MiniSShot

Propellant Casting Review

Rev 2008/04/25

Mini-Shot Casting Review 04/20/2008

The grains were cast on 04/05/2008. 24 grains were cast as close to Richard's specifications as possible. This document will cover all materials and techniques used compiled with propellant densities and casting tube weights.

Casting Tubes

The casting tubes were all **ULINE** brand 3" mailing tubes. I was not able to obtain all the tubes in one location and this presented a discontinuity in the standardization of materials. Some of the tubes had a thin white glassine wrapping which added approximately 1 extra gram to each casting tube. It was proposed that the grains with the glassine wrap be used in the static motor thus freeing up weight for the Mini-Shot flight motor. This is still preferable, however based on the condition of the grains there may be a requirement to use the best quality grains in the flight motor. Below are the cut length of the casting tubes, their dimensions and weights just after being cut.

* = White Coating

Casting Tubes	Length	Diameter	Weight
1	5.315"	3" i.d / 3.125 o.d	50.4 g
2	5.315"	3" i.d / 3.125 o.d	50.5 g
3	5.315"	3" i.d / 3.125 o.d	50.3 g
4	5.315"	3" i.d / 3.125 o.d	50 g
5	5.315"	3" i.d / 3.125 o.d	50.6 g
6*	5.315"	3" i.d / 3.125 o.d	51.7 g
7	5.315"	3" i.d / 3.125 o.d	50.9 g
8	5.315"	3" i.d / 3.125 o.d	50 g
9	5.315"	3" i.d / 3.125 o.d	50.2 g
10	5.315"	3" i.d / 3.125 o.d	50.5 g
11	5.315"	3" i.d / 3.125 o.d	50.5 g
12	5.315"	3" i.d / 3.125 o.d	50.8 g
13	5.315"	3" i.d / 3.125 o.d	50.7 g
14	5.315"	3" i.d / 3.125 o.d	50.5 g
15*	5.315"	3" i.d / 3.125 o.d	51.1 g
16*	5.315"	3" i.d / 3.125 o.d	51.7 g
17*	5.315"	3" i.d / 3.125 o.d	51.4 g
18*	5.315"	3" i.d / 3.125 o.d	51.4 g
19*	5.315"	3" i.d / 3.125 o.d	51.4 g
20*	5.315"	3" i.d / 3.125 o.d	51.5 g
21*	5.315"	3" i.d / 3.125 o.d	51.5 g
22*	5.315"	3" i.d / 3.125 o.d	51.5 g
23*	5.315"	3" i.d / 3.125 o.d	51.4 g
24*	5.315"	3" i.d / 3.125 o.d	51.4 g

A layer of Sorbitol and H2O mixture was then added to the inside of the casting tubes and allowed to dry. Once the mixture had dried for 24 hours, the casting tubes were then weighed once again. Those weights are below.

SO/H2O

1) 50.4 g
2) 50.4 g
3) 50.2 g
4) 49.7 g
5) 50.4 g
6) 52 g
7) 50.7 g
8) 50 g
9) 49.9 g
10) 50.3 g
11) 50.3 g
12) 50.9 g
13) 49.5 g
14) 50.5 g
15) 51.1 g
16) 51.6 g
17) 51.2 g
18) 51.4 g
19) 51.4 g
20) 51.4 g
21) 51.3 g
22) 51.4 g
23) 51.3 g
24) 51.4 g

The weights after the addition of the solution brought the weight per casting tube closer to equal weight among the casting tubes than was achieved prior to the addition of the solution. Still, there were a few odd ball weights and I'm not sure as to why? I can only guess it is due to manufacturing tolerance differences in the thickness of the tubes. One other oddity that was observed was the fact that the casting tubes gained a minor addition of weight after the final weights of cured SO/H2O were recorded. The casting tubes were kept indoors in a dry environment, however it seems they may have absorbed additional moisture due the hygroscopic nature of the SO/H2O solution. The minimal extra weight was not recorded for this series of casting but should be performed on all future castings.

Materials

The KN/SO mixture was a blend of KN03 and Sorbitol supplied by PVC ONLY and Firefox Enterprises. The reason for the mixture of the two manufacturers was due to the required amount of chemicals fell short. As a last minute effort to reach the required amount of chemicals, Matt Campbell used KN03 and Sorbitol supplied by Firefox. The KN03 and Sorbitol were blended over night in a newly purchased cement mixer supplied by Harbor Freight.

The casting stands were made of .75" plywood bases, Proprietary spacer disks and alignment caps supplied by True-Core, and a mixture of Delrin, EPDM, and aluminum coring rods. All required surfaces were coated with Mann 400 mold release.

All safety gear was worn during casting. Thermal controlled heating vessels were used to melt the propellant. The propellant was prepared at a temperature of 276 degrees F. We did our best to maintain this temperature as our casting temperature. The cooler air and high wind made this task challenging at times. The dry propellant mix was melted a little at a time and small amounts of dry mix were then added to the melted mix for ease of melting subsequent additions of dry mix propellant. The casting tubes were filled a third of the volume then rapped against a hard surface to facilitate the packing of propellant and evacuation of air bubbles. This process was repeated until the casting tubes were filled to the top. The grains were cast in a partially open air facility then promptly moved to a trailer outside for cooling. The ambient air temperature was much cooler outside than in the casting facility. The air was considerably humid outside and a weather front was moving in from the North. Since the four of us were trying to get so many grains poured in one day, I feel our ability to properly observe the curing grains became hindered. I attempted to check on the grains at half hour intervals after they were cast. Some showed no signs of shrinkage and many showed signs of minimal shrinkage. There were a few that showed signs of major shrinkage. The reason for the broad spectrum of difference in shrinkage characteristics is a bit of mystery at this point in our research.

