ESPCI
SOFT MATTER DAYS

JULY 2ND–3RD, 2015
GIF-SUR-YVETTE

This internal meeting is intended to provide the opportunity to present and discuss our research activities on soft matter.

Registration on ESPCI website:

http://www.espci.fr/en/events/2015/soft-matter-days-2015

Deadline: March 31st

Organizing committee:

N. Bremond, C. Monteux, R. Nicolaÿ, E. Reyssat, S. Rogue, T. Salez

Table of Content

ESPCI SOFT MATTER DAYS

July 2nd and 3rd, 2015, Gif-sur-Yvette

Thursday, July 2nd

9h00-9h40 **Welcome and Registration**

9h40-10h45 **Talk Session** (A1-A5) [Chair: Costantino Creton]

- **Pascaline Hayoun** (SIMM) *Thin liquid film in polymer tubing: dynamics and dewetting in partial wetting condition*
- **Thibault Derouineau** (MMC) *Dynamic covalent polymers as viscosity modifiers*
- **Lukasz Klotz** (PMMH) *New experiments in shears flows with zero mean velocity*
- **Baudouin Saintyves** (PCT) *Soft Lubrication*
- **Bruno Teste** (MMN) *Lab on chip dedicated to platelets generation*

10h45-11h15 **Coffee Break/Poster Session**

11h15-12h15 **Talk Session** (A6-A10) [Chair: Costantino Creton]

- **Hélène de Maleprade** (PMMH) *Bubble spreading on superaerophilic surfaces*
- **Alba Marcellan** (SIMM) *From gel reinforcement to gel adhesion*
- **Charlotte Pellet** (MMC) *Patterning surfaces with colloid-bottlebrush polymer mixtures*
- **Olivia du Roure** (PMMH) *Deformation and transport of micro-helices and fibers by viscous flows*
- **Emilie Verneuil** (SIMM) *Glass transition accelerates the spreading of volatile droplets on soluble visco elastic polymers*

12h15-13h30 **Lunch**

13h30-15h00 **Poster Session**

15h00-16h15 **Talk Session** (B1-B5) [Chair: Anke Lindner]

- **Axel Huerre** (MMN) *Dynamical properties of droplet's lubrication film in confined microchannels*
- **Laurette Tuckerman** (PMMH) *Can frequencies in thermosolutal convection be predicted from mean flows?*
- **Rémi Deleurence** (SIMM) *Generation and stability of foams made from physical gels*
- **Léopold Mottet** (LCMD) *Semi-permeable capsules with conductive membrane for culture and selection of electroactive microorganisms*
- **Laura Casanellas** (PMMH) *Stabilizing effect of shear thinning on the onset of elastic instabilities in serpentinemicroflows*

16h15-16h45 **Coffee Break/Poster Session**

16h45-18h10 **Talk Session** (B6-B12) [Chair: Anke Lindner]

- **Marc Yonger** (SIMM) *Silicon wafers wetting by polybutadiene melts*
- **Mariana Tasso** (LPEM) *Towards specific markers for biological imaging based on quantum dot nanoparticles*
- **Anne Mongruel** (PMMH) *Edge effects on water droplet condensation*
- **Lucie Imbernon** (MMC) *Mechanical properties of an epoxidized natural rubber network containing dynamic crosslinks*
- **Matteo Ciccotti** (SIMM) *Rate-dependent elastic hysteresis during the peeling of pressure sensitive adhesives*
- **Vincent Miralles** (MMN) *Foam drainage control in a 2D-microchamber: comined effect of thermo- and solutocapillarity*
- **Ramiro Godoy-Diana** (PMMH) *Bio-inspired undulatory swimmers*

18h10-19h00 **Free Time**

19h00-23h00 **Dinner**

Friday, July 3rd

9h30-10h45 **Talk Session** (C1-C6) [Chair: Elisabeth Bouchaud]

- **Rémi Fournier** (MMC) *Reversible covalent associative polymers in water*
- **Annie Colin** (SIMM) *Foams in porous media for oil enhanced recovery*
- **Jérémie Teisseire** (Saint Gobain) *Structured layers on glass substrate for new functionalities: the example of super-hydrophobic surfaces*
- **Jean-François Joanny** (Institut Curie) *Activity induced phase separation*
- **Evelyne Kolb** (PMMH) *Pénétration d'objets flexibles dans des milieux réorganisables*
- **David Lacoste** (PCT) *Shape matters in protein mobility within membranes*

