Australian Government
Department of Defence
Defence Science and
Technology Organisation

Sep 2003

DSTO

Improved Strand Burn Rate Reproducibility Using a New Preparation Methodology for Paint-Based Inhibitors

Andrew H. Hart and
Raoul A. Pietrobon

DSTO-TN-0513

Australian Government
Department of Defence
Defence Science and
Technology Organisation

Improved Strand Burn Rate Reproducibility Using a New Preparation Methodology for Paint-Based Inhibitors

Andrew H. Hart and Raoul A. Pietrobon

Weapons Systems Division
Systems Sciences Laboratory

DSTO-TN-0513

ABSTRACT

Small-scale ballistic characterisation of composite rocket propellants is a critical step in the development of rocket motors and is achieved by measuring linear strand burning rates determined using the Crawford strand burning technique. To utilise this technique, the propellant strands must burn with an end-burning configuration, which is achieved through the application of a water-based acrylic paint as an inhibitor. To be effective, the inhibitor needs to be of such a quality that the resultant coating on the propellant strands will be defect-free. If the inhibitor coating contains defects, erroneous and irreproducible burn rate data can result, a problem that has been evident at this facility in the past. To improve the strand burn rate reproducibility, a series of paint/water compositions, ranging between 65 and 78%(v/v) paint/water, were prepared using a modified preparation methodology. Of the inhibitor compositions investigated, a 70%(v/v) paint/water ratio was found to be optimal. Using this inhibitor composition, coupled with the introduction of a more rigorous inhibitor preparation methodology, a 60% reduction in erroneous burn rate data and a 32% improvement in burn rate reproducibility was achieved.

RELEASE LIMITATION

Approved for public release

Published by

DSTO Systems Sciences Laboratory
PO Box 1500
Edinburgh South Australia 5111 Australia

Telephone: (08) 8259 5555
Fax: (08) 8259 6567

AR-012-881
September 2003

APPROVED FOR PUBLIC RELEASE

Improved Strand Burn Rate Reproducibility Using a New Preparation Methodology for Paint-Based Inhibitors

Executive Summary

Small-scale ballistic characterisation of composite rocket propellants is a critical step in the development of rocket motors and is achieved by burning a series of 170x5x5 mm propellant strands over a range of pressures at a controlled temperature in a pressurised bomb. To determine the burn rate of the propellant strands, the time taken for a known length of propellant to burn is recorded using an electric timing method from which the burn rate can be easily evaluated. To obtain the burn rates using this technique, the propellant strand must burn with an end-burning (cigarette-type) configuration. To achieve this burning configuration, it is necessary to coat the longitudinal faces of the propellant strands with a material exhibiting low flammability properties, typically referred to as an inhibitor.

The inhibitor most commonly used at DSTO Edinburgh consists of a mixture of acrylic paint and distilled water in a pre-determined ratio. To be effective, the inhibitor needs to be of a suitable consistency and must also contain minimal bubbles and entrained air so that the resultant coating on the propellant strands will be defect-free. If the inhibitor coating contains cracks, pores or does not adhere to the propellant surface adequately, the longitudinal faces of the propellant can become exposed to the flame front, enabling the burning zone to burn down the sides of the propellant strand rather than in the desired end-burning configuration. This leads to erroneously high burn rates and poor burn rate reproducibility.

The inability to obtain consistent, reproducible burn rate data has been a problem at DSTO Edinburgh in the recent past. To address this issue, a visit to Australian Defence Industries Limited (ADI) was initiated in April 2002 where it became clear that the methods of inhibitor preparation utilised by DSTO were far less rigorous than those employed at ADI. To overcome this, three different paint/water ratios, ranging between 65 and 78%(v/v) paint, were prepared using a modified preparation methodology that included degassing of the inhibitor and the introduction of techniques to ensure correct inhibitor consistency.

Of the inhibitor compositions investigated, a 70%(v/v) paint/water ratio gave the best compromise between fluidity and adherence to the strand and was therefore selected as the composition of choice. Through the optimisation of the inhibitor composition, coupled with the introduction of a more rigorous inhibitor preparation methodology, a 60% reduction in erroneous burn rate data and a 32% improvement in burn rate reproducibility was achieved.

As a result of these improvements to the inhibitor coating, the quality of the burn rate data obtained is improved and the propellant ballistics can be better and more efficiently characterised for a given number of propellant strands.

Contents

1. Introduction

Small-scale ballistic characterisation of composite rocket propellants is a critical step in the development of rocket motors and provides a foundation for more extensive, representative rocket motor testing. At this developmental stage, linear strand burning in a pressurised, Crawford-type vessel [1,2] is used at the DSTO to obtain propellant burning rates over a range of pressures, typically 2 - 20 MPa.

