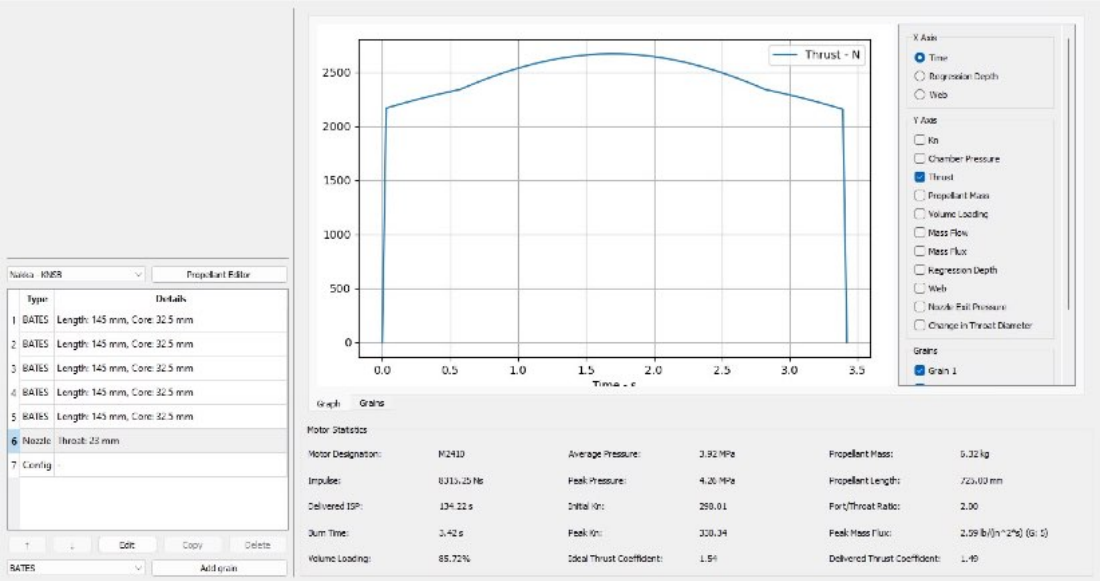
Static Test #5 Failure Analysis



Pretest Conditions

1. <u>Grains</u>

   5 KNSB grains in dry storage for >2 months

   Grain assembly involved wrapping them together in liner material (ceramic cloth and paper)

   2 top grains wrapped separately.

   Length: 145 mm
   D: 86 mm
   Core d: 33 mm
   Port/Throat Ratio: 2.00
   L/D ratio:8.43

2. Igniter

   KNSB + Fe2O3 formulation

   D: approx 30 mm

   Length: approx 145 mm

3. Casing

   Length: 850 mm

   Thickness: 3 mm

   D(outside) 100 mm

   Safety factor: 1. 648

Test Observations

1. Barely 1-sec burn followed by explosion
2. Casing failure at ⅔ position from the bulkhead side
3. No sign of melting at all on any component
4. All grains consumed in explosion. No leftover unburnt grain or presence of grain pieces in the immediate surroundings.
5. Bulkhead & nozzle completely intact
6. Test stand was fairly unscathed except for 1 diagonal bar which was completely dislodged and another which was dislodged on one end.
7. Most electronics sustained burns that rendered then unfunctional.

Failure Hypothesis

Failure was primarily due to over-pressure which could have been caused by one of the following reasons:

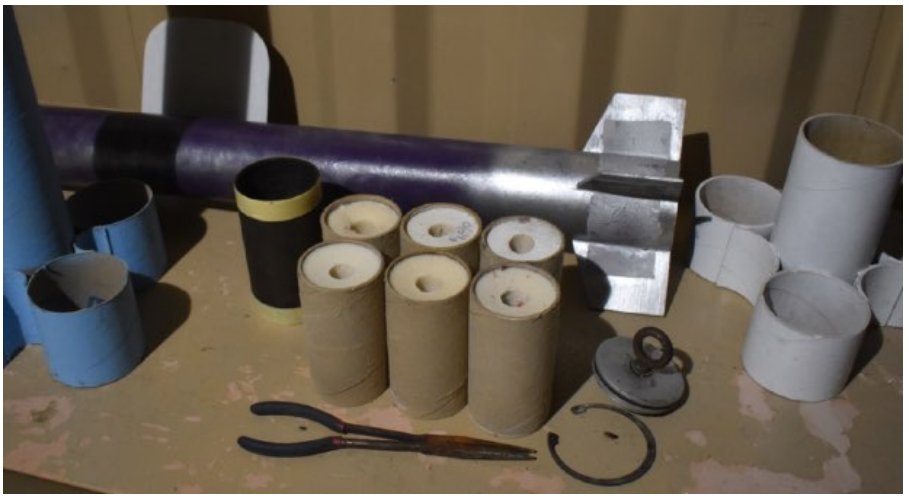
1. **Back-Burn** due to porous liner material and insufficient inhibition of the outer grain surfaces. Hot gaseous material seeped through the porous liner getting to the back surface of the grains. Burning from all the exposed surfaces, this leads to a significant pressure rise (higher than temperature rise) leading to an explosion.
2. Utilization of an **uncharacterized motor** with unknown a and n values. Actual burn rate could be higher than theorized.
3. **High mass flux** of grain #5 (nozzle end).
4. **Poor ignitor design** leads to high initial chamber pressure.

