

# THIOT INGENIERIE

## STUDY ON THE IMPACT BEHAVIOUR OF SIMULATED HAILSTONE

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Shock+Impact Lab.

INNOTESTING 2016

*Synergy in testing*

February 25<sup>th</sup>, 2016

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# OUTLINE

## Introduction

- I. Context of the study
- II. Manufacturing ice
- III. Impact tests on a rigid target
- IV. Impact tests on deformable targets
- V. Numerical simulations

## Conclusions and outlooks

# INTRODUCTION

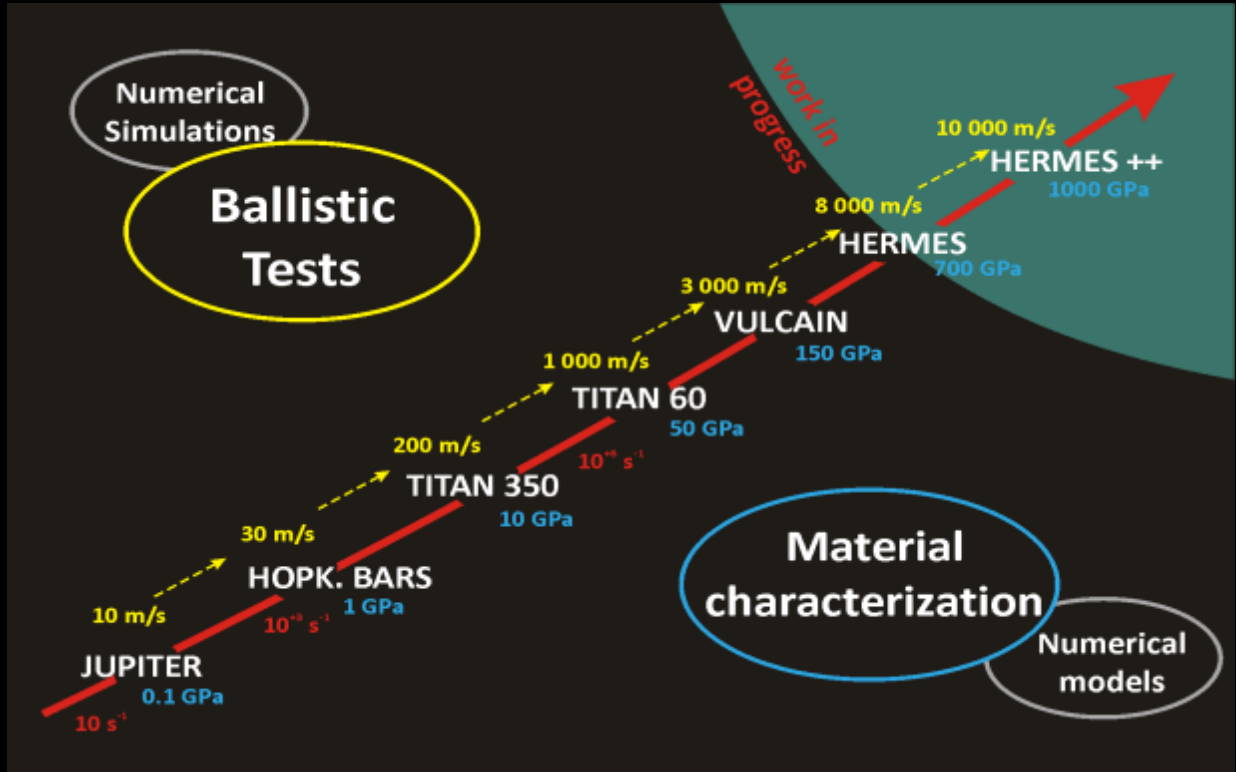
## 1. Shock Physics Laboratory

- 1 Split **Hopkinson Pressure Bar** system
- 2 **Explosion** chambers
- 1 dynamic **Presse**
- 3 light-gas **guns** :
  - 1 single stage
  - 2 double stages



# INTRODUCTION

## 2. Laboratory capacities



# INTRODUCTION

## 3. Fields of application

### CIVIL



### AERONAUTICS



### DEFENSE



### SPACE

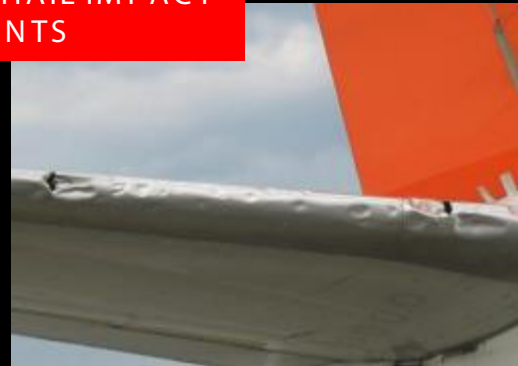
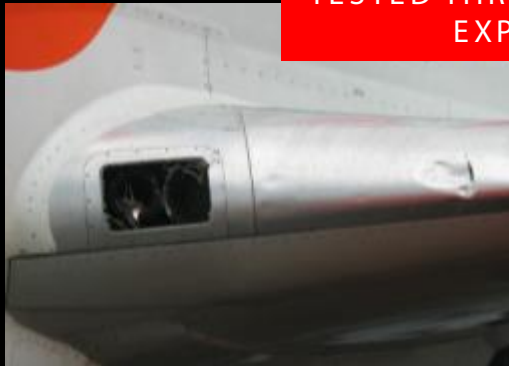


# I. CONTEXT AND OBJECTIVES

## 1. Damages caused by hailstone impacts



EXPOSED PARTS NEED TO BE  
TESTED THROUGH HAIL IMPACT  
EXPERIMENTS



# I. CONTEXT AND OBJECTIVES

## 2. ASTM Standards for hailstone impacts

- Regular ice made with frozen water is too brittle



Hail diameter (mm)	Weight (g)	Tolerance	Cotton weight (g)	Tolerance
	1.0	± 5%	0.14	± 30%
25.4	8.2		1.0	
50.8	66.4		8.0	

