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Participation in conferences

Niklas Wingborg (FOI)

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Front page picture: The project team at Politecnico di Milano, March 2012.

Summary

The project HISP is funded by the European Commission's Seventh Framework Programme. Dissemination of the results from the project to the space propulsion community and the public is important and has been performed by a number of means.

The project team has been very active in participating at a number of different international conferences. This report is a compilation of all abstracts of papers related to the project, presented, or to be presented, at conferences during 2011 and 2014. This includes 23 papers at 14 different conferences.

Contents

1 Introduction

The project HISP is funded by the European Commission's Seventh Framework Programme. HISP stands for High performance solid propellants for In-Space Propulsion, or solid propellant with High Isp (specific impulse). As the name indicates, the objective of the project is to develop high performance solid rocket propellant for spacecrafts.

Propulsion and propellants are key technologies for all space missions. The HISP project has advanced the chemical solid propulsion technology by linking together some of the key players in Europe to develop an advanced high performance solid propellant by using the new high energy density oxidizer ammonium dinitramide, ADN, an energetic binder based on glycidyl azide polymer, GAP, and high energy density fuels such as aluminium hydride (AlH_3), nano-aluminium or activated aluminium.

Dissemination of the results from the project is important to strengthen the competence of the European space propulsion community. The consortium partners thus strive to disseminate as much open information as possible by the following means:

- Project website (www.hisp-fp7.eu)
- Public project reports
- Scientific publication in peer-reviewed papers
- Participation at international conferences

The project team has been very active in participating at a number of different international conferences. This report is a compilation of all abstracts of papers related to the project, presented, or to be presented, at conferences during 2011 and 2014. This includes 23 papers at 14 different conferences. The abstracts are presented in chronological order.

2 Conferences 2011

2.1 4th European Conference for Aeronautics and Space Sciences

EUCASS 2011: European Conference for Aerospace Sciences
St. Petersburg, Russia. 4-8 July 2011.
http://eucass2011.conferencecenter.ru/cs/index.php/eu/2011

ADN Propellant Development

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Abstract
Ammonium dinitramide (ADN), is a powerful oxidizer salt of interest for both missile and space propulsion applications. It has the potential not only to improve the performance, but also to make future propellants more environmental benign. It is mainly intended as oxidizer in solid propellants, but it can also be used in liquid monopropellants dissolved in a fuel/water blend. The physical and toxicological properties of ADN have thoroughly been studied during the last years. The properties of ADN and an overview of the development of solid and liquid ADN-based propellants are presented in this paper.

2.2 9th International Autumn Seminar on Propellants, Explosives and Pyrotechnics

IASPEP: International Autumn Seminar on Propellants, Explosives and Pyrotechnics
Jiangsu, China. 20-23 September 2011.
http://www.iaspep.com.cn/2011iaspep.htm

Innovative Metallized Formulations for Solid or Hybrid Rocket Propulsion

Luigi T. DELUCA, Luciano GALFETTI, Filippo MAGGI, Giovanni COLOMBO, Alice REINA, Stefano DOSSI, Daniele CONSONNI, and Melissa BRAMBILLA
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Abstract
Several metallized solid rocket propellants, of the broad family AP/Metal/HTPB in the ratio 68/18/14, were experimentally analyzed at the Space Propulsion Laboratory of Politecnico di Milano. In general, they feature the same nominal composition, but different metals (micrometric and nanometric Al, B, Mg, and a variety of dual metals) are implemented as high-energy fuel powders and contrasted to a conventional micrometric aluminum (30 μm average grain size) taken as reference. The fundamental ballistic properties of the formulations under study were compared to that of a conventional aluminized propellant used in flight since longtime. It is shown that the propellant microstructure plays a fundamental role in controlling the critical aggregation/agglomeration phenomena occurring below and near the burning surface. Two specific effects of microstructure in terms of steady burning

rate and average agglomerate size are illustrated. Understanding of these effects opens the path to improved ballistic performance in terms of delivered specific impulse for solid propulsion. Likewise, metallized solid fuels can assist in improving performance of hybrid propulsion in terms of higher regression rates, larger specific impulse, bigger density, and reduced throat erosion.

