.2 ± 0.6
5.17	7	5.5 ± 0.8
6.89	8	6.0 ± 0.7
8.62	5	6.1 ± 1.0

*Error given as sample standard deviation.

Figure 1 plots burning rate vs pressure using the data in Table 1 where one sees the burning rate is relatively insensitive to changes in pressure above 2 MPa.

Figure 2 illustrates the fit of the data in Table 2 to

$$r = ap^n, \quad (2)$$

where r = burning rate, g/cm²-s,
 p = pressure, MPa, and
 a, n = constants.

A "slope break" is observed near 2 MPa with a pressure exponent 0.4 in the low pressure region and 0.05 in the high pressure region.

King and Fields^{5,6} measured the burning rates of fuel-rich magnesium-teflon, magnesium-HMX-binder, and magnesium-proprietary oxidizer-binder in the same pressure regime. Precise compositions and specifications are classified. The magnesium-teflon exhibited a positive slope break, while the magnesium-proprietary oxidizer had a negative slope break like the magnesium-sodium nitrate mix. The magnesium-HMX propellant burning rate obeyed equation (2) over the pressure range studied.

TABLE 2. BURNING RATES AND DIMENSIONS OF PRESSED STRANDS OF
MAGNESIUM AND SODIUM NITRATE

Pressure, MPa	Area, cm ²	Density, g/cm ³	Mass, g	Burning Rate, cm/s	Burning Rate, g/cm ² -s
0.10	0.225	1.93	0.967	0.61	1.2
.10	.215	1.94	.929	1.22	2.4
.10	.228	1.90	.965	1.07	2.0
0.69	0.200	1.95	0.866	1.88	3.7
.69	.174	1.96	.761	1.88	3.7
.69	.218	1.93	.933	1.50	2.9
1.72	0.232	1.95	1.002	2.79	5.4
1.72	.211	1.93	.788	3.66	6.8
1.72	.216	1.86	.917	2.59	4.8
3.45	0.225	1.89	0.944	2.59	4.9
3.45	.190	1.86	.785	3.07	5.7
3.45	.194	1.87	.806	2.97	5.6
3.45	.235	1.97	1.028	2.74	5.4
3.45	.225	1.96	0.983	2.84	5.6
3.45	.235	1.98	1.038	1.98	3.9
3.45	.196	1.97	0.860	2.54	5.0
5.17	0.213	1.97	0.890	2.82	5.6
5.17	.209	1.97	.918	2.21	4.4
5.17	.209	1.89	.880	3.38	6.4
5.17	.208	1.94	.902	2.54	4.9
5.17	.211	1.94	.911	3.02	5.9
5.17	.213	1.97	.935	2.54	5.0
5.17	.181	1.94	.781	3.35	6.5
6.89	0.225	1.88	0.945	3.99	7.5
6.89	.203	1.94	.871	2.56	5.0
6.89	.226	1.92	.962	3.00	5.8
6.89	.243	1.93	1.034	3.28	6.3
6.89	.217	1.95	0.942	2.89	5.6
6.89	.228	1.90	.960	3.30	6.3
6.89	.219	1.93	.937	2.97	5.7
6.89	.243	1.97	1.065	2.87	5.6
8.62	0.216	1.98	0.948	2.66	5.3
8.62	.239	2.00	1.046	2.43	4.9
8.62	.206	1.98	.910	3.12	6.2
8.62	.223	1.93	.950	3.73	7.2
8.62	.224	1.95	.960	3.56	6.9

