AVT-340 Research Workshop on Preparation and Characterization of Energetic Materials

Additive Manufacturing of Simple Shape of Nitrocellulose-based Gun Propellants

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Summary

- **Context of the study**
- **Co-layered gun propellants**
- **Setup and operating procedure**
- **Identification of a simulant and 3D printing of inert pastes**
- **3D printing of nitrocellulose-based pastes**
- **Conclusions and future work**

Context of the study

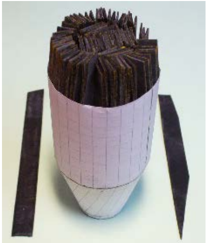
EUROPEAN DEFENCE AGENCY

AMTEM

- **European Defence Agency (EDA) project**
  - AMTEM: Additive Manufacturing Techniques for Energetic Materials
  - 7 countries involved

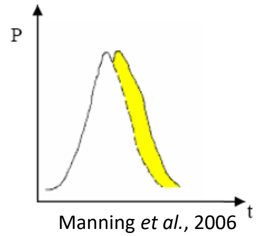
Develop new production techniques for explosives charges and objects, push the boundaries for what is possible in energetic materials and strengthen the European knowledgebase for future advanced energetic materials and their applications

- **ISL work focusing on manufacturing solid propellants by means of 3D printers**
  - Objective in interior ballistics: enhance gun performances without degrading the mechanical stresses
  - Co-layered propellants

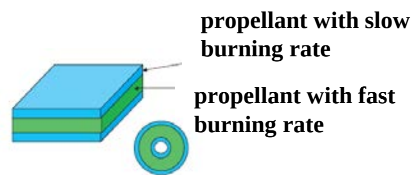


Co-layered propellants

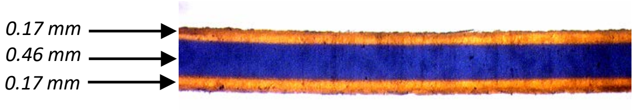
- « Higher performance for gun applications using co-layered propellants based on NENA-formulations », B. Baschung *et al.*, ISL Scientific Symposium 2008



Manning *et al.*, 2006



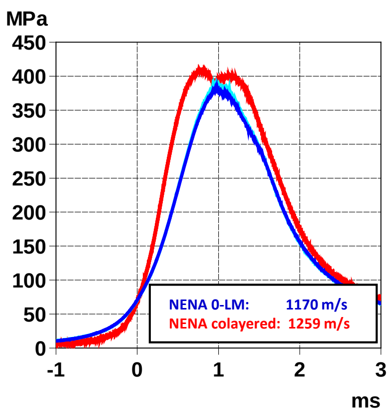
- Manufacturing and characterization of type ABA propellant grains



Burning rate ratio 1.7 : 1

- Ballistic test firing in a 20 mm gun

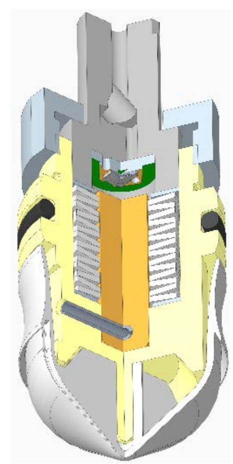
Experimental pressure-time curves



Increase of 15% in muzzle energy **with the co-layered propellant** at equivalent maximum pressures

Setup and operating procedure

- **FDM based 3D printer**
  - Printrbot Simple Metal
- **Extrusion nozzle replaced by the Paste&Food Extruder system from Printrbot**
  - Instrumented piston for pyrotechnic safety
- **Use of EFD Nordson 55cc syringes with tapered tips**



0.84 mm 0.58 mm 0.41 mm 0.25 mm

Setup and operating procedure

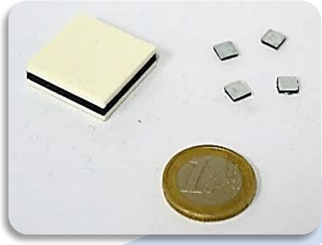
Tests and crystallizer characterizations