3 Conferences 2012

3.1 Space Propulsion 2012

Bordeaux, France. 7-10 May 2012.
http://www.propulsion2012.com/

Overview of ADN Propellants Development

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Abstract
Ammonium dinitramide (ADN), is a powerful oxidizer salt of interest for both missile and space propulsion applications. It has the potential not only to improve the performance, but also to make future propellants more environmental benign. It is mainly intended as oxidizer for solid propellants, but it can also be used in liquid monopropellants dissolved in a fuel/water blend. The physical and toxicological properties of ADN have thoroughly been studied during the last years. The properties of ADN and an overview of the development of solid and liquid ADN-based propellants are presented in this paper.

3.2 43rd International Annual Conference of the Fraunhofer ICT

Karlsruhe, Germany. 26-29 June 2012.
http://www.ict.fraunhofer.de/en/conferences/conferences.html

COMBUSTION MECHANISM OF ADN-BASED COMPOSITE PROPELLANT

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Abstract
Combustion characteristics of pelletized ammonium dinitramide (ADN) and ADN-based propellants have been studied. Micron-meter-sized particles of Al, Fe_2O_3, TiO_2, NiO, $Cu(OH)NO_3$, Cu and CuO, and nanometer-sized Al (Alex) and CuO (nanoCuO) were employed as the additives for pelletized ADN. Only nanoCuO and Alex show the remarkable effects, so they are also added to ADN-based propellant. The binder of ADN-based propellant is thermoplastic elastomer (TP), and three kinds of mixtures (TP:ADN = 30:70, 20:80 and 10:90 mass%) were prepared .The burning rates of pelletized ADN and ADN-based propellants were measured under the pressure range from 0.6 to 6.2 MPa, and the surface temperature profiles were obtained about ADN-based propellants. Nano-sized CuO enhanced the burning rate of pelletized ADN. Alex-incorporated ADN burned with flames even at 0.55 MPa under which pure ADN does not form the flame. Burning rate of non-additive ADN-based propellants has extremely high pressure dependency. In the case of TP/ADN (30:70), burning rate jump are found from the critical pressure approximately 3.2 MPa. The temperature profiles of TP/ADN (30:70) were measured, and the combustion structure was discussed. Both nanoCuO and Alex improved the burning rate characteristics, and the pressure exponents are 0.54 and 0.76 respectively.

3.3 9th International Symposium on Special Topics in Chemical Propulsion

ISICP
Québec, Canada, 9 -13 July 2012.
http://www.9isicp.org/

Innovative Metal Fuels for Solid Rocket Propulsion

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Abstract
Two groups of innovative metal fuels are addressed in this paper. Three nanometric powders nominally ranging from 50 to 100 nm were contrasted to three micrometric activated aluminum powders, in terms of active metal content, specific surface area, scanning electron microscopy imaging, laser granulometry, and ignition properties in air. Both nanosized and activated aluminum powders featured augmented reactivity as well as a higher fraction of oxidized metal with respect to standard micrometric aluminum. All metal powders were also used as fuels for a series of composite AP (ammonium perchlorate)/Hydroxyl Terminated Polybutadiene (HTPB)/metal propellants, in either total or partial replacement of micrometric aluminum (baseline). Burning rates were contrasted to powder properties (mainly, specific surface area of the fuel), discussing the correlation between these parameters. A specific analysis on particle shape factor was also conducted on three micrometric powders. In this regard, a framework for the characterization of particle roundness was implemented and used for the cross comparison among several lots of powders for propulsion application (space-grade) as well as painting industry (industrial-grade), providing a statistical management of particle shape features.

4 Conferences 2013

4.1 96th Canadian Chemistry Conference and Exhibition

Québec, Canada. 26-30 May 2013.
http://www.csc2013.ca/

AMMONIUM DINITRAMIDE, AN ENVIRONMENTALLY BENIGN EXPLOSIVE AND OXIDIZER

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Abstract
Ammonium Dinitramide (ADN) is an explosive and a strong oxidizer with extraordinary properties and several possible uses. It is chlorine free and burns without leaving any toxic residues and it has the potential of being a non-toxic, environmentally friendly alternative to substances such as Ammonium Perchlorate and Hydrazine.

ADN has a high burn rate, a high specific impulse and a high bubble energy. The first satellite using ADN liquid monopropellants for altitude control was launched in June 2010 but the substance can also be used in composite propellants e.g. for rocket propellants and as an underwater explosive.

