



## *DoubleSShot*

Characterization of KNSB propellant with regard to curing rate  
and associated mechanical properties

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## **Introduction**

The potassium nitrate/sorbitol propellant (KNSB) is different than most other sugar-based propellants with regard to mechanical properties following the melt-casting process. Upon cooling, most sugar-based propellants solidify to a state that is rigid, with a typical elastic response to applied stress. This mechanical property is noted as being of high elastic modulus with a brittle nature. KNSB, when it cools following melt-casting, initially retains its viscous quality similar to that of the melted state, except being of much higher viscosity. Over the course of hours, the propellant begins to set up (“cure”), taking on a viscoelastic property. The response to applied stress is partly viscous (flows) and partly elastic (springs back once stress is removed). It is believed that over a period of weeks or months, the viscoelasticity gives way to a purely rigid state, similar to the other sugar-based propellants. The main purpose of this investigation is to attempt to characterize the metamorphosis of KNSB from its initial viscous state to its eventual rigid state. A secondary objective is to determine if the time rate at which the curing takes place can be modified or inhibited by storing the propellant at a low temperature.

The rationale for gaining a better understanding of this curing process is due to the adversity of utilizing a propellant that possesses a high elastic modulus combined with a brittle nature. High elastic modulus means that when a body is deformed, the result is a high internal stress level despite a very small strain. Brittle nature infers that when a sufficiently high stress level is attained, fracture suddenly occurs. This is opposed to “ductile” nature, whereby initial elastic deformation gives way to plastic deformation which often serves to limit the stress level to below that of fracture. Propellant that retains some degree of viscoelastic behaviour can be considered to be ductile, which is clearly a more desirable trait for a propellant. As such, it may be advantageous to fire a KNSB powered rocket motor within a certain time frame following casting, before it loses its ductility. On the other hand, the viscous attribute must be limited to avoid the tendency of a cast propellant grain to “slump”, or lose its original shape due to gravity. The consequence of slump can be likewise detrimental to a rocket motor’s performance.

## **Scope**

This document describes the procedure to measure the viscoelastic properties of KNSB specimens and observe how that property changes over a given time period as curing occurs. Included is the measurement of additional specimens that are initially stored in a freezer for a period of time following casting, to determine if low storage temperature has any affect upon the curing rate.

## **Apparatus and Supplies**

1. Potassium nitrate or inert substitute\*
2. Powdered sorbitol
3. Casting mould

4. Stopwatch
5. Ruler
6. Scale for weighing
7. Camcorder (optional)
8. Specimen holding jig
9. Support wedge
10. Small weight with string
11. Deep freezer
12. Thermometer
13. pH paper (optional)
14. Coffee grinder (optional)
15. Deep fryer or other apparatus for melting KNSB
16. Desiccant (e.g. silica gel or calcium chloride)

\* the use of potassium nitrate is preferred, however, an inert substitute such as NaCl is acceptable if it can be demonstrated that the curing behaviour and mechanical properties of the resulting product are similar to authentic KNSB.

## **Procedure**

### Part A – Initial preparation

1. Record the brand name, grade if known, and physical description of the potassium nitrate and sorbitol in Appendix I.
2. Prepare a saturated solution of potassium nitrate and distilled water (10 grams KNO<sub>3</sub> per 50 ml water), allow to reach 20°C, then measure and record pH (this step is optional).
3. If potassium nitrate is granular form, it may be used “as is”. If in prill form, it must be lightly ground in a coffee grinder (e.g. 10 seconds per 2 tbsps or 30 cc). Make a record this in Appendix I.
4. Sift the sorbitol with a screen (e.g. flour sifter) to remove lumps.
5. Prepare a combination of 65% potassium nitrate granules and 35% sorbitol powder by mass, then blend very well, preferably using a rotating mixer.

### Part B – Preparing specimens

Prepare a minimum of 20 specimens

1. Melt the KNSB combination in the deep fryer at 120-130° C, and cast pour/scoop into casting mould to produce specimens. Record slurry temperature in Appendix II.
2. Allow to cure at room temperature for 24 hours in an airtight container with desiccant. Record room temperature in Appendix II.
3. Remove specimens from their moulds. Inspect for defects and discard any that are misshapen or contain significant voids or bubbles.
4. Place one third of specimens into a deep freezer. Record date and temperature of freezer compartment in Appendix II.
5. Place remaining specimens into an airtight bag or container and record date in Appendix II.

### Part C – slump rate measurement under self-weight

See Figure 1 for setup.

Perform this measurement 48 hours after casting, then every 24 hours thereafter until slump rate become negligible.

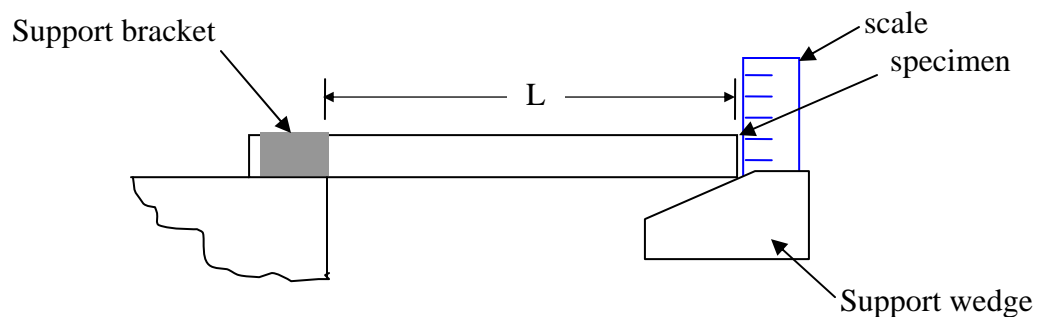


Figure 1 – Part C setup of specimen in support jig

1. Install specimen into holding jig. Place scale near free end.
2. Install support wedge under free end of specimen to prevent slumping
3. Measure and record free length “L” and specimen cross-section dimensions in Appendix III.
4. Set up camcorder to record measurement (optional, to aid in measuring rate).