10h45-11h15 **Coffee Break/Poster Session**

11h15-12h30 **Talk Session** (C7-C12) [Chair: Elisabeth Bouchaud]

- **Corentin Trégouët** (SIMM/MMN) *Multilayer assembly of polymers on liquid interfaces for encapsulation*
- **Guillaume Foyart** (Michelin) *Crack propagation of filled polymer materials during processing*
- **Pierre Bauër** (PMMH) *A new high throughput technique of mechanical measurements applied to cytoskeletal actin networks*
- **Sébastien Bidault** (Institut Langevin) *Colorimetric monitoring of nanometer distance changes in DNA-templated gold nanoparticle dimers*

- **Julien Chopin** (EC2M) *Morphology and dynamics of a crack front in a disordered interface*
- **Bernard Cabane** (LCMD) *Nanoparticles are always polydisperse - Let subpopulations crystallize!*

12h30-13h45 **Lunch**

12h45-14h30 **Poster Session**

14h30-15h45 **Talk Session** (D1-D6) [Chair: Marc Fermigier]

- **Menghua Zhao** (SIMM) *A study of the wetting ridge on soft gels*
- **Olivier Dauchot** (EC2M) *Liquids of active disks : a review of recent experimental and theoretical results*
- **Eliott Varon** (PMMH) *Real-time PIV for closed-loop flow control experiments and rapid investigation of a flow*
- **Max Rottger** (MMC) *Vitrimers a new class of plastic materials*
- **François Lequeux** (SIMM) *The role of dynamical heterogeneities on the mechanics of polymer glasses*
- **Ludovic Keiser** (PMMH) *Washing wedges: a capillary instability*

15h45-16h15 **Coffee Break/Poster Session**

16h15-17h15 **Talk Session** (D7-D11) [Chair: Marc Fermigier]

- **Cesare Cejas** (MMN) *Fouling and clogging in microfluidic channels*
- **Aurélie Legrand** (MMC) *Elastic vitrimer composites*
- **Nuris Figueroa-Morales** (PMMH) *Traffic of E. coli bacteria in a confined flow*
- **David Moreau** (MMC) *Composite ceramic-hydrogel coatings for hydrogel implant*
- **Benjamin Reichert** (MMN) *Modelling 2D droplet displacement in a Hele-Shaw Cell*

17h15 **End of the Soft Matter Days**

Note: talks last 10 minutes + 2 minutes for discussion

A. JEUDI @ 9h40-10h45 / 11h15-12h15

A1. Thin liquid film in polymer tubing: dynamics and dewetting in partial wetting condition

Pascaline Hayoun,[1,2,3] Alban Letailleur,[2] Jérémie Teisseire,[3] Emilie Verneuil,[1] François Lequeux,[1] Etienne Barthel[1]

1 Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

2 Composites and Coatings Department – Saint-Gobain Research, France

3 Glass Surface and Interface (SVI) – Saint-Gobain/CNRS, France

Polymers such as PVC and Silicone are low cost materials widely used in industry to produce tubing for fluid transport. Most of these applications involve repeated, intermittent flow of liquids which can lead to unwanted contamination. This study aims at better understanding contamination mechanisms during intermittent flow in polymer tubing, and at elucidating the relation between flow, wetting and contamination. We experimentally and theoretically investigate, flow regimes as well as dewetting process at the triple line induced by gravity flow of a vertical liquid slug in a cylindrical geometry. We have observed that a moving liquid slug can lead to liquid film deposition at the inside wall of the tube, whose dynamic is controlled by the dewetting of the film. In the literature, Taylor's experiment has revealed that the remaining liquid film after a slug has been displaced through a tube presents a film thickness scaling as Ca2/3. Bretherton derived a model to describe a Taylor bubble based on a lubrication approach coupled with surface deformation of the bubble. In contrast, we do not recover the Taylor and Bretherton prediction, and we have found a linear relationship between the rear meniscus velocity and the dewetting triple line velocity. Based on the film thickness measurement by absorption, we show that this scaling results from gravity driven drainage. Our results on dewetting are in agreement with the classical work of Redon: dynamic dewetting is dependent on liquid viscosity and surface tension and highly dependent on the contact angle with the material. Finally, we will present a phase diagram of more or less complex dynamical processes, such as hydraulic jump creation in the thickness profile, an oscillatory regime and the destabilization of the liquid film which may lead to substrate contamination.