ADN has been produced at EURENCO Bofors since 1997, originally using a process invented by the Swedish Defence Research Agency, but today with an improved method in terms process time, purity and significantly more environmentally friendly. In the EU financed HISP project (High Performance Solid Propellants for In-space Propulsion) more work has been carried out on recycling which could reduce the emissions from the process even more.

4.2 44th International Annual Conference of the Fraunhofer ICT

Karlsruhe, Germany. 25-28 June 2013.
http://www.ict.fraunhofer.de/en/conferences/conferences/anconf.html

JET MILLING OF ADN AND FOX-12

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Abstract
Usually bi or tri modal particle sizes of an oxidizer are used in propellants. One technique to obtain micron sized particles is jet milling. This method is used in the explosive and propellant industry to mill energetic materials such as AP, HMX and RDX. The aim of this work was to determine if this method also would be possible to use for milling ADN and

FOX-12. Several 100 gram batches of prilled ADN, crude ADN and FOX-12 have been jet milled. One 100 gram batch takes approximately 15 seconds to produce. Particle size measurement determined the d50 to 10-20 µm. SEM imaging shows that the shapes of the jet milled particles are highly irregular. Recently initial small scale formulations were made with jet milled ADN and FOX-12 as the small fraction. The initial result shows satisfying properties in respect to the castability.

ALUMINIZED ADN/GAP PROPELLANTS – FORMULATION AND PROPERTIES

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Abstract
The paper presents an overview of the HISP project and focuses on the work performed at ICT concerning Al/ADN/GAP propellant formulation.

ADJUSTMENT OF THE PARTICEL SIZE OF ADN-PRILLS GENERATED BY THE EMULSION CRYTALLIZATION PROCESS

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Abstract
During the last years the high performance, low signature and environmental friendly oxidizer ammonium dinitramide (ADN) gained more and more acceptance for defence and space applications. But the application of ADN in solid propellant formulations leads to a requirement of spherical particles of at least two different particle sizes. Therefore a coarse particle size fraction in the range of 200–250 µm and mediumparticle size fraction in the range of 30–60 µm are demanded. A fine fraction of about 5 µm would be desirable.

To achieve these requirements several process parameters of the emulsion crystallization process for ADN, the so-called ADN-Prilling process, were modified. By the variation of process fluids, additives, stirring energy and recrystallization behaviour it was possible to generatemedium sizedADN-Prills with a mean particle size of 50 µm and coarse ADN-Prills with approx. 200 µm in technical scale.

EFFECTS OF HTPB-COATING ON NANO-SIZED ALUMINUM IN SOLID ROCKET PROPELLANT PERFORMANCE

Alice Reina*, Alexander B. Vorozhtsov**, Igor Krawiec*, Marco Morlacchi*, Giovanni Colombo*, Marat I. Lerner ***, Nikolai G. Rodkevich *** and Luigi T. DeLuca*

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Abstract
Nanosized powders (NP) are quite attractive for space propulsion applications, but they are difficult to handle because of the tendency to form clusters that hinder the complete exploitation of nanomaterials potential. In order to improve the dispersion degree of NP in solid rocket propellants (SP) and to decrease viscosity during manufacture, coating with the same polymer used as binder is considered. First, in this work powders coated with different percentages of HTPB, obtained using various solvents and coupling agents are compared, in terms of size distribution, active aluminum content and stability to moisture. Results show that the best compromise is achieved with mineral spirit as solvent, acetylacetone as coupling agent and using 1% of HTPB. A ballistic characterization is then performed on AP/HTPB propellants in which micrometric aluminum (μAl) is partially or completely substituted by a nanometric one (nAl), comparing uncoated ALEXTM with the selected coated powder (HALEX).

An increase in burning rate is shown by formulations containing H.-ALEX with respect to propellants containing ALEXTM. The increased reactivity of SP containing HALEX is confirmed by the measurement of ignition delay. Rheological tests show that viscosity of uncured formulations is lower for propellants containing H-ALEX.