To ensure that the propellant strands burn with an end-burning (cigarette-type) orientation, it is necessary to coat the longitudinal faces of the propellant with an inhibitor, that is, a material exhibiting low flammability properties. The most commonly used inhibitor at the DSTO for the strand burning of composite propellants is a mixture of paint and distilled water in a 60/40(v/v) paint/water ratio. The methods used for the preparation of this inhibitor have been based upon an investigation into the use of water based acrylic paints as inhibitors for strand burning that have been conducted at this facility in the past [3]. The level of burn rate reproducibility achieved in the low pressure strand burner is not only affected by the homogeneity and defect-free nature of the propellant, but it is also strongly dependent on the quality and preparation of the inhibitor coating itself. Any irregularities in the inhibitor coating, such as cracks, bubbles or poor consistency leading to dewetting from the propellant surface, can lead to the flame front 'flashing' down the longitudinal faces of the propellant, thus resulting in erroneously high burn rates. The inability to obtain consistent, reproducible burn rate data has increasingly become a problem at this facility in the recent past, and culminated when investigating the burn rate data for seven propellants formulated between 16/01/02 and 12/03/02 where in excess of 40% of the burn rate data was considered to be erroneous[1].

To address this issue, a visit to Australian Defence Industries Limited (ADI Ltd.), located in Mulwala, NSW, in April 2002 was initiated. During this trip it became clear that the methods of inhibitor preparation utilised at the DSTO were far less rigorous than those employed at ADI, and that this lack of quality control and thoroughness in inhibitor preparation was the most likely cause for the poor reproducibility of the burn rate data obtained. Because of this, a number of changes, based partly upon advice from ADI [4], were made to the existing inhibitor preparation methodology, and a series of paint/water ratios were investigated in order to obtain an inhibitor coating that gave improved burn rate reproducibility.

In order to gauge the effectiveness of the new methodology used for inhibitor preparation, the burn rate data for nine similarly based propellant formulations coated using the new inhibitor preparation were compared with the burn rate data for seven formulations of similar composition that were coated using the previous inhibitor methodology.

---

[1] Burn rate data was considered to be erroneous if the difference between the burn rates of a formulation at a fixed pressure exceeded 0.25 mm/s.

2. Experimental

2.1 Propellant Formulation

The ingredients used for the manufacture of the propellant used to investigate the effect of the inhibitor paint/water ratio on burn rate reproducibility are listed in Table 1 . The propellant was a standard hydroxy-terminated polybutadiene (HTPB) based formulation containing ammonium perchlorate (AP). The 20 μm median diameter (d_{50}) AP, used as the fine fraction in the formulation, was prepared by passing 5 kg of 400 μm AP through a KEK disc-pin mill with a gap size of 4 mm. The particle size distribution of the 20 μm AP sample was determined using a Malvern Mastersizer 2000. The particle size of the 400 μm (coarse) AP lot was determined by passing the bulk material through a 425 μm Endecotts test sieve. The material passing through the sieve was used as the coarse AP fraction in the formulation. When not in use, all solid ingredients were stored in water-jacketed ovens at 60°C to minimise the absorption of moisture from the atmosphere. Prior to incorporation into the mix, the R-45M HTPB pre-polymer was degassed overnight at 60°C in a vacuum drying oven.

Table 1: Ingredients used in propellant manufacture

Ingredient	Source	Lot No.
HTPB(R45M)	Elf Atochem	MF102/99
DDI	General Mills	MF93/99
Copper Chromite	ADI Ltd.	MF040/02
AP (400μm)	Ker McGee	5683

The propellant was prepared in a vertical, 1-pint capacity Baker Perkins planetary action mixer at 60°C under reduced pressure. At the end of the mix cycle the propellant was cast, under vacuum, into a 7x2x1" Teflon coated mould before being placed in an oven at 60°C for one week to cure.

The effectiveness of changes made to the preparation methodology of the inhibitor coating were assessed by comparing the reproducibility of burn rate data for seven HTPB/AP based formulations coated using the previous inhibitor preparation methodology, with the burn rate reproducibiltiy of nine HTPB/AP formulations coated with inhibitor prepared using the new proposed methodology. These propellants were all cured with dimeryl diisocyanate (DDI), with the ratio of the polymer to curative such that the functionality of the binder was equal to 1.02.

2.2 Propellant Testing

At the completion of the required curing time, the cured propellant was removed from the 7x2x1" moulds prepared at the end of the mix cycle and machined into four slabs of 5 mm thickness. These slabs were designated, from top to bottom, as T (top), MT (mid-top), MB (mid-bottom) and B (bottom). Using a Stanley knife, each of the four propellant slabs was cut into 10 strands of dimensions 170x5x5 mm.