Deposition and adhesion of the viscous compositions (glass, Kapton, …)

Viscosity measurements

Tests on the 3D printer with the **inert composition**

Configuration of the 3D printer and identification of the best candidate (in terms of viscosity)



Printing of a simple shape of gun propellant (flake) with the **energetic composition**

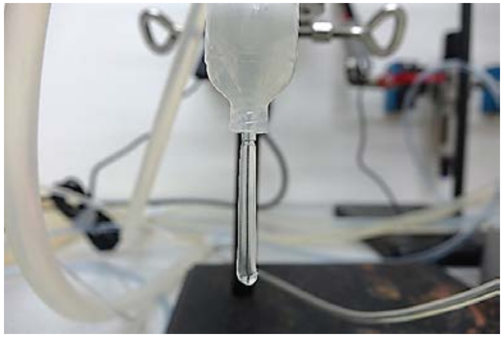
Identification of a simulant

- **Solubility tests in acetone**

1. EVA| 2. Cellulose Acetate | 3. EVAL | 4. Rhodoviol 4/125 | 5. Ultramid 6A | 6. PLA | 7. ABS

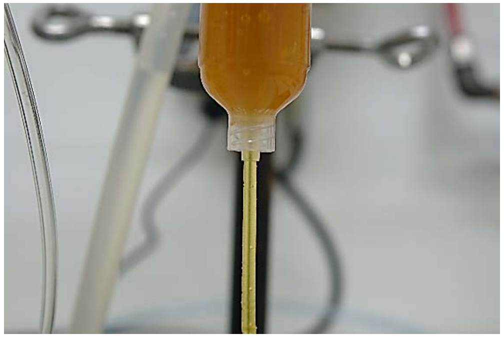
M. Chiroli, F. Ciszek, B. Baschung, "Additive Manufacturing of Energetic Materials", *29th Annual International Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference*, Austin, USA, August 13-15, **2018**, p.1003

- **Extrusion**
  - Energetic material (EM): in-house formulation; 54 wt% of nitrocellulose + NENA plasticizers
  - EVA: significant swelling, highly sticky
  - Cellulose Acetate (CA) no swelling or shrinkage