4.3 5th European Conference for Aeronautics and Space Sciences

EUCASS 2013.
Munich, Germany. 1-5 July 2013.
http://www.eucass2013.de/

High Performance Solid ADN Propellants for Space Applications

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Abstract
Spacecrafts are today propelled using chemical or electrical rocket propulsion systems. Electrical propulsion provides superior specific impulse but very low thrust, whereas chemical propulsion provides low specific impulse but high thrust. If high thrust is required, chemical rocket propulsion is thus the only viable alternative. Depending on the propellants used, chemical rocket propulsion systems are divided in three major categories;

- Liquid propellant rockets (monopropellant and bi-propellant systems)
- Hybrid propellant rockets (solid fuel, liquid oxidizer)
- Solid propellant rockets

Of these three, liquid rockets provide the highest performance and adjustable thrust, but they are complex, costly and use toxic propellants such as hydrazine, mono-methyl hydrazine (MMH) and nitrogen tetroxide (NTO).

Current hybrid rockets are safer and less complex than liquid rockets. They provide excellent theoretical performance, but in reality these performance levels are hard to obtain due to poor combustion efficiency and low fuel regression rate.

The benefits of solid rockets are their storability, compactness and simplicity. No propellant delivery system is required which enables a huge improvement in reliability and cost. However, current solid rockets suffer from two major drawbacks; once ignited the thrust cannot be altered and their specific impulse is low.

The HISP project (www.hisp-fp7.eu) of the European Commission's Seventh Framework Program addresses the latter by developing high performance solid propellants using the high energy density oxidizer ammonium dinitramide (ADN), glycidyl azide polymer (GAP) and high energy density fuels such as aluminium hydride (AlH3), micron- and nano-aluminum and activated aluminum.

The paper presents an overview of the HISP project and focuses on the work performed at FOI concerning ADN particle production, propellant formulation and thermochemical calculations.

Elements for propellants requirements

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Abstract

The objective of the study was to define propellant requirements. The propellant identified requirements will guide the development in the project of a suitable formulation with a high specific impulse. Generally to compare new propellant the product ρ.Is is used, this way to proceed is not really relevant, if the effect the specific impulse is always of first importance, the effect of density and of burning rate on the lay-out is important moreover the result is very different if is considered a first stage or an upper stage. So, to be pertinent an advice have to be funded on an analysis taking into account as much as possible the real context.

Three reference missions were selected:

- Upper stage of Vega launcher
- Apogee/deorbitation motor
- Mars ascent vehicle

Based on ADN and GAP and an energetic fuel (Aluminium or Alane), two "Ideal" propellants were defined. Their potential performance increases were quantified in respective mission by a comparison –using fist design and trajectory tools-with references cases and some of their required properties and a domain of formulation were identified.

The most important properties are:

- Burning rate
- Mechanical properties
- Specific impulse

The first mandatory point is to be able to obtain a propellant with a basic burning rate in the range of 7 to 15 mm/s at 7 MPa. This range could probably be extended for some applications when high acceleration can be accepted. The second prerequisite is to obtain a propellant with good mechanical properties, at least of the level of classical HTPB propellants, to enable a case bonded grain. For space applications end burning grain will also be a common situation even if relatively low burning rate propellants are achievable, so an axis of work would be to look for propellant with mechanical properties much better than the current one so to be able to realize full bonded end burning grain.

These requirements satisfied, the only important parameter is the level of practical specific impulse. With the formulations understudy the performance gain could be dramatic with a potential increase up to more than 30% of the payload of the Vega Launcher by replacing only the propellant of the third stage. For a Mars Ascent vehicle the saving on the lift-off mass could be also impressive but in such an application (launcher of small size) to obtain compatible burning rate level is of first importance and a more detailed system analysis has to be performed.

Advanced aluminum powders for solid propellants

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Abstract
In the framework of HISP Project, a 7th European Framework Project, solid propellants with high specific impulse were targeted, leveraging on proper formulation choice. On the fuel side, different high-energy density ingredients were tested to monitor the consequences of their enhanced reactivity. The improvement of combustion properties in terms of ballistic as well as agglomeration behaviour is envisaged to attain a reduction of agglomerate size and, as consequence, of performance losses due to multiphase expansion.