The strands were then chamfered using aluminium oxide abrasive paper and sub-divided into three groups, with each group being coated with inhibitor coatings consisting of different paint/water ratios. The ratios used were 65, 70 and 78%(v/v) paint/water. Each group of propellants were dipped four times over an eight-hour period and then allowed to dry for 48 hrs. The strands were dipped on four occasions as this has been shown to give optimal inhibition in the past [3]. A detailed methodology for the preparation of the inhibitor is presented in Appendix A. Each of the three inhibitor compositions investigated were prepared using this methodology.

The paint used was a Super Flat Acrylic, Deep Tint Base (Line 500) product supplied by Solver Paints. General properties of this paint are provided in Appendix B so that in the event of this particular line becoming unavailable, paint with similar properties can be utilised in the future. The critical components of the paint are the quantity and type of anti-foaming agents and the level of titanium dioxide (TiO_2).

The effectiveness of an inhibitor coating is gauged by the reproducibility of the burn rate data for a particular formulation. This burn rate data was obtained from linear strand burning rates determined using the Crawford strand burning technique. After being coated with their respective inhibitors, the three batches of strands were burned in a Crawford-type low-pressure strand burner at pressures of 2, 6, 10 and 14 MPa under a nitrogen atmosphere at a temperature of 21°C. A nichrome (Ni-Cr) wire was used to ignite the propellant strands, and solder wires threaded through holes drilled in the propellant at a distance of 127 mm apart were used to determine the burn time, and hence the burn rate, of the propellant strands. In order to mitigate the influence of propellant layer effects (variation in propellant burn rate with mould depth owing to the settling of the oxidiser particles during the cure period) on the reproducibility of the burn rate data for each of the inhibitor ratios considered, all strands from each layer were only burnt at the one pressure.

3. Results

Figure 1, plotted from the data provided in Table 2, compares the burn rate data for the three paint/water ratios used to assess the influence of the inhibitor composition on burn rate reproducibility. Figure 1 shows that, over the pressure range considered, both the 70 and 78% paint/water ratios compared favourably to the 65% composition which displayed greater burn rate variability at a chamber pressure of 2 MPa. There

was minimal difference between the reproducibility of the burn rate data obtained for the 70 and 78% paint/water ratios. The reproducibility of the burn rate data is represented by the standard deviation of the burn rates for each inhibitor composition at each pressure. These values are provided in Table 2.

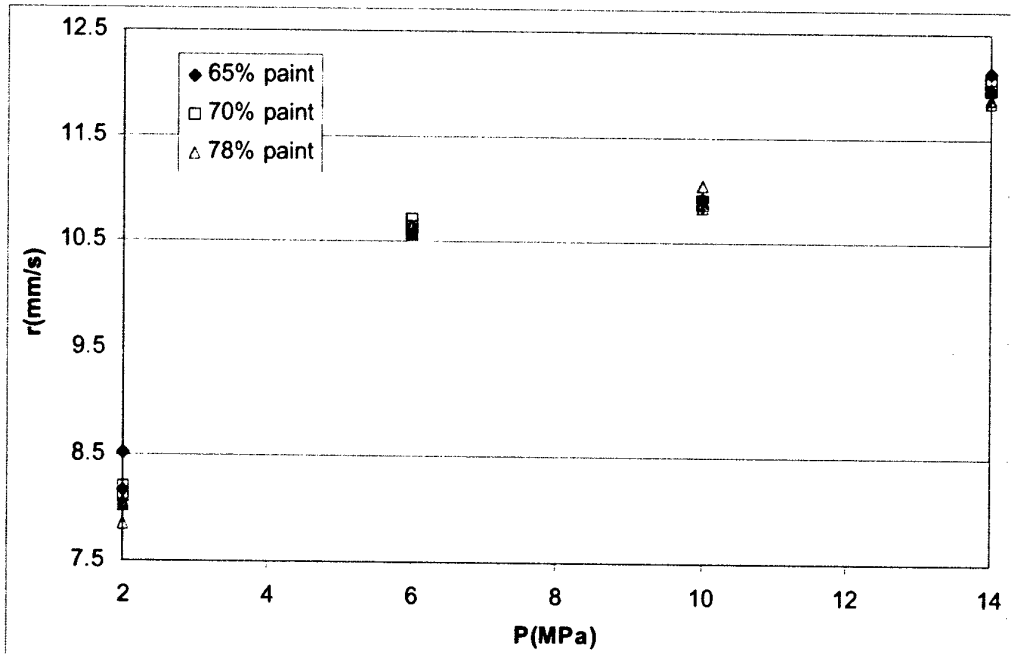

Figure 1: Effect of inhibitor composition on burn rate reproducibility

Table 2: Ballistic data for the inhibitor compositions and associated propellant layers used to assess burn rate reproducibility