EVA / Acetone

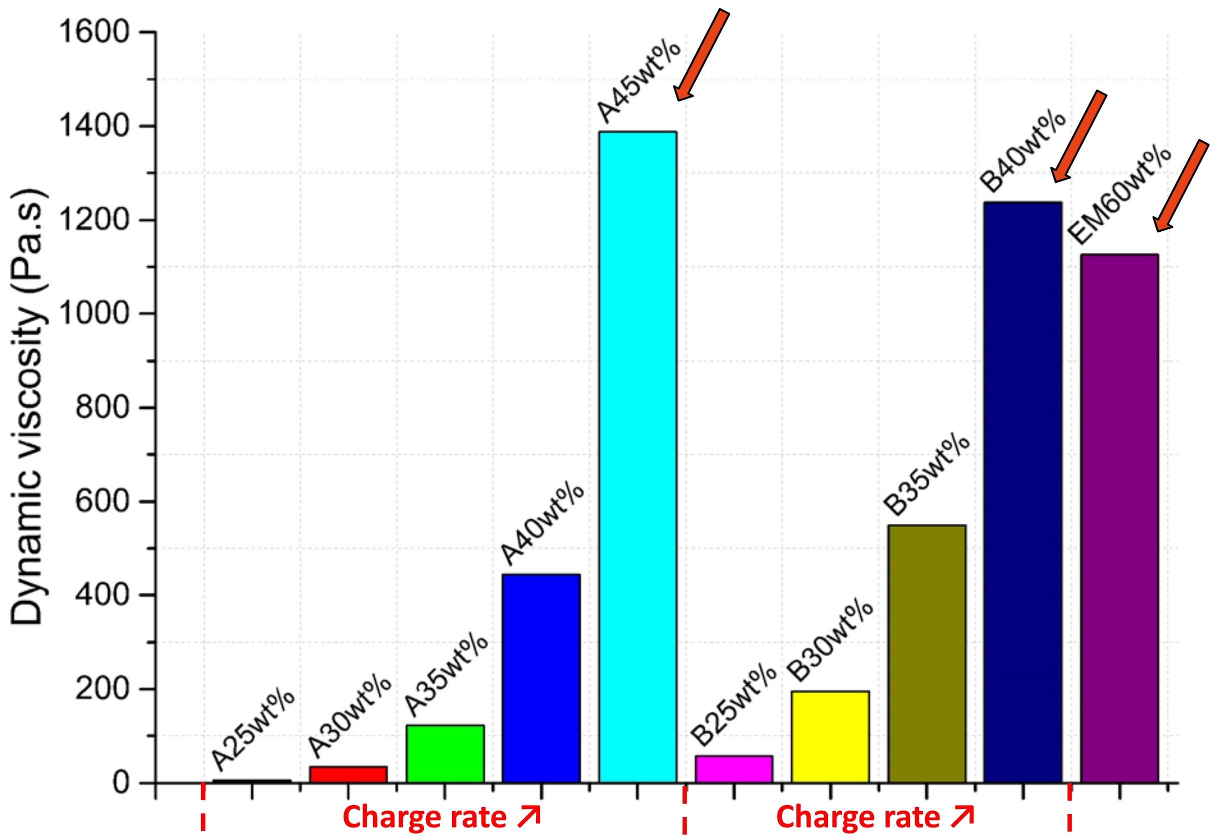
CA / Acetone



EM / Acetone

Identification of a simulant

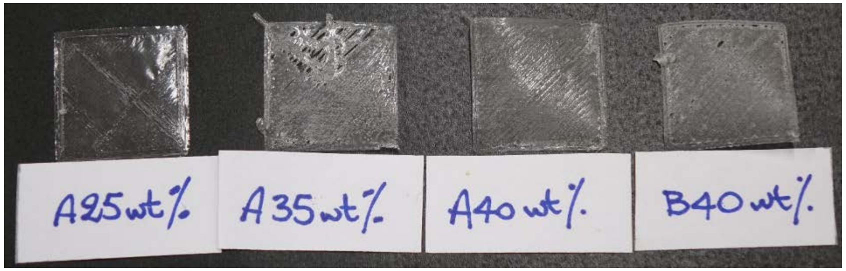
- **Dynamic viscosity measurements**
  - Two different samples of CA powder (A & B)
  - Charge rates: from 25 wt% (fluid paste) to 50 wt% (highly viscous) CA powder
  - Mixture EM / Acetone: ISL development (54 wt% of nitrocellulose + NENA plasticizers)
  - Charge rate: 60 wt%



Shear rate = 4.s^{-1}

3D printing of inert pastes

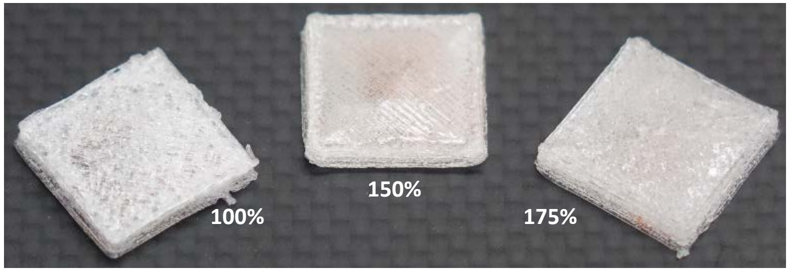
- **Reliable printing of first layers of simulant**
  - Nozzle size = *0.41 mm;* Initial layer thickness = *0.4 mm;* Bottom layer speed = *5 mm.s*$^{-1}$