A2. Dynamic covalent polymers as viscosity modifiers

Thibault Derouineau, Nga Nguyen, Renaud Nicolaÿ, Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

It is still a challenge in many industrial applications, e.g. cosmetics, inks, adhesives, lubricants, paintings, etc., to control the rheological properties of organic formulations. Here, we describe a new approach to control the viscosity of organic solutions as a function of temperature. For that purpose, we designed two sets of random copolymers that have temperature dependant solvent affinity as well as the ability to reversibly connect through the formation of dynamic covalent bonds. Those macromolecules were prepared by controlled radical polymerization which allowed preparing copolymers with adjustable molecular weight, solvent affinity, and functionality. Rheological studies of the linear viscoelasticity and flow behavior as a function of temperature exemplify the efficiency of this system to control the viscosity

of organic solutions. By manipulating the composition and functionality of the copolymers it is possible to adjust the temperature for which the system will respond as well as the resulting viscosity.

A.3 New experiments in shears flows with zero mean velocity

Lukasz Klotz,[1] Gregoire Lemoult,[1,2] Jose Eduardo Wesfreid[1]

1 PMMH, ESPCI-CNRS-UPMC-UPD, France
2 IST, Austria

We describe a new experimental set-up which allows us to study shear flow instabilities in a two dimensional flow, even with zero advection velocity. The facility consists of two independent belts made of transparent plastic film, whose speed may be controlled separately. There is one belt at each of test section's wall. That enables us to set as a boundary conditions two different velocities at each test section's wall. In addition the pressure gradient in streamwise direction can be controlled. One special example of the base flow, which may be obtained in our installation, is the classical plane Poiseuille flow with a mean advection velocity ū equal to zero. First PIV measurements were performed in a preliminary configuration with a single belt, in order to test the possibility to measure the basic flow profile in thin gap and to check the experimental set-up. In a such realisation, the boundary conditions at the wall are set to the same speed (plane Couette flow), where the base flow has the linear evolution across the wall-normal direction. We measured its evolution as Reynolds number is increased. During the conference we will presents our measurements done in the case of plane Poiseuille flow.

A4. Soft Lubrication

Baudouin Saintyves, Théo Jules, Thomas Salez, L. Mahadevan

Laboratoire de Physico-Chimie Théorique, Laboratoire Gulliver – ESPCI ParisTech, France

In this talk, I will present model experiments on a negatively buoyant cylinder that is free-falling in a viscous bath near an inclined wall coated with a gel. A soft lubrication layer exists between the object and the wall, thus influencing the falling speed. We show that there is an elastohydrodynamic lift force - not present in the hard-wall case - that balances gravity, thus allowing for a fast steady-state planing regime. Our experimental results are well supported by a scaling approach. The presented work could be of interest in the description of a broad variety of phenomena, including: landslides, ageing of cartilaginous joints, and motion of a cell in a microfluidic channel or in a blood vessel, where elasticity and hydrodynamics are intimately coupled.

A5. Lab on chip dedicated to platelets generation

Bruno Teste,[1] Antoine Blin,[2] Anne Le Goff,[1] Aurélie Magniez,[2] Sonia Poirault-Chassac,[3] Géraldine Sicot,[2] Feriel Hamdi,[2] Patrick Tabeling,[1] Dominique Baruch,[2] Mathilde Reyssat[1]