This paper presents the characterization of one nanoaluminum produced by means of EEW (Explosion of Electric Wire) and one micrometric activated aluminum, which reactivity was enhanced by means of a chemical treatment. These ingredient batches were tested in term of physical properties (size and specific surface), active metal content, viscosimetry, and ignition temperature. Moreover, some propellants were produced with the aim to test the behaviour of such powders under real combustion conditions, as of burning rate and agglomeration. The investigation also involved four multimodal powder blends where a limited amount of advanced metal fuels was mixed with a standard baseline powder, resulting in a compromise between metal content and reactivity.

Combustion of Metallised ADN/GAP Solid Rocket Propellants with Focus on Agglomeration Effects

V. Weiser, A. Franzin, V. Gettwert, L. T. DeLuca

Abstract
Addition of metals, typically Al powder under several ways (micron-sized, nano-sized, activated, amorphous, etc.) is a well-known approach to increase the gravimetric as well as volumetric (or density) ideal specific impulse of solid rocket propellants. However, it is also well-known that aggregation/agglomeration phenomena, at or near the burning surface, penalizes the specific impulse increase making its delivered value appreciably less than the corresponding ideal value. An impressively large body of literature is available discussing this issue for the classical ammonium perchlorate (AP) / hydroxyl terminated polybutadiene (HTPB) / micrometric Al used for decades in propulsion missions aimed at space access. In this case, the recommended international standard for the two-phase flow losses reads as

$$(\Delta I_{sp})_{2\mathrm{p}} = C_3 \frac{\xi_{cc}^{C4} d_p^{C5}}{p_{cc}^{0.15} \varepsilon^{0.008} d_t^{C6}}$$

where:

ξ_{cc} = molar fraction condensed products in combustion chamber (moles/100g);

d_p = average diameter of the condensed particles (μm);

p_{cc} = combustion chamber pressure (psi);

$\varepsilon \equiv A_e/A_t$ = geometric expansion ratio of the nozzle;

d_t = throat area diameter (in);

C_3, C_4, C_5, C_6 = correlation constants.

The main difficulty in using this equation concerns the parameters associated with the type of loaded solid propellant before and after combustion (respectively ξ_{cc} and d_p). A survey of the many effects and pathways associated with different metal burning in traditional HTPB bound composite solid rocket propellants was offered some time ago [2]. On the contrary, very little can be found in the open literature regarding the ADN/GAP formulation, meant to be a green and highly performing new composite propellant. Which specific path comes out to be the dominating one when AP/HTPB is totally replaced by ADN/GAP at this time is unknown. In this work substitution of AP/HTPB with ADN/GAP is experimentally assessed, by comparing a standard AP/HTPB/Al formulation to the corresponding ADN/GAP/Al formulation in terms of burning rate and agglomeration effects. Thermochemical calculations are carried out to quantify the ideal performance gain obtainable when adding micrometric Al to ADN/GAP matrix as well as the performance loss reasonably associated with the resulting two-phase flow.

4.4 CEAS Air & Space Conference 2013

CEAS: Council of European Aerospace Societies
Linköping, Sweden. 16-19 September 2013.
http://www.ceas2013.org/

High Performance Green Propellants

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Abstract
The interest in green propellants has emerged during the last decades. To stay competitive on a global market, green propellants need to have equal or higher performance compared to current toxic propellants. Possible green high performance mono, bi, hybrid and solid propellants have been identified and some future key development activities are presented.

4.5 10th International Autumn Seminar on Propellants, Explosives and Pyrotechnics

IASPEP
Chengdu, Sichuan Province, China. 24-27 September 2013.
http://www.iaspep.com.cn

High-energy metal fuels for rocket propulsion: characterization and performance

Luigi T. DELUCA, Filippo MAGGI, Stefano DOSSI, Volker WEISER, Andrea FRANZIN, Volker GETTWERT, and Thomas HEINTZ

Abstract
This paper describes a joint international effort to improve solid propellant performance within the framework of a FP7 European Project. Several metallized solid rocket propellants, of the broad family AP/HTPB/Metal in the ratio 68/14/18, were experimentally analyzed seeking to optimize the delivered specific impulse by identifying the most suitable high-energy fuel. Keeping the same nominal composition, different metallic fuels (including micrometric and nanometric Al, AlH3, and a variety of dual metal compositions) were characterized, tested, and contrasted to a conventional micrometric aluminum (30 µm average grain size) certified for space flights. In order to overcome the intrinsic performance limitations of the matrix AP/HTPB, a new matrix consisting of ADN/GAP satisfying also the need for environmentally benign propellant formulation was considered as well. A comparative analysis between the two solid propellant systems in terms of ideal thermochemistry and experimental combustion properties reveals advantages and disadvantages of both. Overall, it is judged worthwhile to develop ADN/GAP propellants, with or without metallic fuels, to enhance the current status of solid rocket propulsion. Controlling morphology and mechanical properties of ADN/GAP compositions and

understanding their flame structure and aggregation/agglomeration properties are the main issues still challenging industrial users.