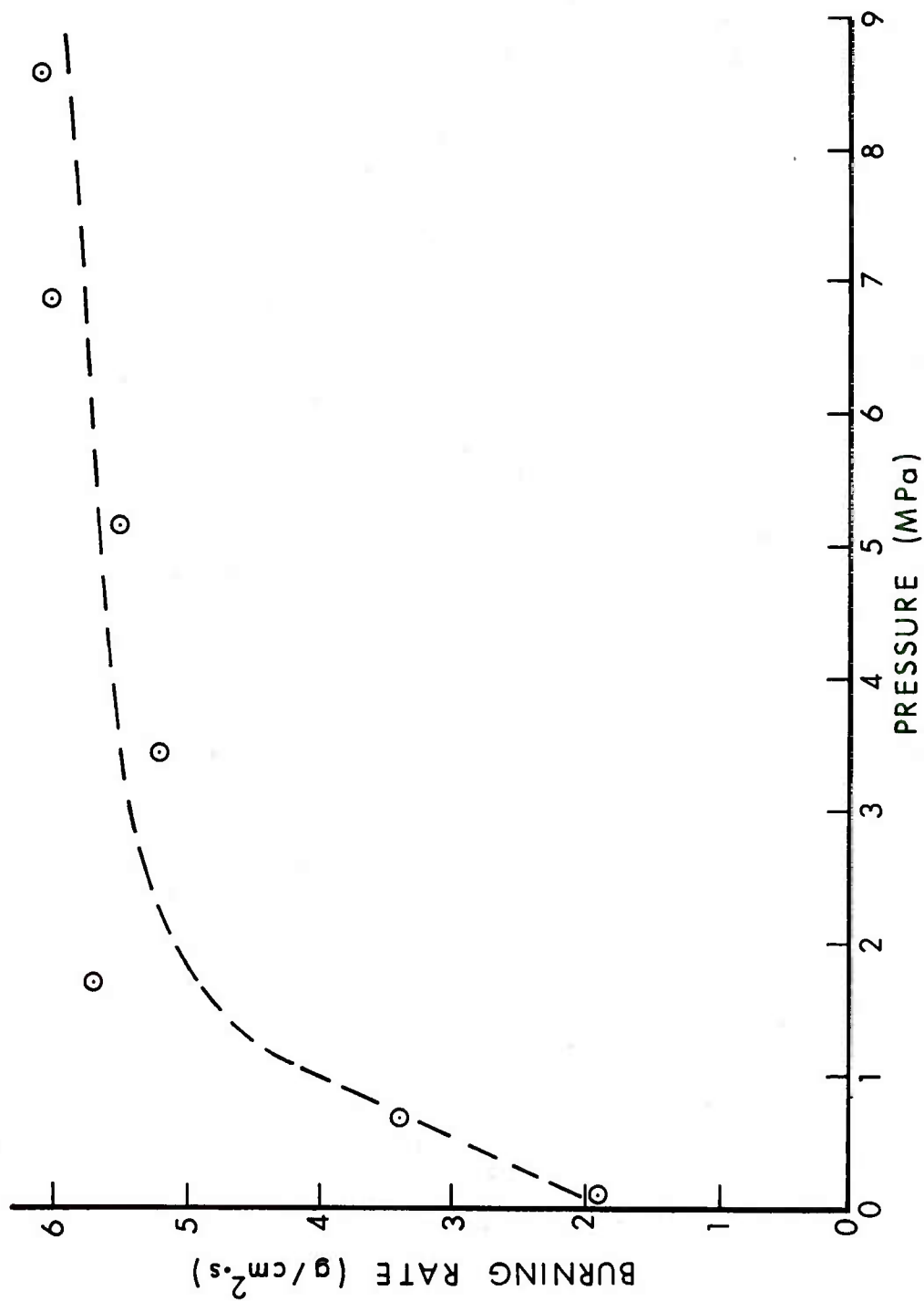


Figure 1. Burning Rate vs. Pressure for Pressed Magnesium-Sodium Nitrate Strands.