1 Laboratoire MMN, Laboratoire Gulliver – ESPCI ParisTech, France

2 PlatOD

3 INSERM

Platelets are small anucleate cells responsible for the healing of wounds. Due to a limited number of donors and a short shelf life of platelets, there is a demand for alternative methods to obtain platelets for transfusions. In the recent years, much effort has been dedicated to developing cell culture methods and bioreactors suitable for platelets production. In vivo, blood platelets are formed by the fragmentation of megakaryocytes (MKs) in the lumen of blood capillaries within the bone marrow. Our work consists in developing microfluidic tools in order to mimic in vivo conditions of platelets generation. We developed a microfluidic device consisting in a wide array of specific protein-coated micropillars. Such pillars act as anchors on megakaryocytes, allowing them to remain trapped in the chamber and subjected to shear. The combined effect of specific anchoring and shear induces the elongation of MKs and finally their rupture into platelets. Our strategy maintains cells viability since the developed microfluidic device allows cells capture without any confinement and labeling that could modify cells structures and therefore platelets generation process. Platelets are then separated from intact MKs by a microfluidic sorter based on objects size differences and collected for biological characterization. The large volume of suspension handled by the system thus allows for an extensive biological characterization of platelet products. We demonstrated that in vitro platelets functionalities were comparable to those obtained from in vivo production. This suggests that our bioreactor is able to produce functional platelets with a high throughput. In that way, our microfluidic tool paves the way to regenerative medicine since future development should lead to platelets transfusion.

A6. Bubble spreading on superaerophilic surfaces

Hélène de Maleprade, Christophe Clanet, David Quéré

Laboratoire d'Hydrodynamique de l'X - Ecole polytechnique, PMMH – ESPCI ParisTech, France

A drop deposited on a common surface can spontaneously spread and the corresponding dynamics have been widely studied for the last 20 years. The behavior of spreading at long and short times is now well characterized. This phenomenon has been analyzed on different types of substrates, varying the wettability from superhydrophilic to hydrophobic, or using a substrate coated by a film of the same liquid as the drop. In this work, we invert the geometry of the previous problem. Instead of observing a drop of liquid spreading in air, we look at a bubble of air surrounded by liquid spreading on a solid. In our experiments, the liquid is water and the substrate is superhydrophobic, that is superaerophilic: bubbles will tend to spread completely on this surface. Typical examples of superaerophilic surfaces are lotus leaves or notonecta, which remain covered by a thin layer of air, even immersed in water. In our experiments, thanks to a transparent coating we can observe from a top view the spreading of the bubble. We show that the dynamics of spreading are completely different from what can be seen for drops, and discuss in particular the existence of a long linear regime of spreading at short times.

A7. From gel reinforcement to gel adhesion

Alba Marcellan

Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

Gels are materials that contain more than 90 wt.% of water, yet they behave as elastic solids. To overcome gel's intrinsic fragility many strategies have been explored, as filling the gels with nanoparticles. Recently, we proposed a new method for gluing gels and soft biological tissues by using nanoparticle solutions as a glue. This method is remarkably simple and versatile; it enables the rapid bonding at room temperature of two gels of different cross-linking densities or different nature. In this talk, I will describe the approach that has consisted to shift from bulk reinforcement to gel adhesion with solid nanoparticles. I will present the ongoing work and some promising perspectives.

A8. Patterning surfaces with colloid-bottlebrush polymer mixtures

Charlotte Pellet,[1] Michel Cloître,[1] Jean-Marc Suau[2]

1 Matière Molle et Chimie (MMC) – ESPCI ParisTech, France
2 Coatex company, Arkema group

The deposition of colloidal particles from liquid droplets on solid substrates is an attractive patterning technology for fabricating biological, electronic or optical devices. One current limitation is the difficulty to achieve uniform patterns during solvent evaporation because the particles tend to deposit along the droplet periphery resulting in a ring-like morphology, known as the coffee-ring effect. Recently the origin and the modeling of the coffee ring effect have stimulated a lot of work but its suppression remains an important challenge in applications. Here we describe a new method based on bottlebrush polymers for inhibiting the coffee ring effect in colloidal suspensions. The bottlebrush polymers we use consist of a highly charged polyelectrolyte backbone and hydrophilic pendant chains densely tethered to it. When added at extremely low concentrations to colloidal mineral suspensions like calcium carbonate, bottlebrush polymers totally suppress the coffee ring effect and produce very uniform patterns free of defects. We will analyze the new mechanism which is at the origin of coffee ring inhibition by bottle brush polymers and discuss the generality of our results for other colloidal suspensions.