4.6 9th High Energy Materials Workshop

HEMs 2013. Civil and Green Application of High Energy Materials
Sagamihara, Kanagawa, Japan. October 7–9, 2013.
http://www.HEMs-2013.jp

Gas dynamics aspects of nanoaluminum use for SRM

A.Vorozhtsov, A.Glazunov, L.DeLuca, A.Gromov, L.Revyagin, N.Kuvshinov and M. Fassina

Abstract
Burning rate and pressure exponent in the Vieille law as well as the gas-dynamic flow behavior change significantly when micron-sized aluminum is replaced by nanoaluminum (nAl) in solid rocket propellants (SP) compositions. Gas-dynamic instabilities triggered by using nAl in SP, along with the reduction of the two-phase losses, could result from the size reduction of solid combustion products (mainly aluminum oxide) in the associated 2-phase flow. This hypothesis leads to the consideration that a low content of solid phase in the flow of combustion products could decrease the critical threshold for combustion stability of solid rocket motors (SRM), as it happens in the case of non-metallized SP. For the latter case, burning stability issues are highly relevant as opposed to metallized SP, where the micron-sized particles of the two-phase flow dissipate the acoustic microimpacts.

The theoretical and experimental evaluation of the above mentioned instabilities, as well as the impact of using nanoparticles in SP from the estimation of two-phase flow losses and acoustic conductivity, are discussed in the present work.

3-D mathematical modeling of two-phase flow and other losses in SRM, when the particle size varies in a wide range of values from ‘quasi zero’ size (for non-metallized SP) to typically 4.2-4.8 mm at the nozzle inlet (for SP loaded with micron-sized aluminum), is carried out.

An experimental and theoretical study of acoustic conductivity of SP, using micron-sized and nAl in comparison with unmetallized fuel, is discussed.

Combustion Behaviour of Aluminium Particles in ADN/GAP Composite Propellants

*V. Weiser, A. Franzin, L.T. De Luca, S. Fischer, V. Gettwert, S. Kelzenberg,
S. Knapp, J. Neutz, A. Raab, E. Roth*

Abstract
Propellants containing ADN/GAP are regarded as a promising green alternative to AP/HTPB solid rocket propellants. The addition of aluminium powder is a classical approach to increase the theoretical specific impulse of composite propellants. Optimum aluminium content is in the range of 16-18% Al. The agglomeration of Al particles at the surface and burning behaviour of aluminised AP/HTPB propellants is in an advanced grade of investigations. But

ADN, a chlorine free oxidiser, and GAP, an energetic binder, generate no chloric acid but more nitrogen in an exothermic decomposition. So, significantly different thermal and chemical conditions impinge on the aluminium particles close to the burning surface. This study concerns with the combustion behaviour of aluminium particles in an ADN/GAP matrix in comparison to AP/HTPB at various pressure up to 15 MPa. For ADN/GAP, temperature measurements close to the propellant surface indicate higher values near the Al boiling point that accelerates the melting of Al-particles and influences the agglomeration process close to the propellant surface. At higher pressure the temperatures are in the magnitude of Al2O3 evaporation and decomposition close to 3000 K.