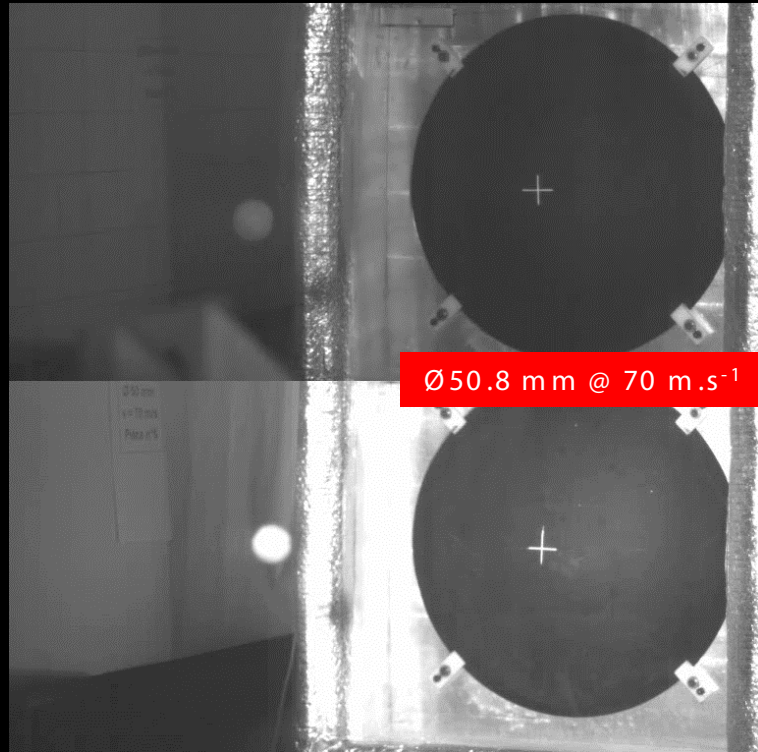
# I. CONTEXT AND OBJECTIVES

## 3. Impact tests examples on CFRP panels

Regular simulated hailstone

Real hailstone ?

Cotton-reinforced simulated hailstone





# I. CONTEXT AND OBJECTIVES

## 4. The “*RAPID*” program

- 3-year **collaborative** project between :
  - LGGE, Grenoble : specialized in glaciology
  - LaMCos, Lyon : laboratory of mechanical engineering
  - THIOT INGENIERIE
- Partially financed by the French **Department of Defense** (ie DGA) for **dual** purposes :
  - Civil : hail impact against aeronautical structures
  - Military : against missiles

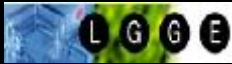
DEVELOPMENT OF A NEW ICE WITH A BEHAVIOUR  
CLOSE TO REAL HAILSTONE

# I. CONTEXT AND OBJECTIVES

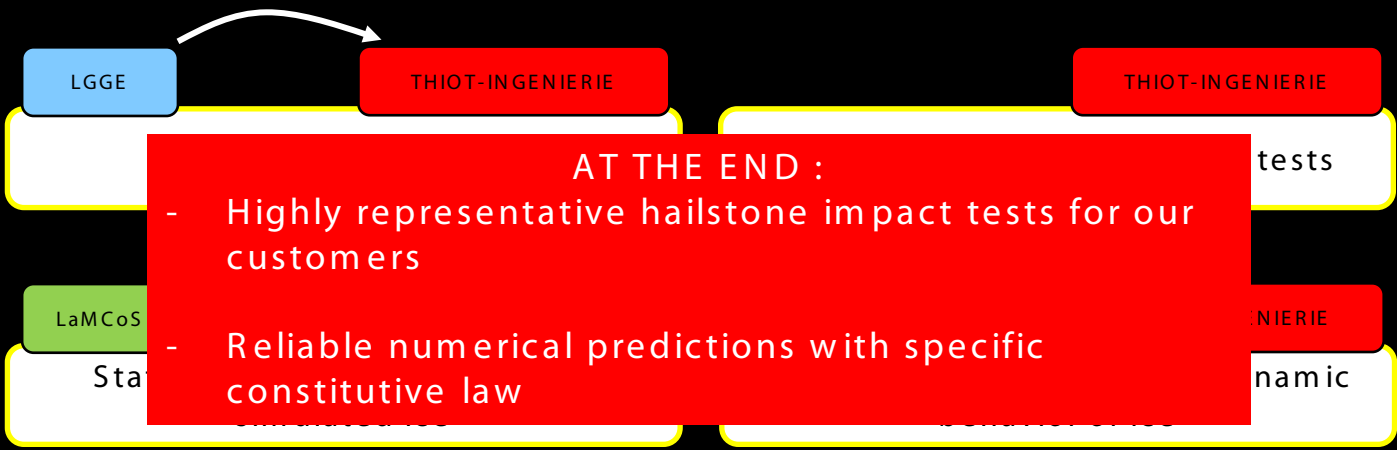
## 5. Partners and activities



Laboratoire de Mécanique des Contacts et Structures



Laboratoire de Glaciologie et Géophysique de l'Environnement



# II. MANUFACTURING ICE

## 1. Understanding real haistones

- Real hailstone collection campaign
  - **Hailstorm** in early September 2015
  - **35** hailstones collected
  - Development of a specific **preservation** protocole