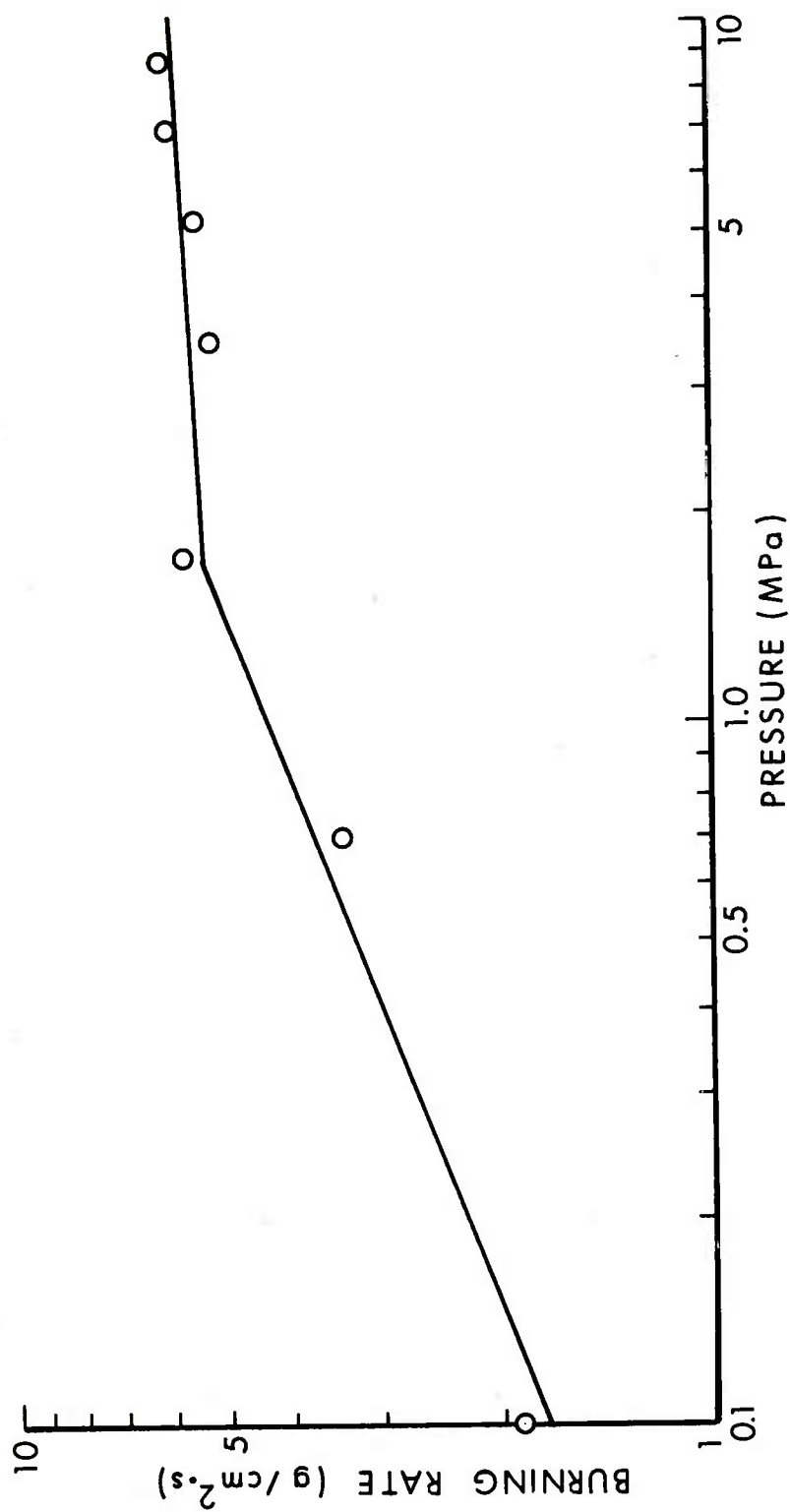


Figure 2. Burning Rate vs. Pressure of Pressed Magnesium-Sodium Nitrate Strand

Other data on the burning rate vs. pressure of pyrotechnic mixes are available at atmospheric and sub-atmospheric pressure.

Rees⁸ reported the burning rate of a 30/70 by weight mixture of ferro-titanium metal and barium peroxide fell from 10 m/s at atmospheric pressure to 0.4 m/s at 20 kPa. Rees estimated the pressure exponent as 0.7 for the region 10 to 50 kPa while the burning rate was insensitive to further increase in pressure.