5. Remove support wedge and, using stopwatch, measure the time over which the specimen slumps a given distance as indicated by the scale. Record in Appendix III.
6. Remove & discard specimen.

Part D – slump rate and spring-back measurement with applied force

See Figure 2 for setup.

After completion of Part C, perform this measurement every 48 hours thereafter until slump rate become negligible.

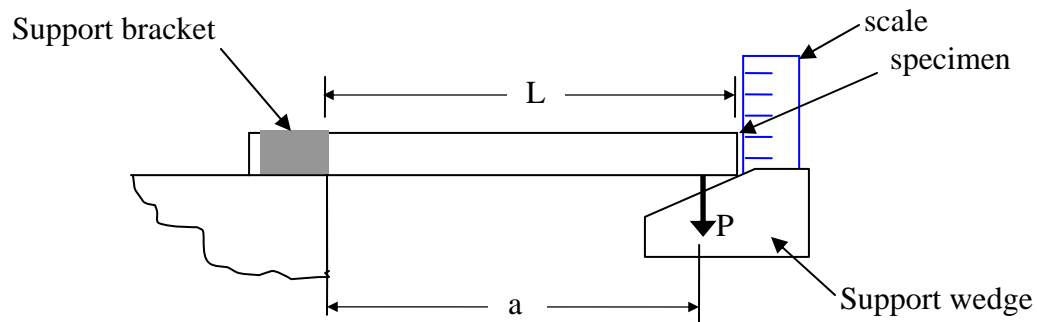


Figure 2 – Part D setup of specimen in support jig

7. Install specimen into holding jig and attached weight..
8. Install support wedge under free end of specimen to prevent slumping
9. Measure and record free length “L” and specimen cross-section dimensions in Appendix III. Also record weight, P, and offset distance, a.
10. Set up camcorder to record measurement (optional, to aid in measuring rate).
11. Remove support wedge and, using stopwatch, measure the time over which the specimen slumps a given distance as indicated by the scale. Record in Appendix III.
12. Remove weight and record spring-back displacement as indicated by scale.
13. Remove & discard specimen.

Part E – repeat Part C procedure using specimens stored in deep freezer.

Part F – repeat Part D procedure using specimens stored in deep freezer.

## **Appendix I**

### **Recording sheet for constituents**

#### Potassium Nitrate

Brand:

Grade/purity level:

As-obtained form (e.g. granular, prills):

Colour:

pH of saturate solution:

Grinding process:

#### Sorbitol

Brand:

Grade/purity level:

As-obtained form (e.g. fine powder):

Colour:

## **Appendix II**

### **Recording sheet for specimens**

Date of casting specimens: \_\_\_\_\_

Temperature of casting slurry (typical): \_\_\_\_\_

Room temperature: \_\_\_\_\_

Date of removal of specimens from moulds: \_\_\_\_\_

Date of storage of specimens in freezer: \_\_\_\_\_

Freezer compartment temperature: \_\_\_\_\_

## **Appendix III**

### **Recording sheets for viscoelastic measurements**

Specimen number: \_\_\_\_\_

Specimen free length, L: \_\_\_\_\_

Applied load, P (Part D only): \_\_\_\_\_

Load location, a (Part D only): \_\_\_\_\_

Specimen cross section dimensions:

Slump displacement: \_\_\_\_\_

Time duration: \_\_\_\_\_

Spring-back displacement (Part D only): \_\_\_\_\_

## Appendix IV

### Calculations of viscoelastic properties using obtained measurements.

Using measured displacements and time durations obtained in Parts C & D, calculate slump rate:

$$\text{slump rate, } R = \frac{\text{displacement}}{\text{time duration}} \quad \text{inch/sec or mm/sec}$$

Using spring-back measurements obtained in Part D, calculate elastic modulus (E):

$$E = \frac{1}{\Delta I} \left[ \frac{P a^2}{6} (3L - a) + \frac{W L^3}{8} \right] \quad \text{lb/in}^2 \text{ or } N/mm^2$$

where  $W$  = weight of cantilevered section of specimen  $lb$  or  $N$

$\Delta$  = spring-back displacement  $inch$  or  $mm$

$I$  = area moment of inertia of specimen cross-section  $in^4$  or  $mm^4$

To compare slump rates between specimens with and without weight,  $P$ , attached, calculate specific slump rate:

The maximum bending stress on the specimen is given by  $s = \frac{1}{Z} \left( P a + \frac{W L}{2} \right)$   $lb/in^2$  or  $N/mm^2$

where  $Z$  = section modulus of specimen cross-section  $in^3$  or  $mm^3$

Relate the slump rate to the stress with the specific slump rate,  $r$ :

$$r = \frac{R Z}{\left( P a + \frac{W L}{2} \right)} \quad \text{inch/sec}/(lb/in^2) \text{ or } mm/sec/(N/mm^2)$$