A9. Deformation and transport of micro-helices and fibers by viscous flows

Olivia du Roure, Nawal Quennouz, Michael Shelley, Jonathan Pham, Alexander Morozov, Alfred Crosby, Anke Lindner

PMMH – ESPCI ParisTech, France

The situation in which a flexible object is deformed and transported by a viscous flow is ubiquitous in nature and industrial applications. The coupling between the mechanics of the object and the hydrodynamics of the flow is non trivial and its study requires controlled experiments. I will present during SMD two different examples dealing with this question. First I will present the deformation and transport of an elastic fiber in a viscous cellular flow. I will show in particular that the free dynamics of the fiber itself determines its deformation. Second, I will discuss the behavior of a micro-helix induced by flow.

A10. Glass transition accelerates the spreading of volatile droplets on soluble visco elastic polymers

Emilie Verneuil,[1] Julien Dupas,[1] Laurence Talini,[1] François Lequeux,[1] Marco Ramaioloi,[2] Laurent Forny[2]

1 Laboratoire SIMM, UMR 7615, CNRS, UPMC, ESPCI ParisTech, 10 rue Vauquelin 75005 Paris, France

2 Nestlé Research Center, route du Jorat 57, 1000 Lausanne 26, Switzerland

The wetting dynamics of solids is well known, but what happens when the substrate is solubilized by the spreading liquid? The first studies on the subject showed that the spreading dynamics of a solvent droplet is governed by the solvent transfers from the droplet to the substrate. More precisely, we showed that evaporation from the droplet condenses solvent in the vicinity of the contact line thus increasing the solvent content in the substrate. As a result both the droplet contact angle q and velocity *U* decrease with time, an effect that can be modeled as a change of the substrate surface tension. Here we build up on our previous findings on melt polymers and we focus on cases where the polymer is initially glassy. The effect of solvent transfer is expected to be two-fold: not only the substrate surface tension is changed, but also, solvation induces a plasticization of the polymer, i.e. a glass transition from an elastic glassy material to a visco-elastic dissipative gel phase before finally turning into a viscous liquid. Interesting coupling between solvent transfers and visco-elasticity of the substrate are therefore expected when a droplet of solvent spreads onto a glassy soluble polymer. The variations of hue at the edge of the droplet reveal the swelling of the polymer by the solvent that extends to large distances at small velocity, and smaller distances at high velocity. In the meantime, the measurements of the contact angle q as a function of the velocity *U* present a different shape when the polymer is initially melt or glassy. Indeed, whereas the q(*U*) curve is smooth for melt substrates, the angle decreases steeply for a given value of the velocity, Ug on glassy substrates. We demonstrate that this change in the dynamics result from a plasticization, i.e. a glass transition, undergone by the polymer layer during spreading, owing to the increase of its solvent content f. By analyzing previous predictions on the wetting of soft viscoelastic substrates, we are able to account for the deformations of the substrate by capillary forces and to model the resulting dissipation in the melt substrate. We can predict the variations of q with *U* close to glass transition, accounting for the change of visco-elastic moduli of the polymer solution with solvent content. So as to extend the validity of our study, we performed a series of similar experiments with droplets of various volatile solvents. Identical results were obtained and an analytical prediction for *Ug* was derived, based on existing predictions for the rate of solvent transfers from the droplet to the substrate. For the polar solvents of different natures we tested, we show that the experimental data compares well to the predicted expression for *Ug*.

B. JEUDI @ 15h00-16h15 / 16h45-18h10

B1. Dynamical properties of droplet's lubrication film in confined microchannels

A. Huerre,[1] O. Theodoly, A. Leschansky, I. Cantat, M.C. Jullien[1]

Laboratoire de Microfluidique, MEMS, Nanostructures (MMN), Laboratoire Gulliver – ESPCI ParisTech, France