As shrinkage was observed, an attempt was made to tamp the "shrinkage" areas down to a solid, concaved grain to which fresh melted propellant was added and packed into the casting tube and alignment caps were put back on. It is my personal opinion that during future casting, the alignment cap should not be put back on the casting setup as the bottom of the grains should set up enough to hold the coring mandrel in its proper position. The alignment caps may lend to unfavorable end surfaces if the propellant sticks to the caps.

All grains were moved to a temporary storage container and later transported to Matt's permanent storage facility. It was at Matt's facility that minor imperfections, core edge cracking, non-adhesion of additional melt cast etc. was discovered. The grains were dressed, and made useable by Matt Campbell. Which grains are to be used for the static firing and which are to be used for the Mini-Shot flight are yet to be determined.

Prognosis

Below is a graphical representation of all finished grains. It contains all the data acquired during the casting process.

Casting Tube number	Recessed depth Top (mm)	Recessed depth Bottom (mm)	Grain length (mm)	Mass of propellant (grams)	Grain density ratio (actual/ideal)
1	3	12	120.5	860.6	95.7%
2	2	10	123.5	850.5	92.3%
3	-1	12	124.5	866.7	93.3%
4	-1	10	126.5	854.0	90.5%
5	1	12	122.5	845.4	92.5%

6	5	10	120.5	815.3	90.7%
7	-3	10	128.5	879.3	91.7%
8	-2	10	127.5	843.0	88.6%
9	1	12	122.5	835.8	91.4%
10	2	12	121.5	839.5	92.6%
11	2	12	121.5	863.5	95.3%
12	-2	11	126.5	868.2	92.0%
13	-2	10	127.5	872.3	91.7%
14	1	10	124.5	847.5	91.2%
15	-1	10	126.5	847.9	89.8%
16	-2	11	126.5	865.3	91.7%
17	1	11	123.5	834.6	90.6%
18	-1	11	125.5	852.6	91.1%
19	-1	11	125.5	852.6	91.1%
20	2	11	122.5	854.5	93.5%
21	-1	10	126.5	866.5	91.8%
22	-1	11	125.5	872.5	93.2%
23	-1	11	125.5	856.6	91.5%
24	3	12	120.5	837.6	93.2%

Green > 92%
Red < 92%
(casting spec calls for quality > 92%)

With the “quality “ level being uneven, I can’t determine at this point which grains will be used for the static test and which ones will be used for the flight motor. When a decision has been made, the grains for each motor will need to have their weights and densities combined, re-calculated and estimates of the motors’ impulse, ISP, thrust, etc. will need to be re-determined and have the data acquired from the static test compared. A more controlled environment and casting procedure will need to be instituted for future casting of motor grains. I believe a 100% consistency in the KNO3 and Sorbitol will need to be instituted as well. The results of the level of quality of cast grains are far below expectations and quality control measures need to be reviewed and improvements to said measures implemented during future operations. At this point, I am leaving it to Richard’s discretion if he wants to use the current grains in the flight motor to be used for the Mini-Shot flight.

Additional Information

During the trial motor assembly we discovered the casting tubes used were not of the proper tube wall thickness. The tubes used were approximately 0.08” in thickness and a tube wall of 0.06” supplied by ULINE is required in order to fit properly in the thermal sleeve of the motor. Casting tubes with the proper wall thickness will be pre-ordered for

all future castings. This will also insure the same "type" of tube is used for all grains cast, ensuring consistency. One other undesirable characteristic we found with the tubes is the depth of the spiral. The thickness of the tube along the spirals is approximated at .02". We are not sure of the effect this will have on the effectiveness of the integrity of the tube as an inhibiter. We hope that the structural integrity of the tubes holds during firing. We may want to look at another supplier for better quality tubes.

Grain Quality

After casting and curing of the grains, each grain was given a "tap test" by Matt Campbell for de-bonding. Matt found that there was no de-bonding except in the areas where shrinkage caused the propellant to recede from the casting tube. These areas are limited to grain ends/ faces. As the coring mandrels were removed and the grains were separated from the casting bases, Matt Campbell observed that some of the bottoms of the grains were either crumbly or foamy looking. I observed the grains as well and there was apparent cracking off of some propellant from the bottoms of some of the grains. I am not sure what caused this? I am not sure of the foaming either, but it may be a reaction of the propellant and the Mann 400 mold release we used on the casting base disks. There were only a couple of grains that appeared to have this anomaly and I do not see it as a threat to the integrity of the grains. The cracking of propellant however, needs to be addressed. We may possibly want to slow down the filling of the grains and allow each third to settle a little before continuing with the next addition. The cracking effect could have been an effect of shrinkage from the very cool ambient temperature. The exact cause cannot be determined at this point and more cautious observation and casting procedures should be used during future castings.

Chemical Properties and Test Results

As mentioned earlier in this report, we ended up with the necessity of having to use two different KN03's. pH tests were performed by Matt Campbell on both products. The KN03 supplied by PVC ONLY had a pH of 7 and the KN03 supplied by Firefox Enterprises had a pH of 6. During the casting process, burn rate test strands were made. The strands were approximately .25" in thickness and 6" in length. I marked the strands with 1" increments and epoxied them in a vertical configuration for the test. I burned the test strand from the top and video taped the burn as it progressed downward through the 1" increments. I downloaded the video and conducted a timeline analysis of the time period of each increment and calculated an average. The average burn rate for the propellant cast was 9.125 seconds per inch. The specification for an optimal burn rate was 9.8 – 10.6 seconds per inch. Our results put us a little on the fast side however, Richard Nakka feels we are still in an acceptable range.