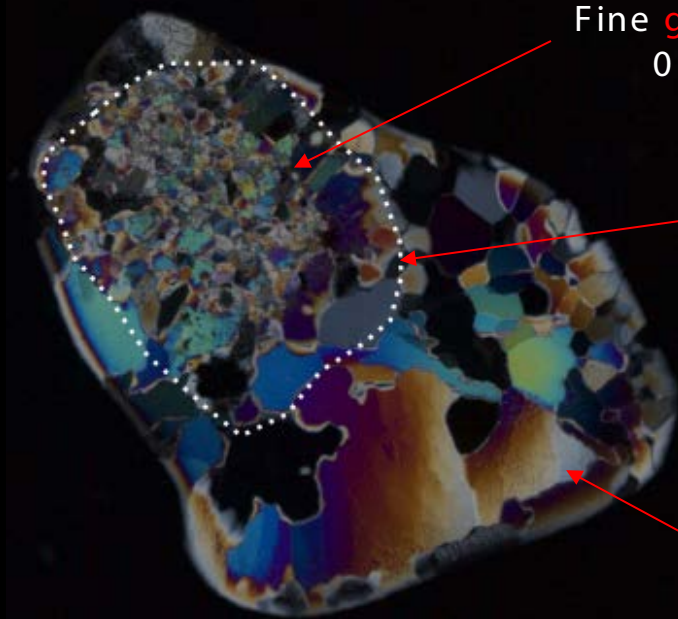
60 g



101 g

# II. MANUFACTURING ICE

## 2. Microscopic observations of real hailstone



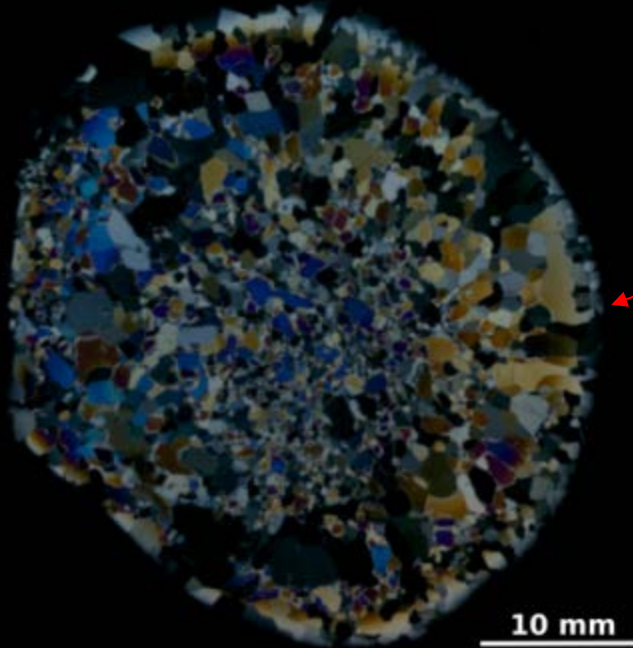
Fine **grain** size zone :  
0.5 – 1.0 mm

Hailstone boundary

Frozen water used to  
**bond** the specimen

## II. MANUFACTURING ICE

### 3. Development of an equivalent microstructure



Fine **grain** size zone :  
0.5 – 1.0 mm

Named  
"Polycristalline ice"

# II. MANUFACTURING ICE

## 4. Manufacturing process

- All types of ice are molded with the same **process**
  - Optimized to control **porosity**
  - Optimized to prevent **micro cracks**

Real hailstone too !



Spherical  
shaping

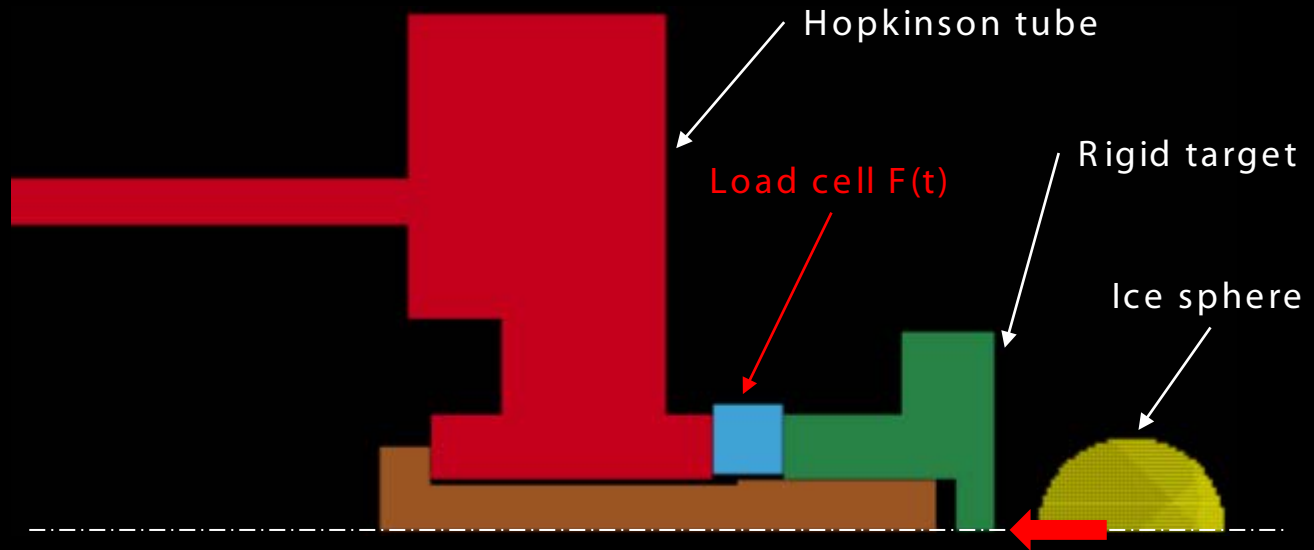


Allows suitable comparison

# III. ICE IMPACT BEHAVIOUR

## 1. Experimental setup

- Evaluating the **impact behavior** of **various** types of simulated hailstone



# III. ICE IMPACT BEHAVIOUR

## 2. Specific measurements

1 MS/s digitizer

Velocimeter

High-Speed camera  
Phantom V20 12  
(up to 666 kfps)





# III. ICE IMPACT BEHAVIOUR

## 3. Test plan

- 3 velocities :
  - 80 m.s<sup>-1</sup>
  - 150 m.s<sup>-1</sup>
  - 200 m.s<sup>-1</sup>
- 2 diameters :
  - 25 mm
  - 40 mm
- Several types of ice
  - Frozen water
  - Cotton-reinforced (following ASTM F320)
  - Polycrystalline
  - Real hail
  - .....