The motion of droplets or bubbles in confined geometries has been extensively studied; showing an intrinsic relationship between the lubrication film thickness (layer between the droplet and the wall preventing from wetting) and the droplet velocity. When capillary forces dominate, the lubrication film thickness evolves non linearly with the capillary number (based on the droplet velocity) due to viscous dissipation between meniscus and wall. However, this film may become thin enough that intermolecular forces come into play and affect classical scalings. We report here the first experimental evidence of the disjoining pressure effect on confined droplets (oil in water + SDS) by measuring droplet lubrication film thicknesses in a microfluidic Hele-Shaw cell. We find and characterize two distinct dynamical regimes, dominated respectively by capillary and intermolecular forces. In the former case viscous boundary conditions at the interface are evidenced through film thickness dynamics, exhibiting the signature of viscosity. We observe for concentrated solutions a spinodal decomposition at intermediate capillary numbers, stemming from the oscillatory shape of the disjoining pressure. It allows us to perform interface velocity measurement and reconstruct full interfacial tension profile. Finally, the 3D topography of the film thickness becomes complex at larger capillary numbers. This experimental shape is not yet predicted by models and provides new clues for the full understanding of droplets dynamics.

B2. Can frequencies in thermosolutal convection be predicted from mean flows?

Laurette Tuckerman

PMMH – ESPCI ParisTech, France

The von Karman vortex street is one of the most striking visual images in fluid dynamics. Immersed in a uniform flow of sufficient strength, a circular cylinder periodically sheds propagating vortices of alternating sign on either side of the "street". Although the von Karman vortex street can be simulated numerically with great accuracy, predicting its properties from general theoretical principles has proved elusive. It has been shown that the vortex shedding frequency can be obtained by carrying out a linear stability analysis about the temporal mean, but there is no understanding of why the correct answer emerges from such an unorthodox procedure. We have carried out a similar analysis of thermosolutal convection, which is driven by opposing thermal and solutal gradients. In a spatially periodic domain, branches of traveling waves and standing waves are created simultaneously by a Hopf bifurcation. We find that linearization about the mean fields of the traveling waves yields an eigenvalue whose real part is almost zero and whose imaginary part corresponds very closely to the nonlinear frequency, consistent with the cylinder wake. In marked contrast, linearization about the mean field of the standing waves yields neither zero growth nor the nonlinear frequency. It is shown that this difference can be attributed to the fact that the temporal power spectrum for the traveling waves is peaked, while that of the standing

waves is broad. We give a general demonstration that the frequency of any quasi-monochromatic oscillation can be predicted from its temporal mean.

B3. Generation and stability of foams made from physical gels

Rémi Deleurence,[1,2] Tamar Saison,[2] François Lequeux,[1] Cécile Monteux[1]

1 Soft Matter Science and Engineering, ESPCI ParisTech, Paris, France.

2 Saint-Gobain Recherche, Aubervilliers, France

Foam stability is a critical issue for many applications such as in the food and chemical industries, for flotation or decontamination processes, or elaboration of porous materials. However, it seems often difficult to combine a high stability with a good foaminess. For example increase the viscosity of the continuous phase of the foam enables to enhance its stability, but usually leads to lower volume of foam and less air entrapment. We have developed a process enabling to generate large volumes of highly stable foams, in which the continuous phase is a gel-like material. We show that the stability of these foams is strongly enhanced with respect to the stability of standard soap foam. The drainage kinetics, which is controlled by the viscosity, occurs over several weeks. Furthermore, we demonstrate that the polymer and cross-linker concentrations are crucial parameters, which control the amount of air trapped in the gelled foams. We will relate this result to the ability of the bubbles to stretch and break up during the foaming process.

B4. Semi-permeable capsules with conductive membrane for culture and selection of electroactive microorganisms

Léopold Mottet,[1] Nicolas Bremond,[1] Jérôme Bibette,[1] Philippe Pouliné[2]

1 LCMD – ESPCI ParisTech, France

2 CRPP, groupe Nanotubes et graphène, 115 Avenue du Dr Albert Schweitzer, 33600 Pessac

Nowadays, some electroactive microorganisms are a promising way to convert organic matter into electricity. Their metabolisms are well known but their life time and their performances are still limited in natural environment. Yet the immense diversity of microorganisms suggests a hidden potential that conventional technologies cannot explore. High throughput encapsulation is a promising way to study and explore microorganism biodiversity. Therefore, we developed a conductive hydrogel in order to create a biocompatible capsule with a conductive membrane. This semi-permeable conductive hydrogel is a double network of alginate and carbon nanotubes, synthetize by ionic gelation and dialysis of a specific surfactant. Electrically connected by the membrane, the encapsulated bacteria are able to release electrons outside the capsule and generate current. This biocompatible conductive capsule promises to be a smart tool to easily screen and select powerful electroactive micro-organisms.