	65%(v/v) Paint/Water		70%(v/v) Paint/Water		78%(v/v) Paint/Water		
P (MPa)	r(mm/s)	Std Dev.	r(mm/s)	Std Dev.	r(mm/s)	Std Dev.	Layer
2	8.52		8.12		7.85		T
2	8.16	0.26	8.13	0.04	8.06	0.10	T
2	Misfire		8.20		8.04		T
2	-		-		8.03		T
6	10.63		10.58		10.61		MT
6	10.62	0.02	10.71	0.06	10.62	0.01	MT
6	10.65		10.65		10.60		MT
10	10.85		10.91		10.85		MB
10	10.88	0.04	10.89	0.02	10.92	0.10	MB
10	10.93		10.87		11.04		MB
14	11.98		11.98		11.85		B
14	12.14	0.11	12.04	0.05	11.89	0.02	B
14	Misfire		12.08		11.86		B
14	Misfire		-		-		B

Table 3 shows that of the 232 HTPB/AP based propellant strands burnt between 30/07/02 and 29/10/02 since the new inhibitor preparation was employed, 38, or 1 in 6 strands gave erroneous results. This compares with the strands coated using the previous inhibitor preparation technique, where 85 of the 204 strands tested between 16/01/02 and 12/03/02 were considered to lay outside the previously defined range of acceptable reproducibility. This equates to 1 in every 2 to 3 strands. Misfires, resulting from things such as problems with timing wires or head conductivity were not included in the analysis, as they are independent of the inhibitor coating.

From Table 3, using the new inhibitor preparation, the average standard deviation[2] of the burn rate data over the formulations tested was ± 0.19 mm/s. This compares with the average standard deviation of ± 0.28 mm/s using the previous inhibitor preparation technique.

Table 3: Effect of the new inhibitor preparation on burn rate reproducibility and the number of erroneous data points

	Previous Inhibitor Preparation		**New Inhibitor Preparation**	
P(MPa)	**Strands Burnt**	**Erroneous Results**	**Strands Burnt**	**Erroneous Results**
2	17	4	20	3
3	1	0	7	1
4	23	10	20	3
5	2	1	16	4
6	22	9	20	1
7	5	2	3	0
8	21	8	20	3
9	4	3	9	5
10	19	8	19	1
11	3	2	8	3
12	23	11	21	5
14	21	10	20	2
16	17	8	20	3
18	12	3	18	3
20	14	6	11	1
Total	204	85	232	38
Avg. Std. Dev. (mm/s)	0.28		0.19	

[2] The average standard deviation presented for the previous and the new inhibitor preparation was taken as the average of the standard deviations over all formulations for both the new and the previous inhibitor preparation. Although being included in the analysis when evaluating the number of erroneous points, burn rate data lying more than 2 mm/s outside the other burn rate data at that particular pressure were not included in the standard deviation calculations as it was felt that their inclusion would be misleading in gauging the burn rate reproducibility.

Figure 2 compares the effect of altering the paint/water ratio using the previous inhibitor preparation technique, and also compares the reproducibility of the previous inhibitor preparation with that of the new methodology. Figure 2 shows that using the new inhibitor preparation technique offers a marked reduction in the number of erroneous data points when compared with the strands coated with the inhibitor compositions prepared using the previous methodology. The level of reproducibility at each pressure is also higher using the new inhibitor preparation technique.

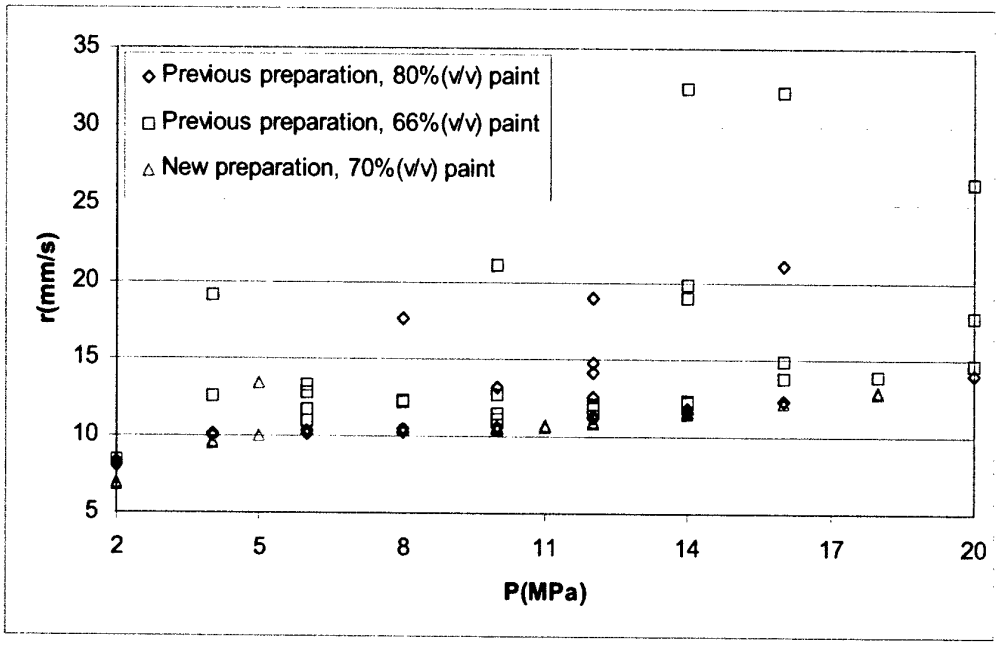

Figure 2: Effect of inhibitor preparation and composition on the reproducibility of the burn rate data for three formulations of identical composition