Resnick⁹ studied the effect of altitude and temperature on the burning times of flare mixes composed of magnesium, sodium nitrate, and a binder. Figure 3 is a plot taken from Resnick's report of inverse burning time vs pressure plotted on logarithmic scales. The fuel-rich mix, Y-2, has a pressure exponent less than 0.1 in the region near atmospheric pressure, while the nearly stoichiometric mix, Y-1, has an exponent of 0.3 in the same pressure region. The fuel-rich mix also has a larger burning rate at a given pressure.

Resnick's experiments include the effect of the binder. One can show the trends that Resnick observed for flares hold for binary magnesium-sodium nitrate mixes. This can be done by combining the present results with earlier burning rate measurements¹⁰ on fuel-rich, magnesium-sodium nitrate strands (60/40 percent by weight). Table 3 summarizes the burning rates from the earlier tests along with burning rates from the present series of experiments in a common pressure range. One sees the fuel-rich mix burns faster from comparing burning rates at 0.1 MPa. Using data for the 60/40 mix at the only two pressures available gives a pressure exponent of 0.05 between 0.1 and 1.0 MPa. Burning rates for the 60/40 mix were only done at two pressures because the primary purpose of the experiments was to determine temperature sensitivity.

The burning-rate insensitivity to pressure suggests the burning rate is unaffected by gas phase reactions. To test this hypothesis, one strand of the stoichiometric mix was burned in an oxygen atmosphere at 3.45 MPa. The burning rate in oxygen was 5.7 g/cm²-s; Table 1 reports the burning rate in nitrogen as 5.2 ± 0.6 g/cm²-s suggesting reaction of magnesium with oxygen in the surrounding atmosphere does not affect the burning rate of the pressed strand. This result is consistent with

⁸G.W. Rees, "Non-Gaseous Layer Combustions: Part 2. The Effects of Reduced Pressure and Rotational Motion," *Fuel*, 52, 226 (1973).

⁹S. Resnick, "Simulated High-Altitude Tests of Illuminating Compositions," Picatinny Arsenal Technical Report No. 2166, April 1955.

¹⁰R.C. Strittmater, H.E. Holmes, and J.R. Ward, "Sensitivity of Burning Rate to Initial Temperature for a Binary Magnesium-Sodium Nitrate Mix," BRL Memorandum Report No. 02889, December 1978. (AD #A066119)