B5. Stabilizing effect of shear thinning on the onset of elastic instabilities in serpentinemicroflows

Laura Casanellas,[1,2] Sandra Lerouge,[2] Anke Lindner[1]

1 PMMH - ESPCI ParisTech, Paris, France

2 MSC, Université Paris Diderot, Paris, France

Elastic instabilities may occur at vanishing Reynolds number in the flow of viscoelastic fluids and a general criterion for the onset of such instabilities can be established based on the curvature of flow streamlines and fluid elasticity. Our goal is to study experimentally the onset of elastic flow instabilities in viscoelastic (polymeric or wormlike micellar) solutions of various rheologies in different flow geometries. Experiments realized in microfluidic serpentine channels using diluted polymeric solutions showed that indeed the onset of elastic instabilities strongly depends on the channel curvature. More recently, experiments performed using more concentrated polymeric solutions show that the shear-thinning behavior has an stabilizing effect on the microfluidic flow. The control of the onset of purely-elastic instabilities in microfluidic devices is essential for the development of lab on a chip applications. In particular, serpentine microchannels can be used as microfluidic rheometers, by conveniently utilizing the onset of elastic instabilities, in order to measure the relaxation time of viscoelastic fluids.

B6. Silicon wafers wetting by polybutadiene melts

Marc Yonger,[1] Hélène Montes, [1] Emilie Verneuil, [1] François Lequeux, [1] Aurélie Papon,[2] Laurent Guy[2]

1 Soft Matter Science and Engineering, ESPCI ParisTech, Paris, France

2 Solvay, France

We are studying oxidized silicon wafers wetting by polybutadiene melts and we are interested in the effects of atmosphere relative humidity and in the polymer chains lengths. We observe macroscopic polybutadiene droplets spreading on wafers surface in controlled humidity conditions. In fact, we are in pseudo partial wetting conditions and there is a strong effect of nanometric wetting films on macroscopic droplets spreading. We observe these films by ellipsometric microscopy in controlled humidity condition.

B7. Towards specific markers for biological imaging based on quantum dot nanoparticles

Mariana Tasso,[1] Manish K. Singh,[2,3] Alexandra Fragola,[1] Vincent Loriette,[1] Emerson Giovannelli,[1] Nicolas Lequeux,[1] Marie Frugier Regairaz,[3] François Dautry,[3] François Treussart,[2] Thomas Pons[1]

1 Laboratoire de Physique et Etude de Matériaux, UMR 8213, ESPCI ParisTech, Paris, France.

2 Laboratoire de Photonique Quantique et Moléculaire, Ecole Normale Supérieure, Cachan, France.

3 Laboratoire de Biotechnologies et Pharmacologie Génétique Appliquée, Ecole Normale Supérieure, Cachan, France.

Inorganic quantum dot (QD) nanoparticles have distinctive optical properties, including high photostability and quantum yield, as well as narrow symmetrical emission peaks that render them very valuable as probes for fluorescence-based detection methods. The versatility in QDs' emission wavelengths (from UV to IR) attributable to variations in their composition and size makes them intrinsically suitable for multiplexing in immunological diagnostics, cell trafficking analysis or cell identification via multiple markers. Realizing this potential requires the stable and specific functionalization of QDs with biological molecules, such as antibodies or other cell membrane-binding units, like lectins. In our group, a stable surface chemistry strategy has been developed to enable the passage of inorganic QDs to aqueous media and their further functionalization with bioactive molecules.

The work here presented focus on the various biofunctionalization strategies currently under investigation and on their promising applications in immunohistochemistry, cell identification and cell receptor trafficking analysis. Antibody immobilization to CdSe/CdS/ZnS QD nanoparticles is carried out following oriented and cleavable linker approaches. The biofunctional nanoparticles are characterized regarding total protein content, biological recognition specificity and stability in biological media. Relevant applications of these nanoparticles illustrate on the advantages of biofunctional QDs as fluorescent nanoprobes for the inspection of biological features and processes.