Over 45 tests

# III. ICE IMPACT BEHAVIOUR

## 4. Impact tests results

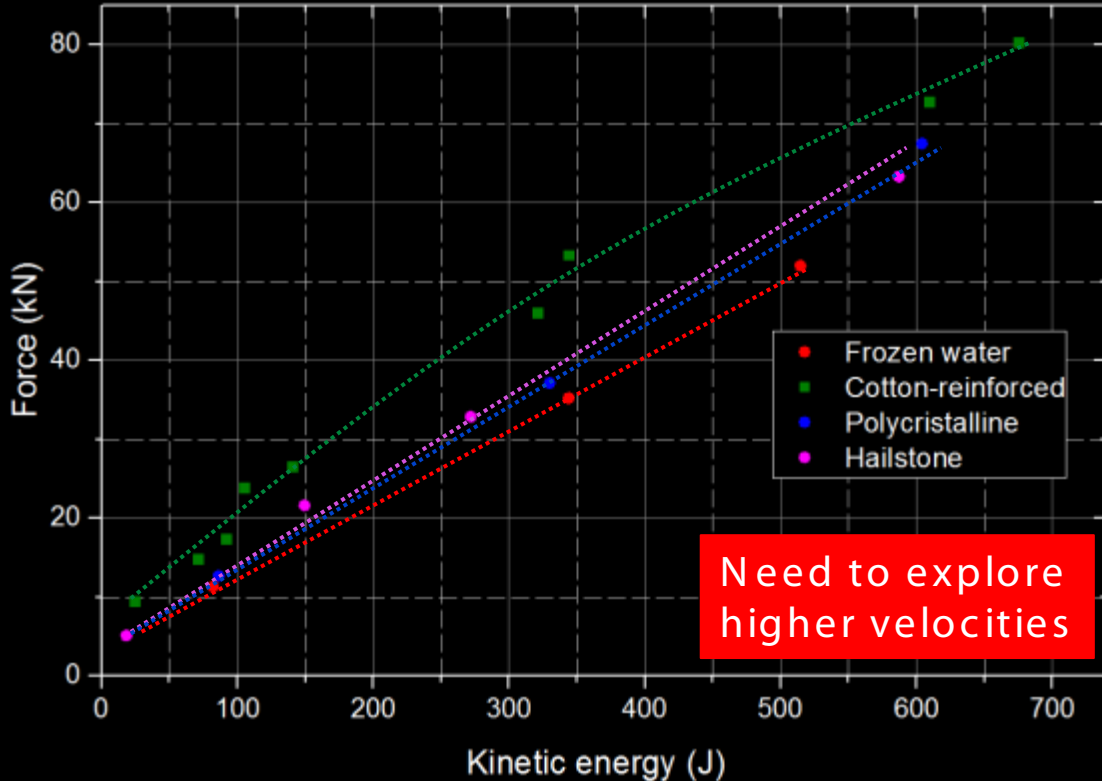
Frozen water

Cotton

Polycrystalline

# III. ICE IMPACT BEHAVIOUR

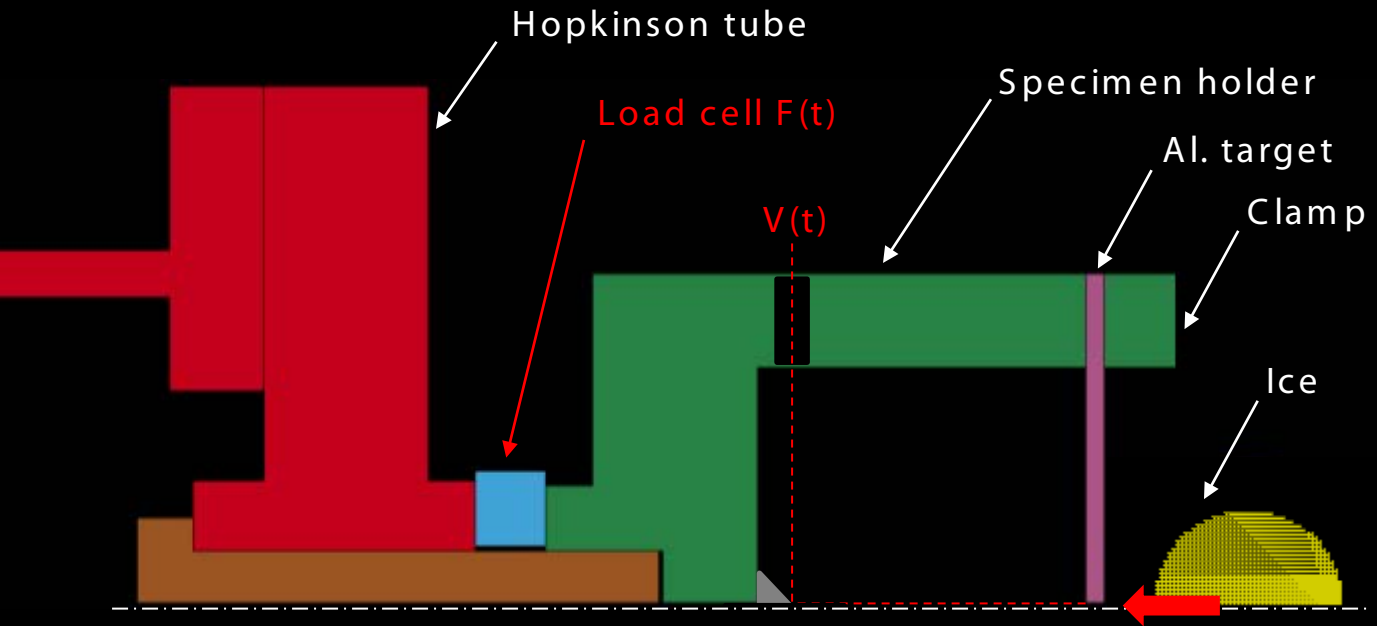
## 4. Impact tests results



# IV. IMPACT TESTS ON TARGETS

## 1. Experimental setup

- Evaluating the **impact behavior** on deformable Aluminum **targets**

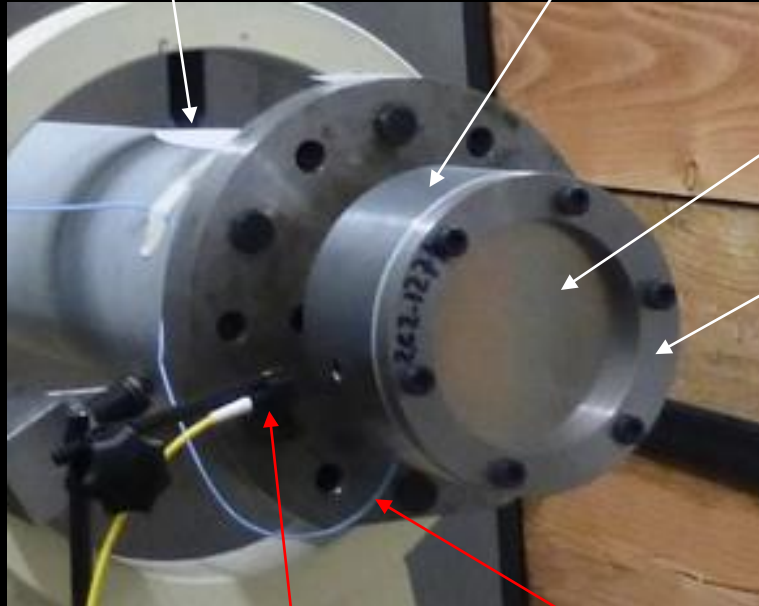


# IV. IMPACT TESTS ON TARGETS

## 1. Experimental setup

Hopkinson tube