Survey of Aggregation and Agglomeration Phenomena in Solid Rocket Propulsion

L.T. DeLuca, F. Maggi, S. Dossi, V. Weiser, A. Franzin, V. Gettwert

Abstract
Controlling flame structure and aggregation/agglomeration properties are among the main issues still challenging industrial users whenever new high-performance formulations for space propulsion are tested. Several heterogeneous solid rocket propellants families, of the broad class Oxidizer/Metal/Binder, were experimentally analyzed at the Space Propulsion Laboratory (SPLab) of Politecnico di Milano in cooperation with the Fraunhofer-Institut für Chemische Technologie (ICT). In general, each family features the same nominal composition, but different metals (nature and size) are investigated as fuel powders and contrasted to a conventional, flight- proven micrometric aluminum (30 µm average grain size) taken as reference. Although the metal oxidation process follows a common set of events, aggregation and agglomeration phenomena near the burning surface (below, at, or just above) may be noticeably different depending on the enforced operating conditions and details of the solid propellant formulation (kind of oxidizer, kind of binder, mixture ratios, grain size distributions, and so on). Understanding of these effects opens the path to improved ballistic performance by means of a decreased fraction of the dominating two-phase (2P) flow losses in the actually delivered gravimetric specific impulse. This study reports a quick survey of several experimental datasets collected over the years on Ammonium Nitrate (AN), Phase-Stabilized Ammonium Nitrate (PSAN), Ammonium Perchlorate (AP), different versions of dual AN-AP, and Ammonium Dinitramide (ADN) - based solid rocket propellants. Only laboratory level testing is discussed in this paper. For motor applications, full-scale testing is needed to assure a complete mastering of the process.

5 Conferences 2014

5.1 9th High Energy Materials Conference & Exhibit

HEMCE
Thiruvananthapuram, India. 13-15 February 2014.
http://www.hemce2014.org/

New Energetic Ingredients for Solid and Hybrid Rocket Propulsion

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To improve performance of solid rocket propulsion, several metallized solid propellant formulations, of the broad family Oxidizer/Binder/Metal in the ratio 68/14/18, were theoretically and experimentally analyzed. Systematic attempts were made to optimize the delivered specific impulse by identifying the most suitable ingredients, with particular attention to high-energy metal fuels. Keeping the same nominal composition, different metallic fuels (including micrometric and nanometric Al, different versions of activated Al, AlH3, and a variety of dual metal compositions) were characterized, tested, and contrasted to a conventional micrometric aluminum (30 μm average grain size) certified for space flights. In order to overcome the intrinsic performance limitations of the standard AP/HTPB matrix commonly used in space propulsion, a new matrix consisting of ADN/GAP satisfying also the need for environmentally benign propellant formulation was considered as well. A comparative analysis between the two solid propellant systems in terms of ideal thermochemistry and experimental combustion properties reveals advantages and disadvantages of both. Overall, it is judged worthwhile to further develop ADN/GAP propellants, with or without metallic fuels, to enhance the current status of solid rocket propulsion. In particular, controlling morphology and mechanical properties of ADN/GAP compositions as well as understanding their flame structure and aggregation/agglomeration properties are the main issues still challenging industrial users.

Concerning high-energy metal fuels, although the metal oxidation process follows a common set of events, aggregation and agglomeration phenomena near the burning surface (below, at, or just above) may be noticeably different. The final outcome of the whole process depends on the enforced operating conditions and details of the solid propellant formulation, such as: kind of oxidizer, kind of metal, oxygen balance, grain size distributions, and so on. Mastering of these effects opens the path to improved internal ballistic rocket performance by means of a decreased fraction of the dominating two-phase (2P) flow losses in the actually delivered gravimetric specific impulse.

Ballistic characterization of solid fuels for hybrid rocket propulsion was performed by considering both HTPB- and Paraffin-base solid fuels burning in gaseous Oxygen. The effects of operating conditions and several high-energy additives were elucidated by monitoring, over a reasonable pressure range, the instantaneous regression rates of the solid fuel in a 2D radial micro-burner. An optical time–resolved technique was used to evaluate the quasi–steady regression history of single perforation, cylindrical fuel samples. The effects of oxidizer injection, metallized additives and radiant heat transfer on regression rates were assessed. Under the investigated operating conditions, comparative analyses of the collected experimental data show an appreciable influence of metal hydrides and properly coated selected nano-sized metals on ballistic properties.

For all configurations, only laboratory level testing is discussed in this paper. For motor applications, full-scale testing is needed to assure a complete mastering of the process.