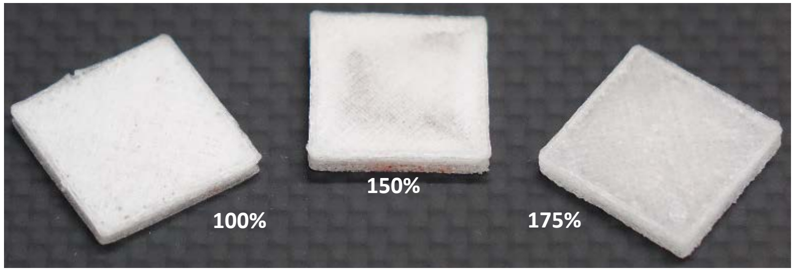
M. Chiroli, F. Ciszek, B. Baschung, "Identification of Simulants for Additive Manufacturing of Gun Propellants", *Proceedings of Europyro 2019, 44th International Pyrotechnics Society Seminar*, Tours, France, June 03-07, **2019**, p.175

- **Selection of only 3 simulants for the printing of full objects**
  - A30wt%, A40wt% and B40wt%

Variation of the flow parameter



A40wt%



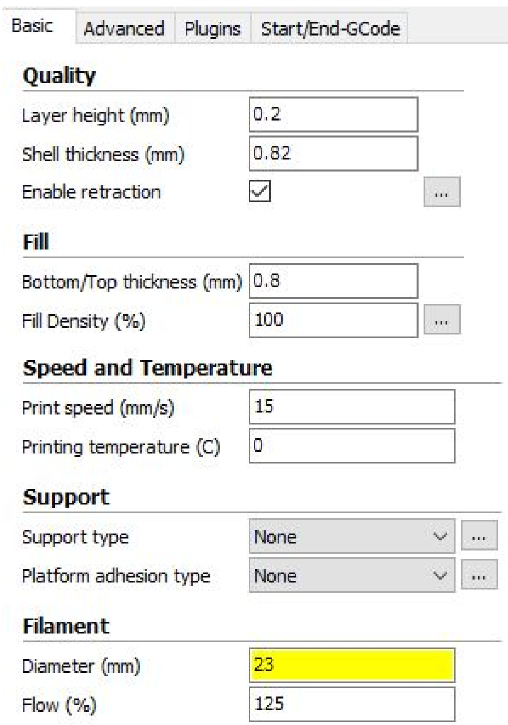
B40wt%

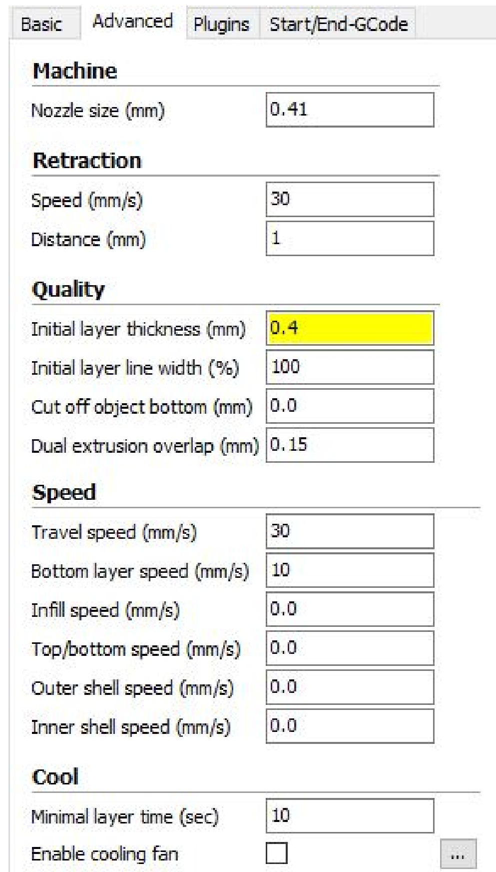
- **Best results with the most viscous simulant B40wt%**

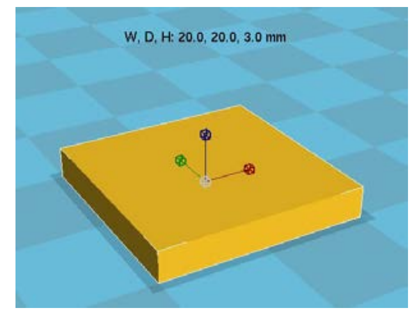
3D printing of nitrocellulose-based pastes