4. Discussion

In order to be effective, an inhibitor needs to not only exhibit low flammability properties, but must also be of a suitable consistency free of bubbles or impurities when applied to the propellant surface. From discussions with key technical personnel at ADI Ltd. [4], it became clear that erratic burn rates arose almost entirely due to irregularities and imperfections in the inhibitor coating. The presence of bubbles and cracks in the inhibitor coating can expose the longitudinal faces of the propellant surface to the flame front, enabling the burning zone to burn down the sides of the propellant rather than in the desired 'end-burning' configuration. As the flame front 'flashes' down the longitudinal faces of the propellant it burns through the stop timing wire on the strand burner head. This leads to a faster burn time than would be the case had the propellant burnt in a linear fashion. The consistency of the inhibitor plays a vital role in the prevention of this phenomenon, as one needs an inhibitor coating that

has sufficient fluidity to flow into any imperfections on the propellant surface, yet is thick enough to adhere to the propellant surface with minimal dewetting. However, if the inhibitor coating is too thick, it becomes more susceptible to cracking under the forces exerted upon the propellant strand during the pressurisation of the strand burner. Any such cracks would have the potential to expose extra burning surface, thus resulting in enhanced burn rates.

In order to obtain an inhibitor of appropriate consistency, the correct paint/water ratio must be chosen. Prior to this work being conducted, since 1997, paint/water ratios consisting of between 70 and 90%(v/v) paint have been used, with the strands being dipped four times over an 8 hr period. No quality control from inhibitor batch to batch was employed. The burn rate data used to investigate the previous inhibitor preparation was based upon strands coated with 66% and 80%(v/v) paint/water ratios, with little difference between the reproducibility resulting from the two inhibitor compositions being noted, an example of this is provided in Figure 2. As is illustrated from the data presented in Table 3, this methodology led to an unacceptably high number of erroneous or 'fast burns'. Due to this, three inhibitor coatings containing different proportions of paint were investigated. These results are provided in Table 2 and Figure 1, and show that the best reproducibility, particularly at the 2 MPa chamber pressure, is obtained with the 70 and 78%(v/v) paint/water ratios. Given the negligible difference in performance between the 70 and 78% inhibitor compositions, the 70% coating was selected as it provided the best compromise between fluidity and adherence to the strand.

If one considers the burn rate data presented in Figure 2 for the two formulations coated with the previous inhibitor methodology, coupled with the data presented in Table 2 for the three different inhibitor compositions prepared using the new inhibitor methodology, one can see that the paint/water ratio does not have a significant effect on the number of 'fast burns' and burn rate reproducibility over the composition ranges considered. This indicates that, provided the consistency of the inhibitor is such that it will adhere to the propellant surface without significant dewetting, the composition of the inhibitor is not as critical as the preparation of the inhibitor solution itself. To improve the homogeneity of the inhibitor solution, the paint is passed through a 211 μm sieve after being combined with the distilled water in order to remove any conglomerated paint, which could cause an uneven coating on the propellant strands. To determine whether the inhibitor will be of a suitable consistency, 100 ml of the prepared inhibitor solution is passed through a separating funnel at 21°C, the time taken is recorded and the flow rate determined. Using a 200 ml conical-shape separating funnel with one end open to the atmosphere, the resultant flow rate was found to be approximately 45 ml/min. Clearly, this flow rate is dependent upon the type of flow cup or separating funnel used; because of this it was necessary to develop a standard with the same viscosity of the inhibitor solution. To do this, a series of glycerol/water mixtures were prepared and their flow rates measured using the previously stated separating funnel. By doing this, it was found that an 89% glycerol/11%(v/v) water solution had the same consistency as the inhibitor solution at

a temperature of 21°C. If the flow rate lies outside of this baseline then the preparation of the inhibitor batch is repeated.

When the paint is combined with the distilled water and passed through the sieve, air is entrained into the mixture. These air bubbles pose significant problems when trying to obtain an even inhibitor coating, this is of particular importance for the first coating where good inhibitor coverage of the propellant surface is critical. Due to this, after determining the flow consistency, the resultant solution is degassed under vacuum at ambient temperature for 30 min. This minimises any porosity in the resultant inhibitor coating and therefore provides a more homogenous coating that is less likely to promote 'flashing' down the longitudinal faces of the strands. Through the introduction of these changes to the inhibitor preparation methodology, from the data presented in Table 3, a 60% reduction in erroneous burn rate data, and a 32% increase in burn rate reproducibility is achieved when compared with the previous method of inhibitor preparation.