Specimen holder



Al. target

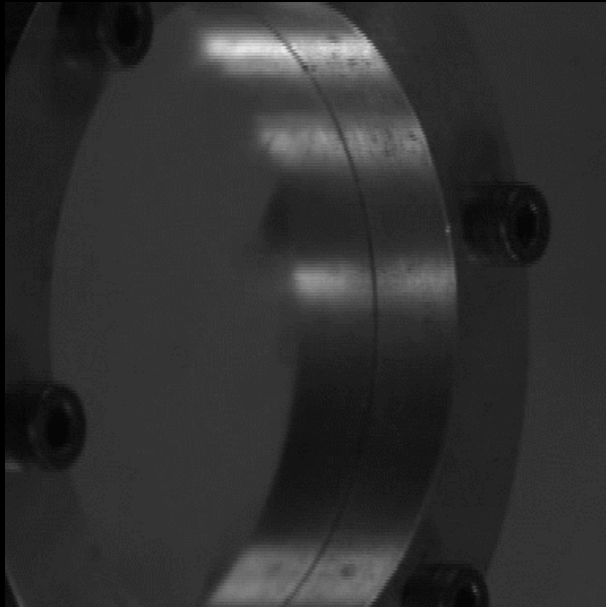
Clamp

$V(t)$

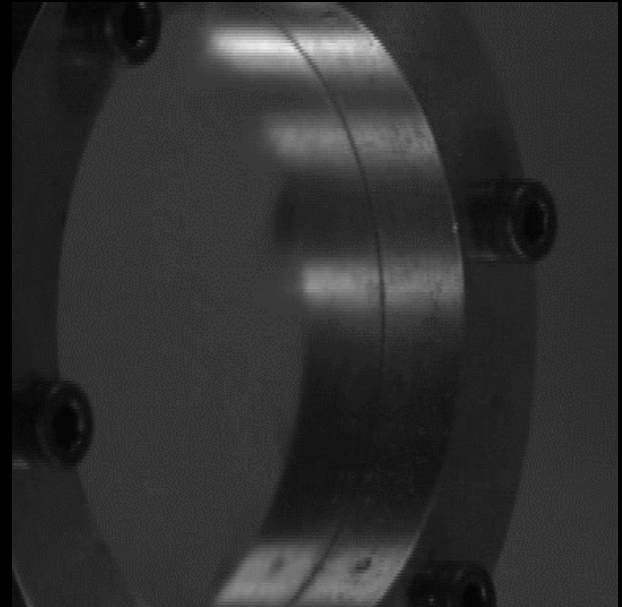
$F(t)$

# IV. IMPACT TESTS ON TARGETS

## 2. Results



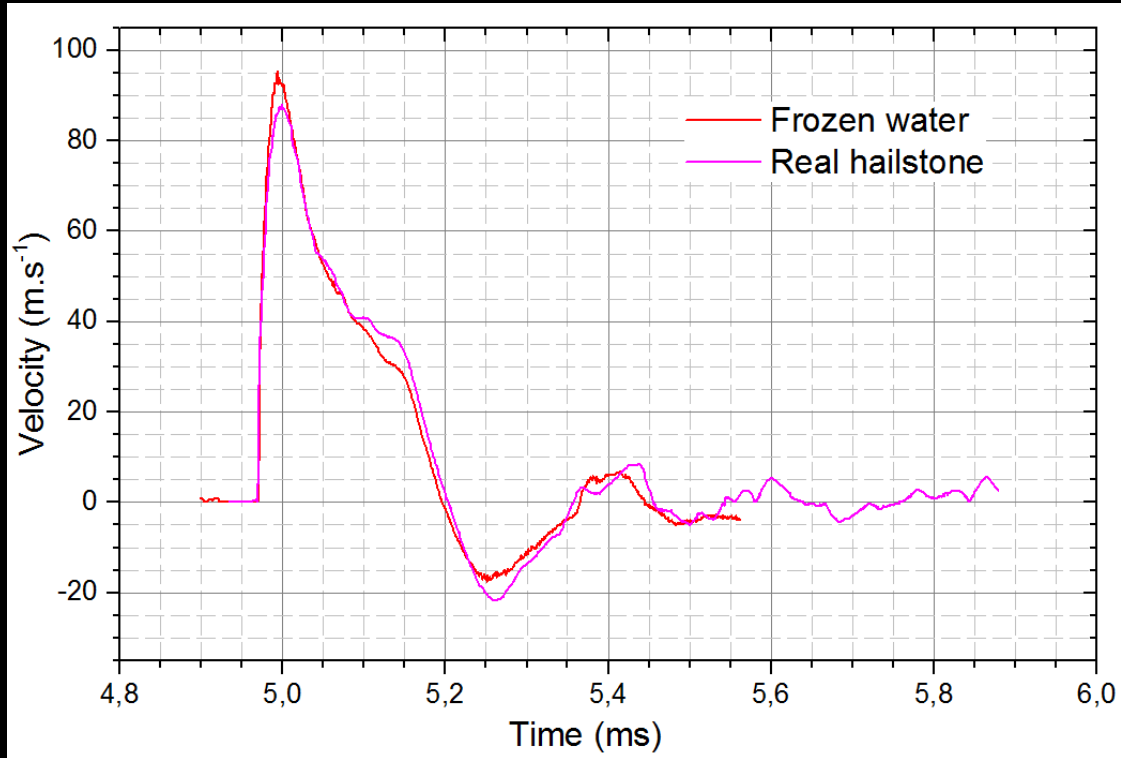
Polycristalline



Real hailstone

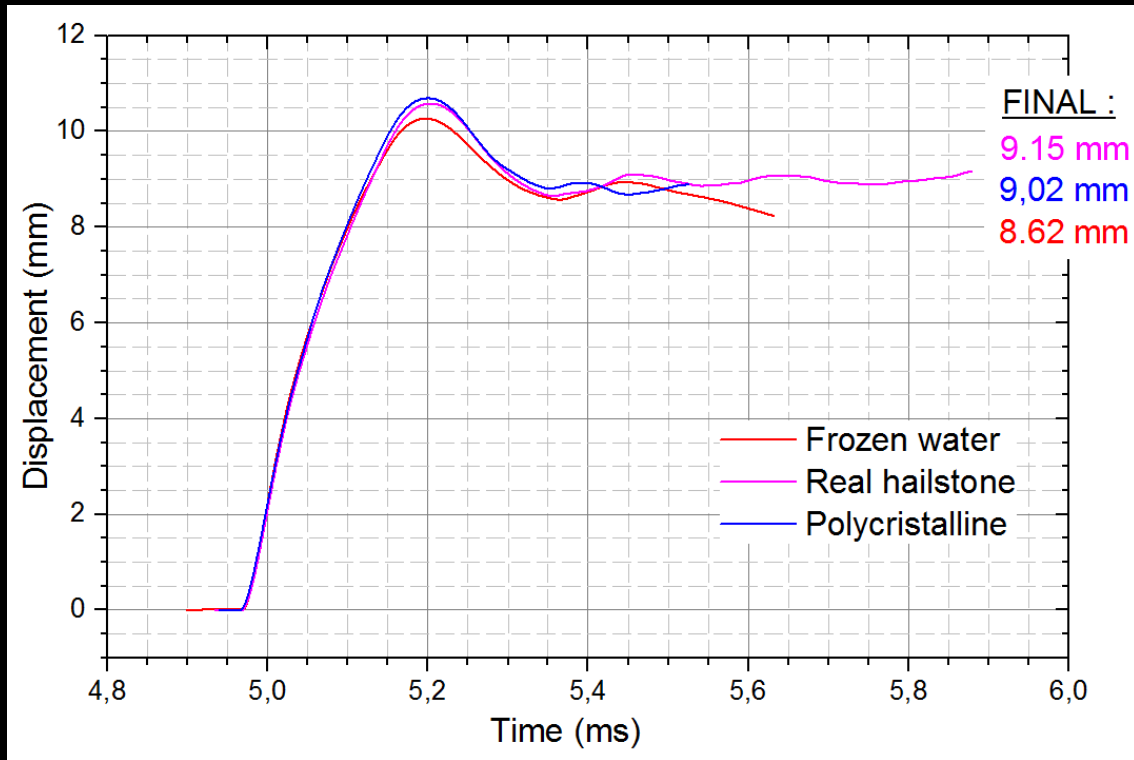
# IV. ICE IMPACT BEHAVIOUR

## 2. Results



# IV. ICE IMPACT BEHAVIOUR

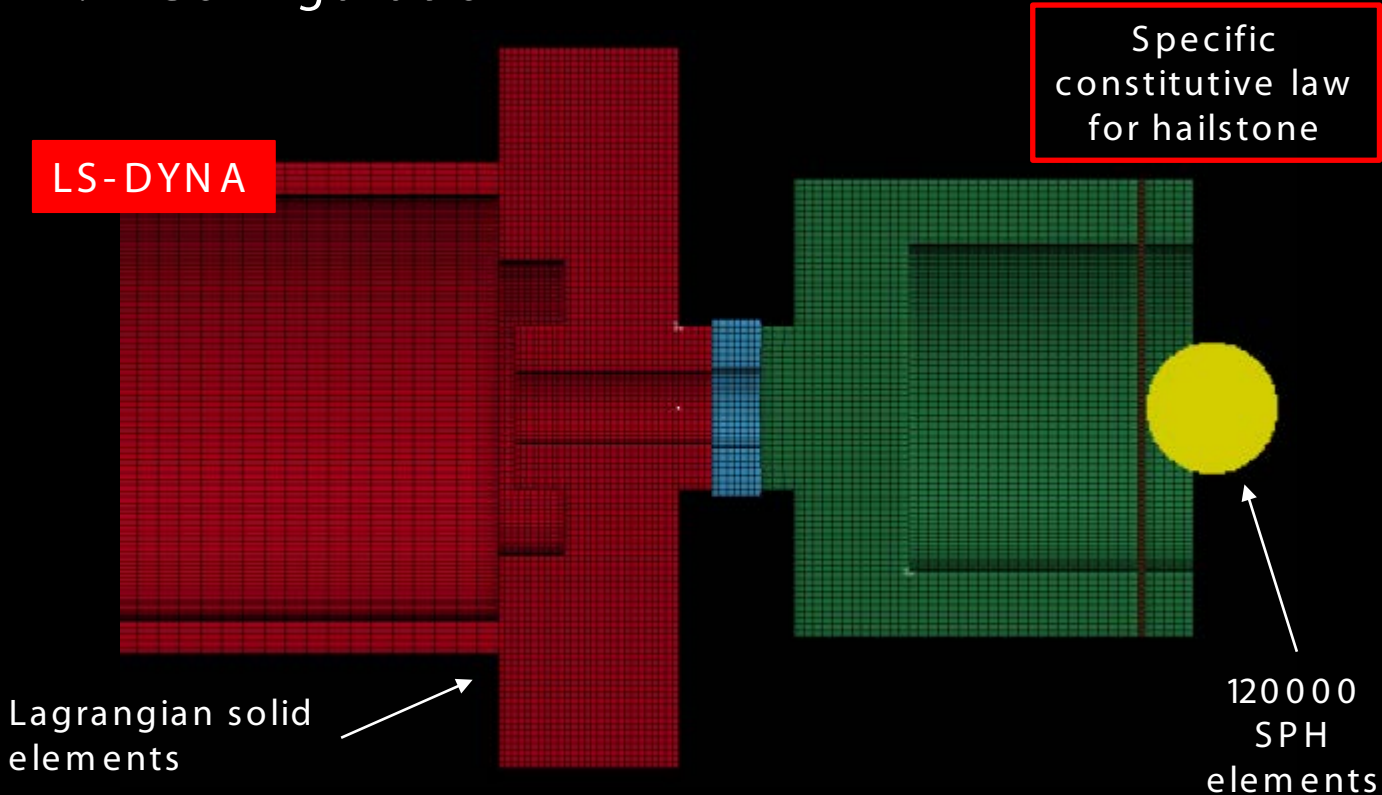
## 2. Results





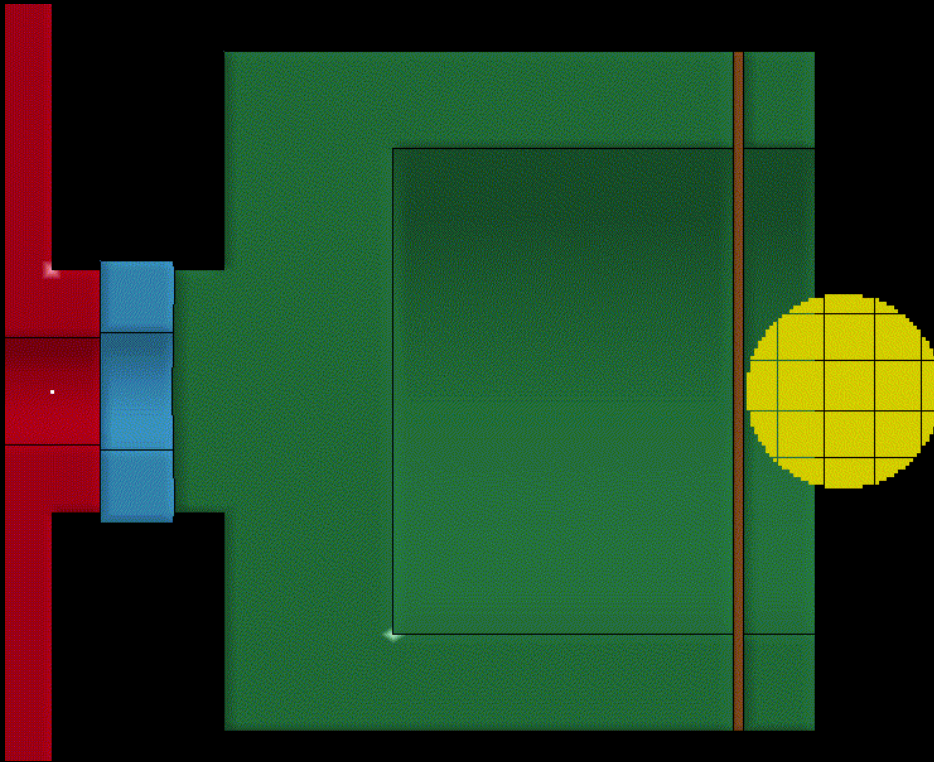
