

## TIME TABLE

| TIME          | Monday<br>July 11 | Tuesday<br>July 12 | Wednesday<br>July 13 | Thursday<br>July 14 | Friday<br>July 15 |
|---------------|-------------------|--------------------|----------------------|---------------------|-------------------|
| 9.00 - 9.45   | Registration      | Ghadiri            | Blum                 | Valverde            | Ghadiri           |
| 9.45 - 10.30  | Valverde          | Ghadiri            | Blum                 | Valverde            | Ghadiri           |
| 11.00 - 11.45 | Walton            | van Wachem         | Bouwman              | Valverde            | van Wachem        |
| 11.45 - 12.30 | Walton            | van Wachem         | Bouwman              | Walton              | van Wachem        |
| 14.30 - 15.15 | Bouwman           | Valverde           | Ghadiri              | Walton              |                   |
| 15.15 - 16.00 | Bouwman           | Valverde           | Ghadiri              | van Wachem          |                   |
| 16.30 - 17.15 | Blum              | Walton             | Blum                 | van Wachem          |                   |
| 17.15 - 18.00 | Blum              | Walton             | Blum                 |                     |                   |

### ADMISSION AND ACCOMMODATION

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it> or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

The 700,00 Euro registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday not included), hot beverages, on-line/downloadable lecture notes and wi-fi internet access.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel. Requests should be sent to CISM Secretariat by **May 11, 2011** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

The Deutscher Akademischer Austausch Dienst (DAAD) and the Deutsche Forschungsgemeinschaft (DFG) offer support to German students. Please contact:

DAAD, Kennedyallee 50, 53175 Bonn  
tel. +49 (228) 882-0  
e-mail: [postmaster@daad.de](mailto:postmaster@daad.de)  
web site: <http://www.daad.de/de/kontakt.html>

DFG, Kennedyallee 40, 53175 Bonn  
tel. +49 (228) 885 2655  
e-mail: [ing4@dfg.de](mailto:ing4@dfg.de)  
web site: <http://www.dfg.de>

Information about travel and accommodation is available on our web site, or can be mailed upon request.

*For further information please contact:*

CISM  
Palazzo del Torso - Piazza Garibaldi 18  
33100 Udine (Italy)  
tel. +39 0432 248511 (6 lines)  
fax +39 0432 248550  
e-mail: [cism@cism.it](mailto:cism@cism.it)

Centre International des Sciences Mécaniques  
International Centre for Mechanical Sciences

ACADEMIC YEAR 2011  
The Germain Session



## MECHANICS OF FINE COHESIVE POWDERS

Advanced School  
coordinated by  
**José Manuel Valverde**  
University of Seville  
Spain

**Udine, July 11-15, 2011**

## MECHANICS OF FINE COHESIVE POWDERS

Granular materials are perfect examples of complex systems. The mechanical behavior of a single grain is well understood, yet the behavior of a large collection of grains exhibits a rich variety of yet unexplained phenomena. Complexity is boosted when particle size is decreased below a few tens of microns. Fine powder cohesiveness leads to agglomeration, poor flowability, clumping, difficulty in fluidizing, irregular avalanching behavior, etc. Despite all the inconveniences, fine powder processes pervade the chemical, pharmaceutical, agricultural and mining industries among others. The course will be opened by demonstrating the rich phenomenology exhibited by fine powders, which are particularly characterized by their strong interaction with the surrounding gas and high compactability. A

part of the course will be focused on a formal mechanical description and the rheological characterization of fine powders. Dispersion of fine powders, which is a subject of concern in numerous industries, triboelectrification, usually causing dust explosions, and vibration processes, will be particularly considered as phenomena of special relevance in practical applications. A further focus of the course will be a description of modern noninvasive techniques for characterizing the microstructure of fine powders, which allow for a correlation between the microscopic structure and the bulk powder behavior. Understanding the behavior of fine powders is not just relevant for their applications in earth but also for their role in space. This is a nice example that illustrates the highly interdisciplinary nature of the study on powder mechanics. In this context, studying the mechanics of agglomeration of

fine particles is of great importance in order to investigate the formation of planetesimals, the kilometer-sized precursors of the solid planetary bodies in our solar system. Common phenomena apply to naturally-occurring particles on earth, in space, or in newly manufactured nanoparticles. An important part of the course will be devoted to current advances on the use of computational tools to predict the behavior of granular materials. Advanced modeling tools, such as Computational Fluid Dynamics and the Discrete Element Method, are highly attractive. Various formulations will be described and their assumptions shown. All practical formulations require closures which will be discussed as a central theme during the course. Gaining an understanding of how and why bulk powder behavior changes as particle size decreases

becomes important to researchers in a broader range of applications as more and more manufactured products utilize fine powders. Due to its marked interdisciplinary character, the behavior of fine powders cannot be understood without the sharing of knowledge between specialists on a variety of disciplines. An overall aim of the course is to contribute to develop the capacity of interdisciplinary research fields to understand these complex systems. This course is thus intended for doctoral and postdoctoral academic and industrial researchers in applied physics, mechanical-, chemical- or geotechnical engineering, who are interested in the sharing and integration of knowledge bases from this disparate set of disciplines into a single interdisciplinary subject area oriented to the special characteristics of fine powders.

## PRELIMINARY SUGGESTED READINGS

K. Rietema, *The Dynamics of Fine Powders* (Elsevier, London 1991).

R. Nedderman, *Statics and Kinematics of Granular Materials*, (Cambridge University Press, UK 1992).

R. Jackson, *The Dynamics of Fluidized Particles* (Cambridge University Press, Cambridge 2000).

J. Schwedes, *Mechanical properties of a powder bed*, in *Powder Technology Handbook* by Hiroaki Masuda, Ko Higashitani, Hideto Yoshida.