All propellants machined on-site for strand burning are machined dry. Because of this, it is not critical to precondition strands at specific levels of relative humidity (RH) and temperature in order to achieve post-machining moisture stability. Having said this, it is still desirable to minimise moisture uptake from the atmosphere as this can cause the leaching of propellant ingredients, thus influencing measured burn rates. To mitigate such effects, ADI condition their machined propellants in a desiccator overnight before painting in order to drive out any absorbed moisture that would otherwise be trapped within the propellant after the inhibitor coatings have been applied. After being dipped four times in a 66/34(v/v) paint/water formulation, ADI leave the coated strands to dry overnight at 50% RH and 22°C [4]. Strands prepared at the DSTO are stored in a desiccator above silica gel at ambient temperature before and after coating. It would be expected that the storage of the machined propellants in a low moisture environment would be more critical before coating takes place, as the inhibitor coating would be expected to act as a barrier to the absorption of moisture from the atmosphere.

The influence of the time between when a propellant is coated and when it is burnt has been investigated by Kempson et. al [3] and it was found that the effect was minimal for non-plasticised systems. Of the 16 propellants investigated in this study, reproducible burn rate data has been obtained up to 6 months after a propellant has been formulated and 16 days after applying the inhibitor coating to the propellant, beyond this period no on-site data is available. For non-plasticised systems one should aim to coat the propellant strands as soon as possible after the propellant block has been machined, after this time, the period between when the propellant is coated and when it is burnt is of less importance. When dealing with plasticised systems one should try to minimise the time between coating and burning as the paint/water coating has the potential to cause the migration of the plasticiser to the propellant surface [3]. Using the new inhibitor preparation methodology, it is recommended that a minimum of 48 hrs be allowed between the application of the final coat and the

burning of the first strand in order to ensure that the inhibitor coating is completely dry before commencing the burning of the strands.

All formulations compared in this report were of a similar composition with comparable burn rates. Intuitively, one would expect that as the burn rate increases, the rate of heat feedback to the burning surface would also increase, thus meaning that a greater number of inhibitor coatings would be required to maintain adequate inhibition. However, four layers of inhibitor have been found to be effective for higher burn rate formulations up to 30 mm/s [5], beyond which the authors do not have any burn rate data using the new inhibitor methodology. This agrees with work conducted by Kempson et. al [3] which has indicated that, provided the inhibitor is of a suitable consistency, four coats should provide sufficient inhibition over the range of burn rates that one would expect to encounter for the majority of propellant formulations tested on-site.

5. Conclusions and Recommendations

A 70%(v/v) paint/water mixture, degassed and tested for consistency, was found to give greater burn rate reproducibility and fewer 'fast burns' than the inhibitor prepared using the previous methodology. Through the introduction of the more rigorous inhibitor preparation technique, a 60% reduction in erroneous burn rate data and a 32% increase in burn rate reproducibility was achieved when compared with the previous inhibitor preparation.

Provided the consistency of the inhibitor, governed by the paint/water ratio, is such that it will adhere to the propellant strands with minimal dewetting, the preparation of the inhibitor solution, particularly the degassing under vacuum, is the most critical step in obtaining reproducible burn rate data.

The application of four inhibitor coatings has been found to give sufficient inhibition for burn rates up to 30 mm/s, beyond which no data is available. It is recommended that a minimum of 48 hrs be allowed between the application of the final inhibitor coat and the burning of the propellant strands in order to ensure complete drying of the inhibitor coating.

6. References

1. Crawford, H.L., Hugget, C.M., *Direct Measurement of Burning Rates by an Electric Timing Method,* **National Defence Research Committee report A-286**, August 1944, as cited in; Kempson, R.M., Hamshere, B.L., Kirk, D.R., *A Water Based Acrylic Paint as an Inhibitor for Strand Burning of Cast Double Base and Composite Propellants,* **WSRL-0420-TR**, July 1985.

2. Jolley, W.H., Kirk, D.R., *Description of the WRE Strand Burning Facilities and Instructions for Use,* **WRE-MA-1850(W)**, July 1977.

3. Kempson, R.M., Hamshere, B.L., Kirk, D.R., *A Water Based Acrylic Paint as an Inhibitor for Strand Burning of Cast Double Base and Composite Propellants,* **WSRL-0420-TR**, July 1985.