- **Syringe EM60wt%**
  - 60wt% of EM dissolved in acetone

- **Same printing parameters as for B40wt%**



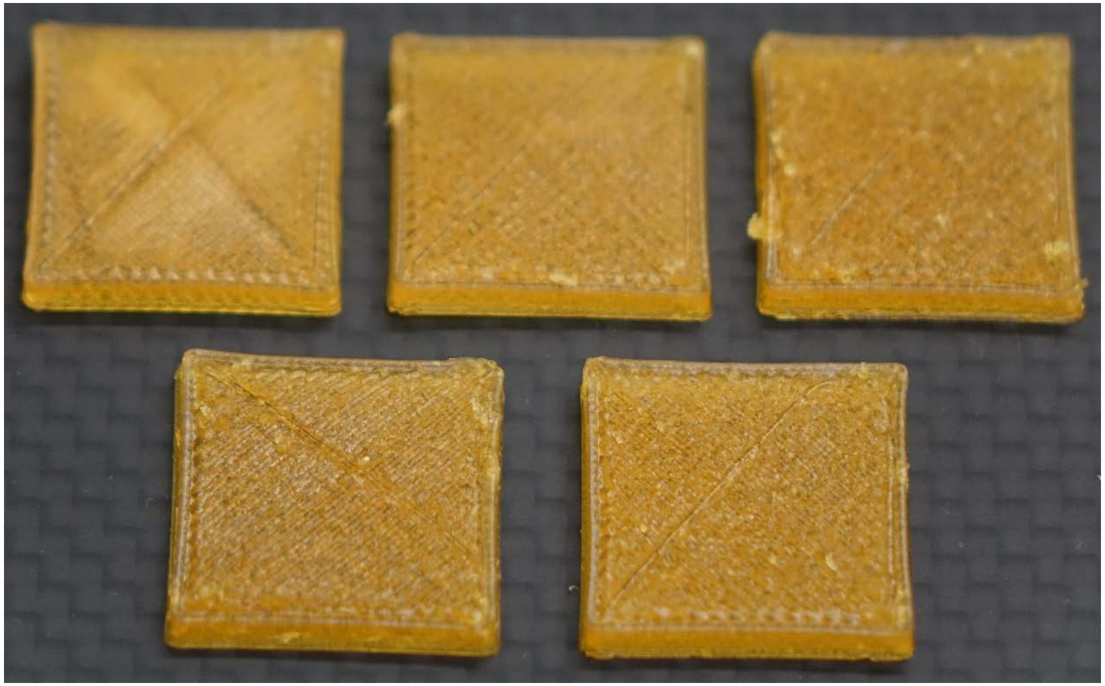




Total printing time = 19 minutes

3D printing of nitrocellulose-based pastes

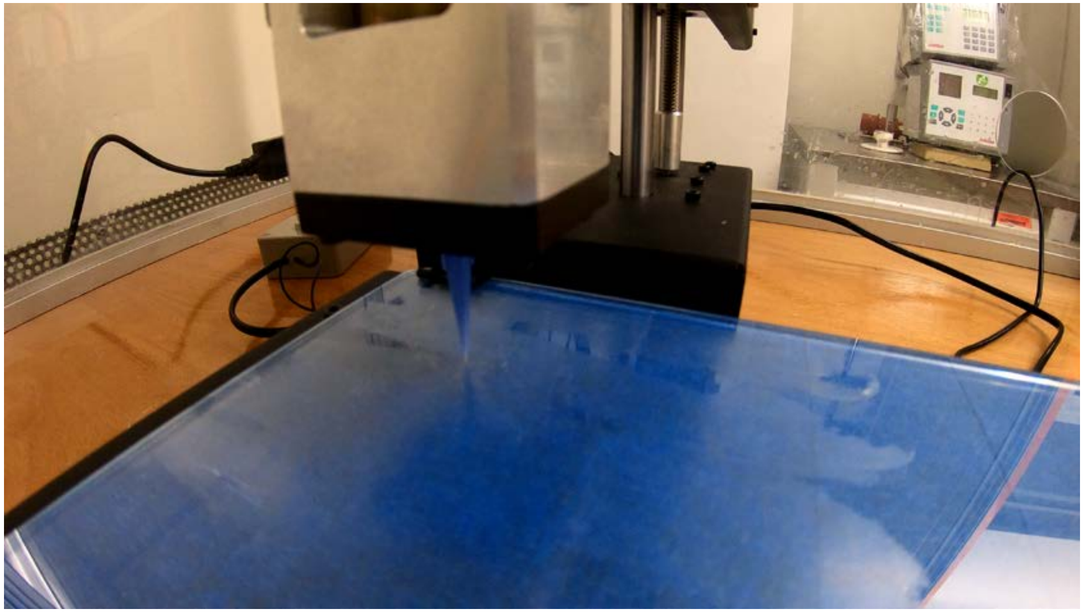
- **Printing of flakes (EM60wt%)**

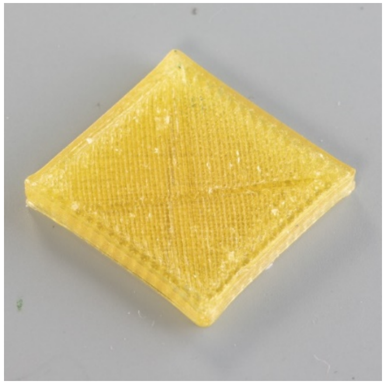


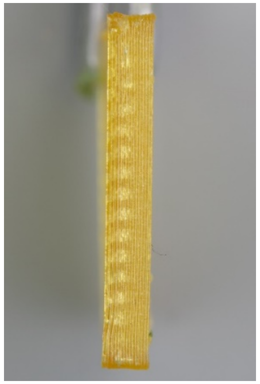
  - Grains detached from the printing plate after 24 hours of air drying
  - Malleable, rubbery behavior: surely still contain solvent