5.2 Space Propulsion 2014

Cologne, Germany. 19-22 May 2014.
http://www.propulsion2014.com

Green Solid Propellants for Space Applications

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Abstract
State of the art solid propellants are based on the oxidizer ammonium perchlorate, AP. AP is in many ways an excellent oxidizer but unfortunately it has negative impacts on the environment and on personal health due to:

- Ozone depletion
- Ground water contamination
- Thyroid gland interference
- Acid rain formation

The ESA Clean Space initiative emphasize the development of green technologies to reduce the environmental impact of space programs, taking into consideration the overall life-cycle and the management of residual waste and pollution resulting from space activities, both in the Earth eco-sphere and in space. Finding substitutes to AP is thus of interest. This paper presents ways to reduce the environmental impact of solid propellants by using:

- Scavengers to neutralize the HCl in the exhaust plume
- Using alternative oxidizers such as AN, ADN, HNF

Properties such as performance, safety, toxicity, cost and availability of alternative solid propellants will be considered and status of current development will be presented.

Application of advanced metal fuels in solid propellants

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Abstract
Solid propellant systems are reliable, simple to build, cost-effective, and ready to operate. However, they feature relatively low specific impulse (Is), if compared to other thermochemical propulsion options (hybrid and liquid). The current industrial standard in composite solid space propellants is represented by micrometric aluminum embedded in a thermosetting inert polymer matrix (polybutadiene or similar) along with a crystalline inorganic oxidizer (ammonium perchlorate or similar). If compared to a non-metalized HTPB/AP formulation, the addition of aluminum ideally grants about +20 seconds but such formulation is prone to agglomeration processes which lead to performance losses, primarily attributed to multiphase flow and nozzle erosion. In order to increment the delivered Is, two main strategies can be adopted: on one side, the reduction of losses which are consequence of the agglomeration process is envisaged while, on the other side, energetic ingredients granting higher ideal specific impulse can be used. In the frame of the HISP FP7 project, the Space Propulsion Laboratory has investigated the application of different types of aluminum powders with enhanced reactivity belonging to the categories of nanoaluminum, of activated aluminum and of aluminum hydride. Despite the expected benefits in the combustion process, such materials introduced drawbacks related to the active metal content, the compounding process as well as the ideal performance level. Detailed investigations are still progressing. The achievements obtained so far are summarized in this paper.

5.3 10th Int. Symposium on Special Topics in Chemical Propulsion & Energetic Materials

ISICP
Poitiers, France. 2-6 June 2014.
http://www.10isicp.org/

Hot-wire based experimental set-up for characterization of metal powder ignition temperature

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Metal powders (e.g. Aluminum, Boron, and Magnesium) are widely used in several fields such as thermites, propellants, and pyrotechnics, to enhance performance. However, despite the strong combustion enthalpy, the effect of most of these materials is hindered by difficult ignition and slow combustion phenomena, especially when micrometric powders are used. During past years, several strategies were studied and implemented in order to increase metal powder reactivity such as size reduction (nano-powders), mechanical activation (with and without additives) or chemical activation. Reactivity quantification is then a primary issue to characterize present and future metal powders. In this respect, one of the most diffused method of analysis is the differential scanning calorimetry, which is able to supply very precise information on powder behavior at low heating rates. However, during combustion processes, powders are subjected to very fast warm-up that cannot be reproduced during a DSC or a DTA analysis. Ignition tests at high heating rates try to overcome this problem. Several set-up have been proposed by different authors and can be distinguished mainly by the heating source: laser or electricity. In the first case, a laser beam is focused directly on the powder or on its support. This technique presents several advantages mainly connected with the positioning of the sample. However, the power Gaussian distribution of a laser beam makes difficult a homogeneous powder heating. Moreover, problems in reaching high heating rates can be observed when an indirect warm-up of the sample is selected. These problems can be reduced using a hot wire instead of a laser. This technique is very interesting since it allows a fine control of the heating rate as well as a uniform sample warm-up. In this article, a new hot wire experimental rig, designed in the framework of the European FP7 program "HISP", is proposed. An accurate description of the facility will be carried out with a special care to the heating element and to the temperature sensor (a micro-thermocouple), that will be described in terms of manufacturing and mounting. Details concerning experiment preparation/conduction, data rejection and post processing will be discussed as well. Some typical results obtained for several powders ignited at different heating rates will be introduced and analyzed. Finally, an ignition model based on an energetic approach will be proposed and described.