4. Personal communication, Mr Peter Poll, ADI Ltd. Mulwala, 23/4/02.

5. Hart, A.H., DSTO, WSD, unpublished data.

6. Personal communication, Mr Simon Watts, Technical Manager, Solver Paints, Kilburn Technical Centre, 4/4/03.

Appendix A: New Inhibitor Preparation Methodology

1. Mix a quantity of paint[3] with distilled water to achieve a dilution ratio of 70%(v/v). As a guide, 600 ml (420 ml paint, 180 ml distilled water) of inhibitor will coat 40 strands with four coats of inhibitor solution.

2. Pass the inhibitor solution through a 211 μm aperture Endecotts sieve in order to remove any conglomerated paint material.

3. The viscosity of the resultant paint/water solution is such that a given volume passes through a flow cup at the same rate as an 89% glycerol/11%(v/v) water solution at a temperature of 21°C. If the flow rate of the inhibitor solution differs significantly from the flow rate of the glycerol/water solution, then the inhibitor batch and possibly the stock paint[4] needs to be replaced.

4. The inhibitor solution is placed under vacuum at ambient temperature for approximately 30 min to remove any entrained air present in the solution.

5. Pour the degassed inhibitor into a dipping tank, filling the tank to around 2 cm below its lip. Allow the inhibitor to stand for 15 min so the solution can settle and any remaining air bubbles can rise to the surface and be scraped off.

6. The strands to be coated should be attached to brass battens by means of the alligator clips.

7. Dip the strands into the tank for 2-5 s and ensure that each of the strands is wetted with inhibitor up to the level of the attached clips. The strands should not be allowed to touch either the base of the tank or each other.

8. Remove the batten from the dipping tank and suspend it on a drying stand to allow the strands to dry. The strands should be left to dry for approximately 2 hr before being re-dipped. The dipping tank should be covered when not in use.

9. After the first coat has dried, a visual inspection should be made of the coated surface and any bare areas along the longitudinal faces should be touched up using a small paintbrush.

---

[3] The paint used is a Super Flat Acrylic, Deep Tint Base (Line 500) product supplied by Solver Paints.

[4] Solver Paints recommends that the paint be used within two years of manufacture to achieve best results.

10. Steps 8 and 9 should be repeated until the strands have been coated four times. The coated strands may be dried overnight at 50% RH and 22°C, although these conditions are not critical.

11. For best strand burning results, a minimum of 48 hr should be allowed between the application of the final coat and the burning of the first strands to ensure complete drying of the inhibitor coating.

12. The paint inhibitor solution can be used for up to a week after its preparation as long as it is stored in a sealed glass container at the end of each day and that steps 2 to 6 are repeated before the re-use of the inhibitor.

Appendix B: General Properties of Paint used in Inhibitor[6]

Super Flat Acrylic, Deep Tint Base (Line 500) product contains 37-38%(w/w) pigment, which is comprised of TiO_2, calcium carbonate ($CaCO_3$), diatomaceous earth and synthetic clay.

In order to improve the compatibility and dispersion properties of the TiO_2, Line 500 uses a heavily coated, flat grade TiO_2. The coatings typically used are Silicon (Si), Zirconium (Zr) and organic compounds.

The type of defoaming agents used in paints varies with gloss profile and viscosity of the paint in question. Line 500 uses a silicon active form of defoaming agent that comprises approximately 0.26%(w/w) of the paint's composition.

Line 500 conforms to the Australian Paint Approved Scheme Standard 0260/5.

DISTRIBUTION LIST

Improved Strand Burn Rate Reproducibility Using a New Preparation Methodology for Paint-Based 0Inhibitors

Andrew H. Hart and Raoul A. Pietrobon

AUSTRALIA

DEFENCE ORGANISATION

Task sponsor

Director, Ordnance Safety Group	1

S&T Program

Chief Defence Scientist	shared copy
FAS Science Policy	
AS Science Corporate Management	
Director General Science Policy Development	
Counsellor Defence Science, London	Doc Data Sheet
Counsellor Defence Science, Washington	Doc Data Sheet
Scientific Adviser to MRDC, Thailand	Doc Data Sheet
Scientific Adviser Joint	Doc Data Sheet
Navy Scientific Adviser	Doc Data Sht & Dist List
Scientific Adviser - Army	Doc Data Sht & Dist List
Air Force Scientific Adviser	Doc Data Sht & Dist List
Scientific Adviser to the DMO M&A	Doc Data Sht & Dist List
Scientific Adviser to the DMO ELL	Doc Data Sht & Dist List
Director of Trials	1

Systems Sciences Laboratory

Chief of Weapons Systems Division	Doc Data Sheet & Dist List
Research Leader Emerging Weapon Technology	Doc Data Sheet & Dist List
Head Propulsion Systems Technology	1
Dr. A. White	1
Mr S.G. Odgers	1
Mr A.H. Hart	1
Mr R.A. Pietrobon	1