  - Excellent reproducibility
  - Some nozzle friction causing inaccuracies; collapsing of the first layers

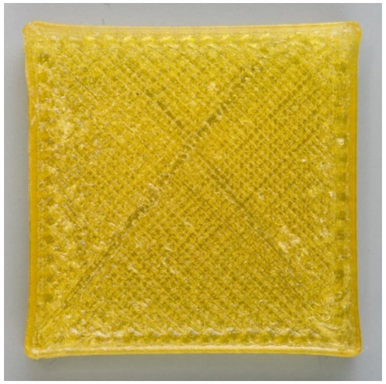
3D printing of nitrocellulose-based pastes

- **Increase in the charge rate: EM65wt%**





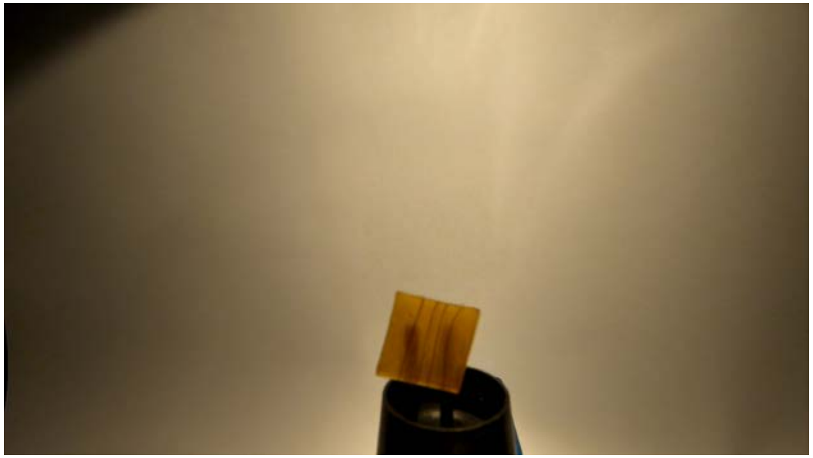




3D printing of nitrocellulose-based pastes

- **Drying of the printed flakes**
  – Detached from the printing plate after 5 days of air drying + drying at 30°C and 400 mbar during 4,5 days (36 hours)