# V. NUMERICAL SIMULATIONS

## 1. Configuration



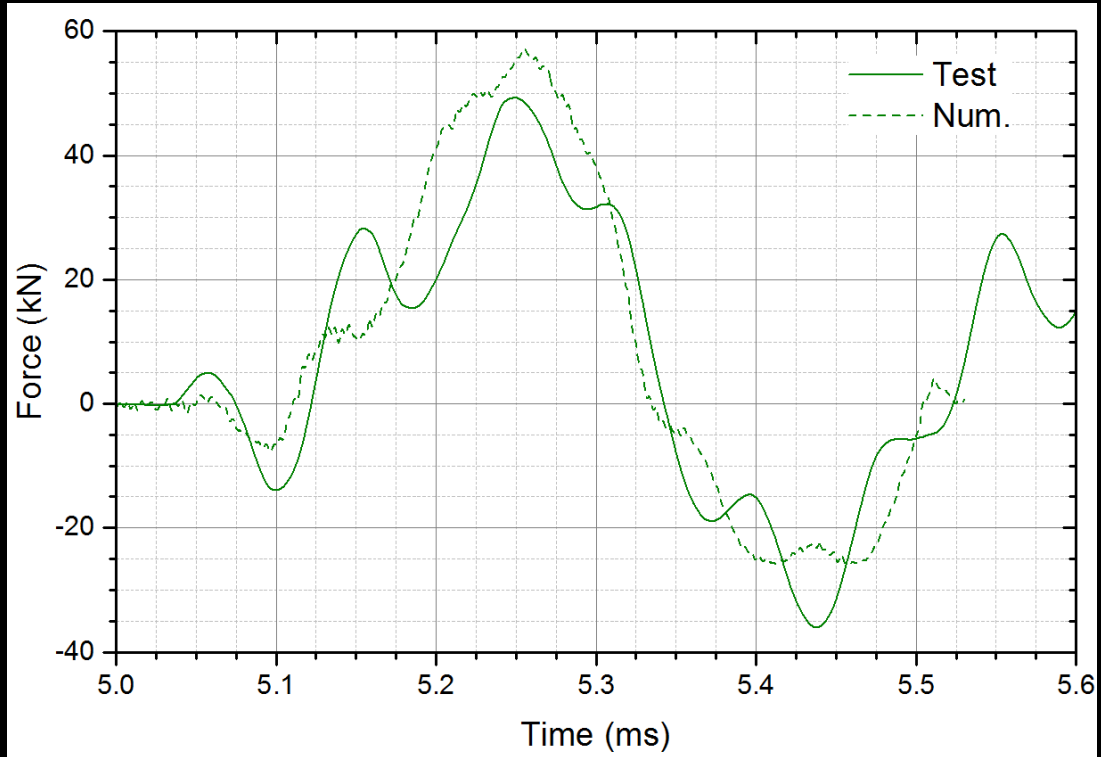
# V. NUMERICAL SIMULATIONS

## 2. Video



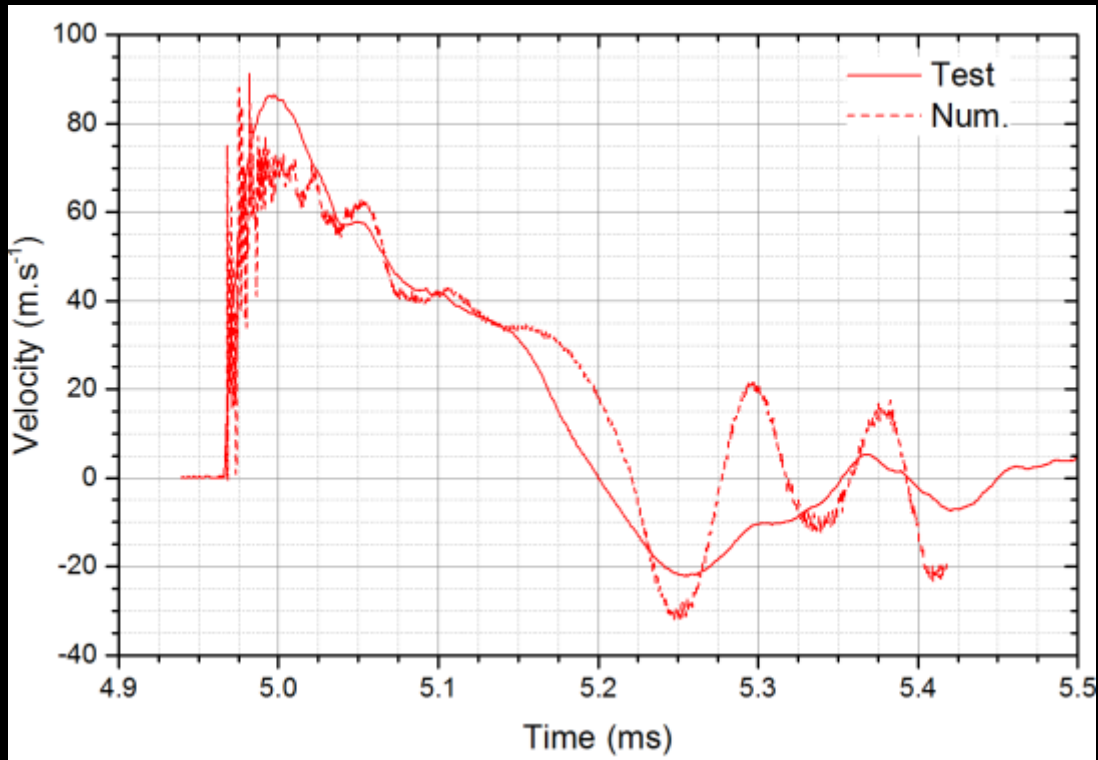
# V. NUMERICAL SIMULATIONS

## 3. Results



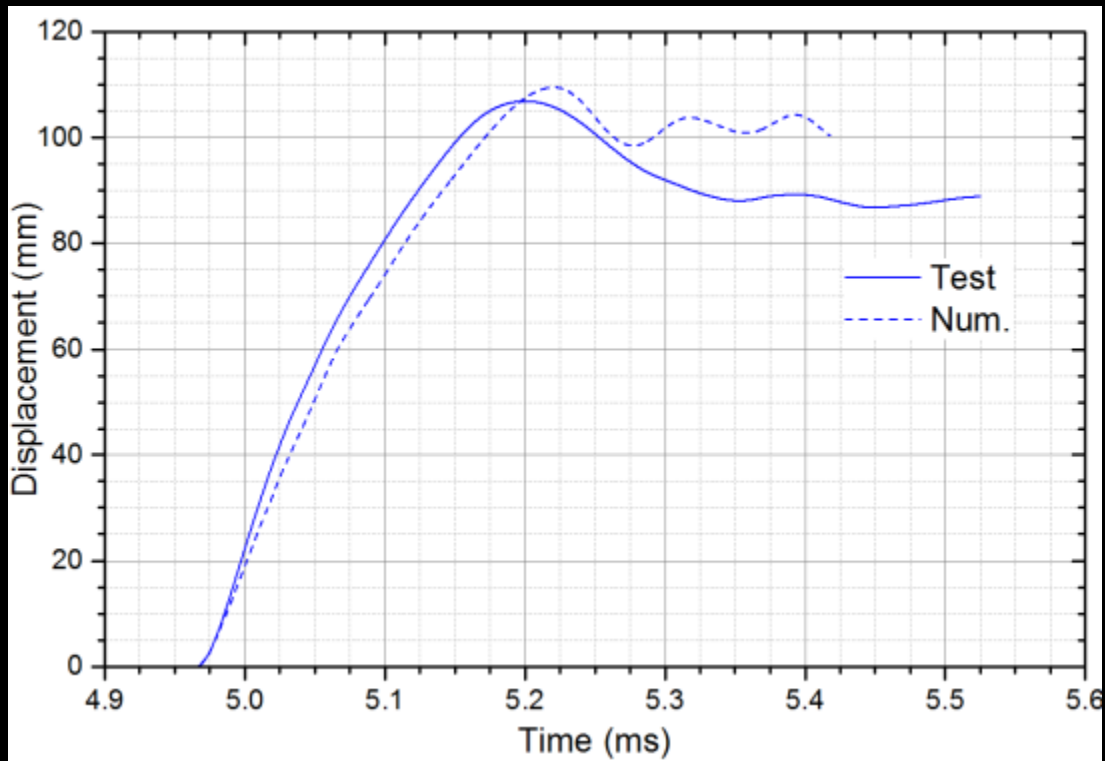
# V. NUMERICAL SIMULATIONS

## 3. Results



# V. NUMERICAL SIMULATIONS

## 3. Results



# CONCLUSIONS AND OUTLOOKS

## 1. Conclusions

- Fully **collaborative** project :
  - Total **synergy**
  - Multidisciplinary study : **numerical** modelling, **experiments** and **material** analysis
- Specific impact configurations to :
  - Highlight ice **impact** behavior for different ice types
  - Evaluate the **performances** of **simulated** hailstones
- Development of **simulated** hailstone with microstructure and impact behavior **close** to **real** one
- First numerical simulations with :
  - Good **agreement** with experimental measurements

# CONCLUSIONS AND OUTLOOKS

## 2. Outlooks

- Exploring **higher** velocities
  - Does the ice microstructure also has an effect at higher impact velocities?
- Feed the numerical model with accurate **material properties** obtained from:
  - Static tests (Brazilian and compressive tests)
  - Dynamic tests (Split Hopkinson Pressure Bars tests)
- Implement a **multiphase** equation of state in LS-Dyna

Thank you for your attention

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