DSTO Library and Archives

Library Edinburgh	1 & Doc Data Sheet
Australian Archives	1

Capability Systems Division

Director General Maritime Development	Doc Data Sheet
Director General Aerospace Development	Doc Data Sheet
Director General Information Capability Development	Doc Data Sheet

Office of the Chief Information Officer

Chief Information Officer	Doc Data Sheet

Deputy CIO — Doc Data Sheet
Director General Information Policy and Plans — Doc Data Sheet
AS Information Structures and Futures — Doc Data Sheet
AS Information Architecture and Management — Doc Data Sheet
Director General Australian Defence Information Office — Doc Data Sheet
Director General Australian Defence Simulation Office — Doc Data Sheet

HQAST

SO (Science) (ASJIC) — Doc Data Sheet

Navy

SO (SCIENCE), COMAUSNAVSURFGRP, NSW — Doc Data Sht & Dist List
Director General Navy Capability, Performance and Plans, Navy Headquarters — Doc Data Sheet
Director General Navy Strategic Policy and Futures, Navy Headquarters — Doc Data Sheet

Army

ABCA National Standardisation Officer, Land Warfare Development Sector, Puckapunyal — e-mailed Doc Data Sheet
SO (Science), Deployable Joint Force Headquarters (DJFHQ) (L), Enoggera QLD — Doc Data Sheet
SO (Science) - Land Headquarters (LHQ), Victoria Barracks NSW — Doc Data & Exec Summ

Intelligence Program

DGSTA Defence Intelligence Organisation — 1
Manager, Information Centre, Defence Intelligence Organisation — 1
Assistant Secretary Corporate, Defence Imagery and Geospatial Organisation — Doc Data Sheet

Defence Materiel Organisation

Head Airborne Surveillance and Control — Doc Data Sheet
Head Aerospace Systems Division — Doc Data Sheet
Head Electronic Systems Division — Doc Data Sheet
Head Maritime Systems Division — Doc Data Sheet
Head Land Systems Division — Doc Data Sheet

Defence Libraries

Library Manager, DLS-Canberra — Doc Data Sheet
Library Manager, DLS - Sydney West — Doc Data Sheet

OTHER ORGANISATIONS

National Library of Australia — 1
NASA (Canberra) — 1
Library of New South Wales — 1

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy
Library — 1

Head of Aerospace and Mechanical Engineering	1
Hargrave Library, Monash University	Doc Data Sheet
Librarian, Flinders University	1

OUTSIDE AUSTRALIA

INTERNATIONAL DEFENCE INFORMATION CENTRES

US Defense Technical Information Center	2
UK Defence Research Information Centre	2
Canada Defence Scientific Information Service	e-mail link to e-report
NZ Defence Information Centre	1

ABSTRACTING AND INFORMATION ORGANISATIONS

Library, Chemical Abstracts Reference Service	1
Engineering Societies Library, US	1
Materials Information, Cambridge Scientific Abstracts, US	1
Documents Librarian, The Center for Research Libraries, US	1

SPARES	5
Total number of copies:	**32**

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE

Improved Strand Burn Rate Reproducibility Using a New Preparation Methodology for Paint-Based Inhibitors

3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)

Document	(U)
Title	(U)
Abstract	(U)

4. AUTHOR(S)

Andrew H. Hart and Raoul A. Pietrobon

5. CORPORATE AUTHOR

Systems Sciences Laboratory
PO Box 1500
Edinburgh South Australia 5111 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TN-0513	AR-012-881	Technical Note	September 2003

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
E9505-25-104	JTW 03/066	DOSG	13	6

13. URL on the World Wide Web

http://www.dsto.defence.gov.au/corporate/reports/DSTO-TN-0513.pdf

14. RELEASE AUTHORITY

Chief, Weapons Systems Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

18. DEFTEST DESCRIPTORS

Burning rate, composite rocket propellants, strands, inhibitors.

19. ABSTRACT

Small-scale ballistic characterisation of composite rocket propellants is a critical step in the development of rocket motors and is achieved by measuring linear strand burning rates determined using the Crawford strand burning technique. To utilise this technique, the propellant strands must burn with an end-burning configuration, which is achieved through the application of a water-based acrylic paint as an inhibitor. To be effective, the inhibitor needs to be of such a quality that the resultant coating on the propellant strands will be defect-free. If the inhibitor coating contains defects, erroneous and irreproducible burn rate data can result, a problem that has been evident at this facility in the past. To improve the strand burn rate reproducibility, a series of paint/water compositions, ranging between 65 and 78%(v/v) paint/water, were prepared using a modified preparation methodology. Of the inhibitor compositions investigated, a 70%(v/v) paint/water ratio was found to be optimal. Using this inhibitor composition, coupled with the introduction of a more rigorous inhibitor preparation methodology, a 60% reduction in erroneous burn rate data and a 32% improvement in burn rate reproducibility was achieved.