- **Combustion of the printed flakes**



Conclusions

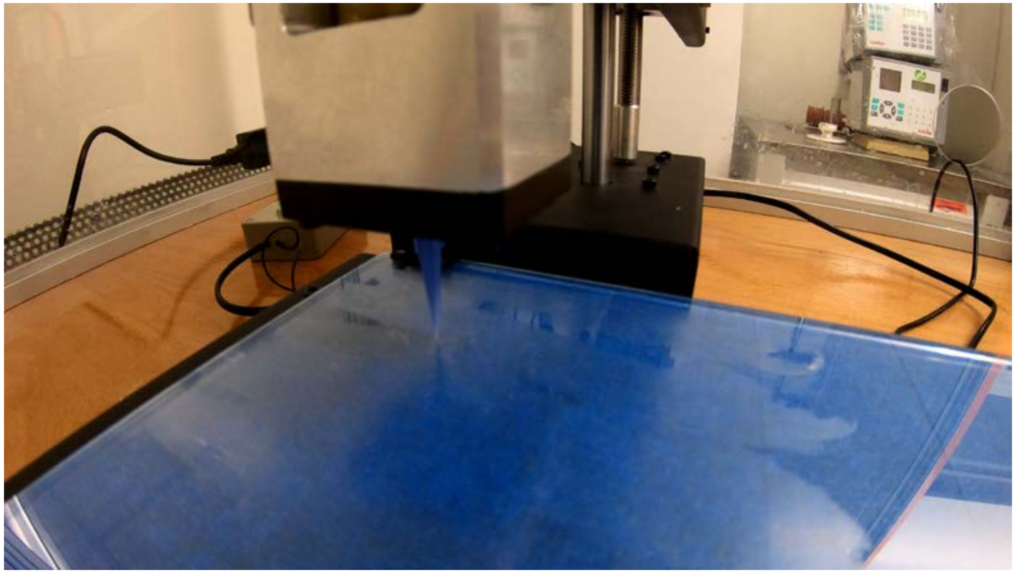
- **Identification of a simulant**
  - Mixture of CA/Ac presents a similar behaviour as compared to an EM/Ac paste
  - Charging rate adjustment to reach different viscosities
- **Configuration of the printer with the simulant**
  - Possibility to print reproducible and reliable inert flakes
  - Printability seems to be increased with the viscosity
- **Successful additive manufacturing of nitrocellulose-based gun propellants**
  - No issues when going from simulant to energetic
  - Better printability by increasing the charge rate
  - Around 100 grains were printed so far

Future work

- **Further optimization of the 3D printing of the NC-based propellants**
  - Enhance the surface finishes and manage the porosities

- **Study of the combustion behaviour of the printed grains**
  - Density measurements
  - Closed vessel experiments
    - Comparison with classically made grains

- **New printer to print co-layered propellants**



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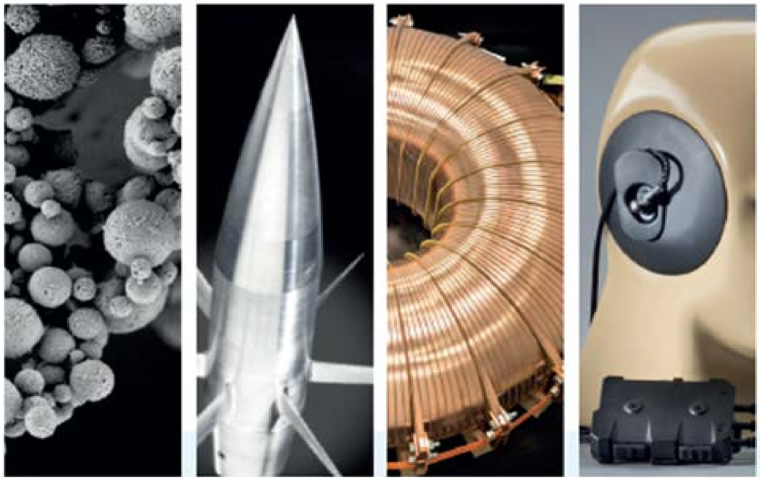

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