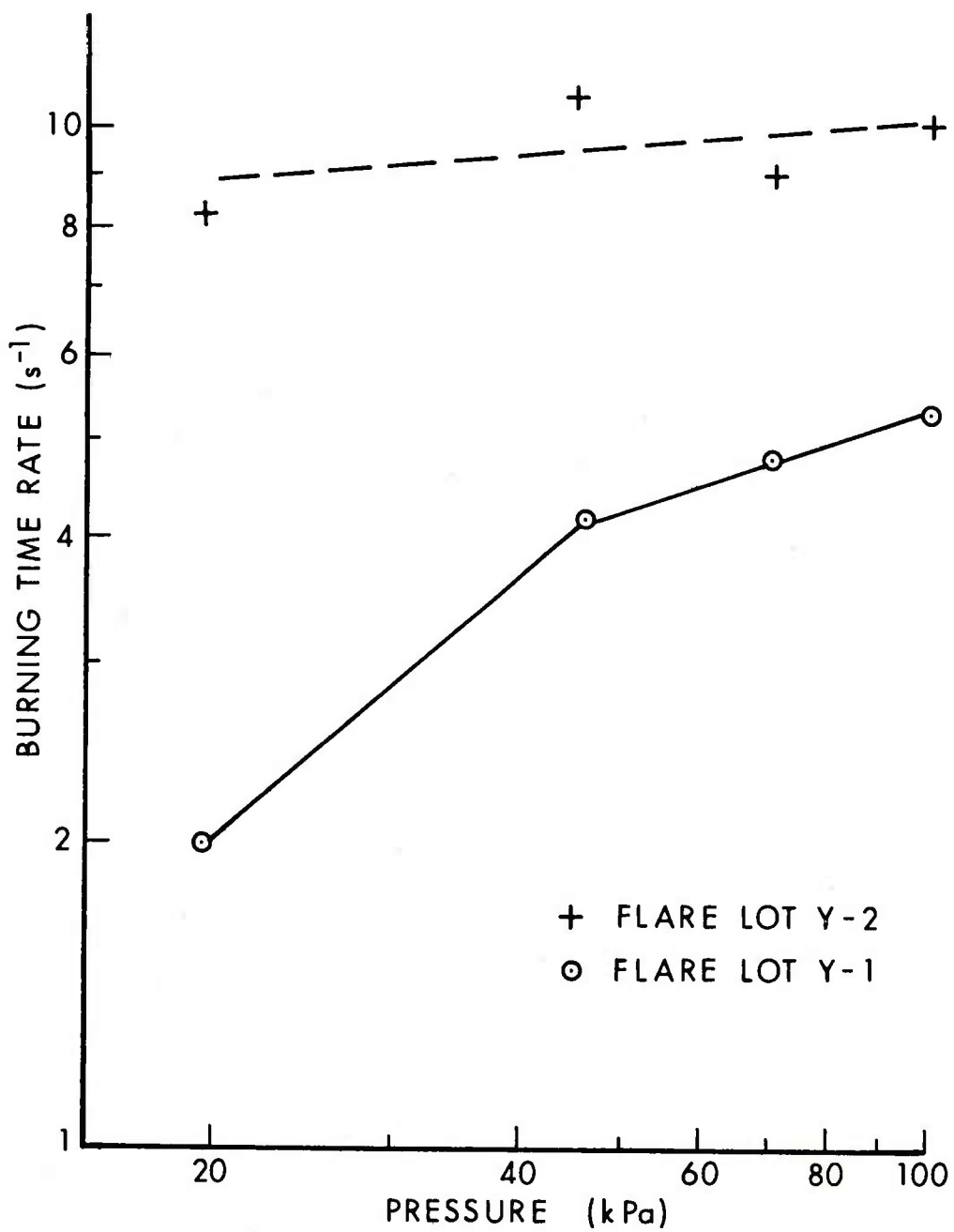


Figure 3. Burning Rate vs. Pressure for Yellow Flares at 294K

TABLE 3. BURNING RATES OF BINARY MAGNESIUM-SODIUM NITRATE MIXES

Pressure, MPa	Burning Rate, g/cm ² -s	
	Stoich	Fuel-Rich
0.10	1.9 ± 0.6	3.7 ± 0.2
0.69	3.4 ± 0.5	-
1.0	-	4.2 ± 0.1

* Error given as sample standard deviation.

**Reference 10.

Bond and Jacobs^{11,12} who found replacing argon with air had no effect on the decomposition of sodium nitrate-magnesium mixes or on the time to ignition of the same mixes.

IV. CONCLUSIONS

1. The burning rate of pressed strands of a stoichiometric magnesium-sodium nitrate mix was measured over the pressure range of 0.1 to 8.6 MPa. The burning rate increases with pressure from 0.1 MPa to 2 MPa above which the burning rate is insensitive to pressure.

2. The burning rate determined in a pure oxygen atmosphere at 3.45 MPa was the same as the rate determined in nitrogen at the same pressure.

3. The burning rate of strands made from a fuel-rich mix of magnesium-sodium nitrate was nearly twice as fast as that of the strands prepared from the stoichiometric mix.

4. A plot of burning rate vs pressure on logarithmic scales for the stoichiometric mix exhibited a "slope break" near 2 MPa. The slope of the line in the low pressure region was 0.4; in the high pressure region, the slope was 0.05. The fuel-rich magnesium-sodium nitrate mix had a slope of 0.05 over the 0.1 to 1.0 MPa pressure range, suggesting that the higher magnesium content reduces the slope-break pressure as well as increases burning rate.

¹¹B.D. Bond and P.W.M. Jacobs, "The Thermal Decomposition of Sodium Nitrate," *J. Chem. Soc. A*, 1265 (1966).

¹²B.D. Bond and P.W.M. Jacobs, "Chemical Reaction and Ignition in Mixtures of Magnesium and Sodium Nitrate," *Comb. and Flame*, 10, 349 (1966).

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