The failure is hypothesized to have been a confluence of these factors but major contributions might have been from back burn and utilization of an uncharacterized motar.

Next Step Suggestions

1. Preventing Backburn

We suggest addressing all the above issues starting primarily from the most probable, back burn. The liner material and inhibition method utilized was identified to be insufficient. Improved methods for both should be employed. We suggest using of a kraft paper liner tube to act as both inhibitor and liner. This would allow for direct casting eliminating any space between the inhibitor and the grains. The solid nature of the kraft paper tube also eliminates any grain movement during hot fires. A final result ought to look like so,



To obtain the requisite thickness and diameter of the cardboard tube, several layers of kraft paper would be rolled on a **mandrel** with **epoxy** to form a tight bond.

2. Characterization of the mortar

It is paramount to characterize the mortar and verify its values a, and n values which have a very significant effect on the **burning rate**. Typically, the burning rate,r is related to the chamber pressure Pc by,

$$r = a.Pc^{n}$$

Where, r = burning rate

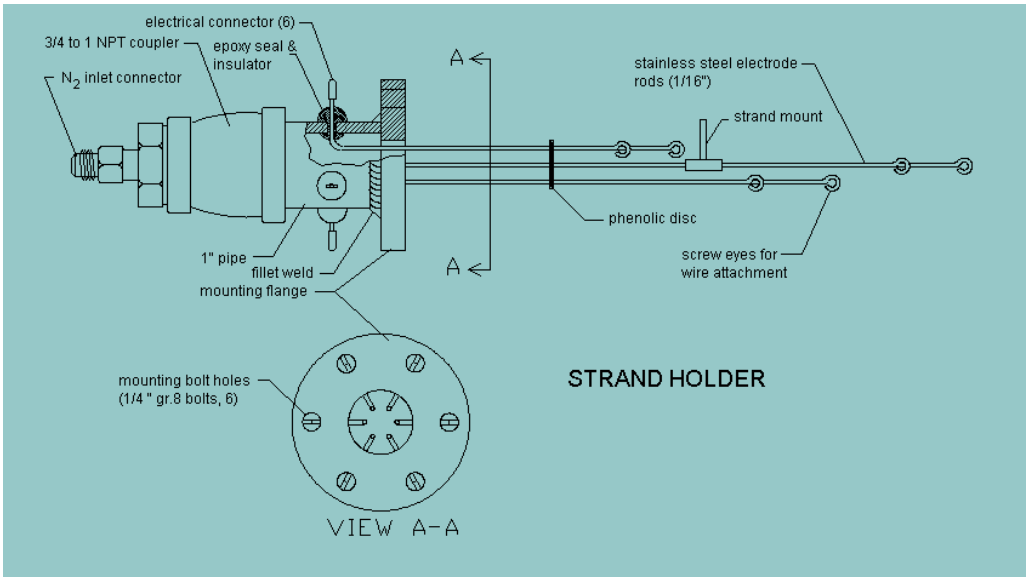
a = burn rate coefficient

n = pressure exponent

The values of a and n are determined empirically for a particular propellant formulation, and cannot be theoretically predicted. These can be determined experimentally in one of two ways:

I. Strand Burner Method

A small amount of propellant in a large pressure vessel essentially gives a constant-volume, constant-pressure burn. Each run determines the burn rate at a given pressure. Many runs are required to give a burn rate vs pressure curve. More info is outlined in Strand Burner for Burn Rate Measurements. A typical strand burner setup looks as such,



Ii. Determination from Static Test Pressure measurement

If the pressure-time curve is available, the burn rate coefficient and pressure exponent can also be deduced from static test data. This method is fairly simple, as only the **test pressure data** is needed. The methodology is outlined in Burn Rate Determination from Static Test Pressure Measurement.

The setup for measuring both pressure and thrust needs a few additional components aside from the usual load cell. These are describe in Measuring Chamber Pressure and Determining C-Star and Thrust Coefficient. Setup may look so,

3. Igniter Design

The igniter serves two major purposes for which its design must address:

1. Generating a heat flux of hot dense gases which should ignite all the grains simultaneously.
2. Pressurizing the combustion chamber to the design pressure such that the burn rate is sufficient to maintainthis pressure.

Generally, for high class motors such as our, pyrogen igniter are desired compared to pyrotechnic igniter. Pressure generated by combustion of the igniter charge may be estimated through,

$$P = \lambda\Delta\frac{\rho}{\rho-\Delta}G + Pa$$

Where,

P = pressure in combustion chamber at time, t

r= density of charge material

D = loading density = C / V

C = original mass of charge

V = free volume of combustion chamber at time, t

λ = R T/ M "effective force" (energy),

R = universal gas constant

M = effective molecular weight of combustion products (system mass divided by number of moles of gas)

T = adiabatic flame temperature

G = fraction of original charge mass consumed by time, t

P_a = atmospheric pressure