J. Tomas, *Adhesion of ultrafine particles — A micromechanical*

approach, *Chemical Engineering Science* 62:1997-2010, 2007.

P.A. Cundall, O.D.L. Strack, *A discrete numerical model for granular assemblies*, *Geotechnique* 29:47–65, 1979.

A Castellanos, *The relationship between attractive interparticle forces and bulk behaviour in dry and uncharged fine powders*, *Advances in Physics* 54:263—376, 2005.

P.J. Armitage, *Planet Formation*, chapters 1-4 (Cambridge University Press, 2010).

A Castellanos, J. M. Valverde, A. Pérez, A. Ramos and P. K. Watson, *Flow regimes in fine cohesive powders*, *Physical Review Letters* 82:1156-1159, 1999.

J. M. Valverde, A. Castellanos, *Types of gas fluidization of cohesive granular materials*. *Physical Review E* 75:031306, 2007.

J. Blum, *Dust Agglomeration*, *Advances in Physics* 55:881-947, 2006.

J. Blum, G. Wurm, *The Growth Mechanisms of Macroscopic Bodies in Protoplanetary Disks*, *Annual Re-*

*view of Astronomy and Astrophysics* 46:21-56, 2008.

G. Calvert, M. Ghadiri and R. Tweedie, *Aerodynamic dispersion of cohesive powders: A review of understanding and technology*, *Advanced Powder Technology*, 20:4-16, 2009.

R. Andersson, W.G. Bouwman, S. Luding, et al. *Stress, strain, and bulk microstructure in a cohesive powder*, *Physical Review E* 77:051303, 2008.

J.S. Curtis and B.G.M. van Wachem, *Modeling particle-laden flows: A research outlook*, *AIChE Journal* 50:2638-2645, 2004.

## INVITED LECTURERS

**José-Manuel Valverde** - University of Seville, Spain  
*6 lectures on:* The phenomenology of granular materials. Fluidization of fine cohesive powders. Types of gas-fluidization of fine cohesive powders. Jamming and compaction of fine cohesive powders. Magnetofluidization of fine cohesive powders. Electrofluidization of fine cohesive powders.

**Jürgen Blum** - Technische Universität zu Braunschweig, Germany  
*6 lectures on:* Agglomeration of fine cohesive powders. Fine powder agglomeration into the context of planet formation. Principles of dust agglomeration. Dust-collision experiments. A complete collision model for protoplanetary dust. Monte-Carlo modeling of protoplanetary dust growth.

**Wim G. Bouwman** - Delft University of Technology, The Netherlands  
*4 lectures on:* Stress, strain, and bulk microstructure of fine cohesive powders. Spin-Echo Small-Angle Neutron Scattering (SESANS). Density correlation functions. Application of SESANS to fine powders. Neutron and X-ray tomography.

**Mojtaba Ghadiri** - University of Leeds, UK  
*6 lectures on:* Flow and dispersion of fine cohesive powders. Powder Mechanics. Bulk failure characterization. Rheological characterization of powders. Dry Powder Dispersion. Electrostatic and vibration effects.

**Berend van Wachem** - Imperial College, London, UK  
*6 lectures on:* Simulation of multiphase flows by means of Computational Fluid Dynamics (CFD). The Lagrangian formulation. Eulerian formulation. Closure relations. Turbulence and the kinetic theory of granular flow. Computational aspects of fluid-particle modelling.

**Otis Walton** - Grainflow Dynamics Inc., Livermore, CA, USA  
*6 lectures on:* Discrete particle simulation methods for fine cohesive powders. Fundamentals of Discrete Element Method (DEM) simulations. DEM simulations of fine cohesive powders. Limitations of DEM and range of applications. Coupling of CFD/DEM models. Application of DEM to simulate behavior of lunar regolith.

## LECTURES

All lectures will be given in English. Lecture notes can be downloaded from CISM web site, instructions will be sent to accepted participants.

# MECHANICS OF FINE COHESIVE POWDERS

Udine, July 11 - 15, 2011

## Application Form

(Please print or type)

Surname \_\_\_\_\_

Name \_\_\_\_\_

Affiliation \_\_\_\_\_

Address \_\_\_\_\_

\_\_\_\_\_

E-mail \_\_\_\_\_

Phone \_\_\_\_\_ Fax \_\_\_\_\_

**Method of payment upon receipt of confirmation (Please check the box)**

*The fee of Euro 700,00 includes IVA/VAT tax and excludes bank charges*

I shall send a check of Euro \_\_\_\_\_

Payment will be made to CISM - Bank Account N° 094570210900,  
VENETO BANCA - Udine (CAB 12300 - ABI 05035 - SWIFT/BIC VEBHIT2M -  
IBAN CODE IT46 N 05035 12300 09457 0210900).  
*Copy of the receipt should be sent to the secretariat*

I shall pay at the registration counter with check, cash or VISA  
Credit Card (Mastercard/Eurocard, Visa, CartaSi)

**IMPORTANT: CISM is obliged to present an invoice for the above sum. Please indicate to whom the invoice should be addressed.**

Name \_\_\_\_\_

Address \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

C.F.\* \_\_\_\_\_

VAT/IVA\* No. \_\_\_\_\_

(\*) Only for EU residents or foreigners with a permanent business activity in Italy.

### Only for Italian Public Companies

I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).

**Privacy policy:** I understand that data received via this form will be used only to provide information about CISM and its activities, within the limits set by the Italian legislative decree no. 196/2003 and subsequent amendments.

Complete information on CISM's privacy policy is available at [www.cism.it](http://www.cism.it).

I have read the "Admission and Accommodation" terms and conditions and agree.

Date \_\_\_\_\_ Signature \_\_\_\_\_