B8. Edge effects on water droplet condensation

Marie-Gabrielle Medici,[1] Anne Mongruel,[2] Laurent Royon,[3] Daniel Beysens[4]

1 LPMC et Université de Nice-Sophia Antipolis
2 PMMH et Université Pierre et Marie Curie
3 MSC et Université Paris Diderot
4 PMMH et CEA Grenoble

In diffusion limited water droplet condensation, it is observed that substrate discontinuities have a strong effect on the growth of the droplets. These discontinuities can be geometric (edges, corners, cavities etc ..) or thermal (difference in substrate cooling properties), and growth can be enhanced or reduced. These effects are evaluated experimentally. For instance, in certain cases, growth enhancement can reach 500 % on edges and corners. Numerical simulations of the water vapor diffusion process for various substrate geometrical discontinuities reproduce the observed differential droplet growths.

B9. Mechanical Properties of an Epoxidized Natural Rubber Network Containing Dynamic Crosslinks

L. Imbernon, E. K. Oikonomou, S. Norvez, L. Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

Disulfide bonds were used to create a dynamic covalent network of Epoxidized Natural Rubber (ENR). ENR is a unique elastomer retaining most of the properties of natural rubber from which it derives, in particular high tensile properties and resistance to crack propagation up to 50 mol% epoxidation. Our group recently showed that ENR can be efficiently crosslinked by dicarboxylic acids. The disulfide functions were introduced in the rubber through crosslinking by dithiodibutyric acid (DTDB).Self-healing materials were already designed using disulfide chemistry. These materials however show weak elastomeric properties: at the rupture point, stress is less than 1 MPa and strain usually limited to 200 %. Using a high molecular weight polymer derived from natural rubber should thus allow to combine with reversible behavior and strong elastomeric properties. Here, we show that the resulting network is able to relax most of the applied stress and that it starts creeping significantly under stress at a temperature allowing disulfide exchanges. The material is not fully mendable and processable because of the occurrence of side reactions, but a new sample can be rebuilt from a grinded crosslinked piece, by pressing the rubber powder at 180 °C for less than one hour. This recycled material recovers more than 60 % of its initial properties (stress and strain at break).

B10. Rate-dependent elastic hysteresis during the peeling of pressure sensitive adhesives

Matteo Ciccotti

Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

The modelling of the adherence energy during peeling of Pressure Sensitive Adhesives (PSA) has received much attention since the 1950's, uncovering several factors that aim at explaining their high adherence on most substrates, such as the softness and strong viscoelastic behaviour of the adhesive, the low thickness of the adhesive layer and its confinement by a rigid backing. The more recent investigation of adhesives by probe-tack methods also revealed the importance of cavitation and stringing mechanisms during debonding, underlining the influence of large deformations and of the related non-linear response of the material, which also intervenes during peeling. Although a global modelling of the complex coupling of all these ingredients remains a formidable issue, we report here some key experiments and modelling arguments that should constitute an important step forward. We first measure a non-trivial dependence of the adherence energy on the loading geometry, namely through the influence of the peeling angle, which is found to be separable from the peeling velocity dependence. This is the first time to our knowledge that such adherence energy dependence on the peeling angle is systematically investigated and unambiguously demonstrated. Secondly, we reveal an independent strong influence of the large strain rheology of the adhesives on the adherence energy. We complete both measurements with a microscopic investigation of the debonding region. We discuss existing modellings in light of these measurements and of recent soft material mechanics arguments, to show that the adherence energy during peeling of PSA should not be associated to the propagation of an interfacial stress singularity. The relevant deformation mechanisms are actually located over the whole adhesive thickness, and the adherence energy during peeling of PSA should rather be associated to the energy loss by viscous friction and by rate-dependent elastic hysteresis.

B11. Foam drainage control in a 2D-microchamber: comined effect of thermo- and solutocapillarity

Vincent Miralles, Isabelle Cantat, Marie-Caroline Jullien

Laboratoire de Microfluidique, MEMS, Nanostructures (MMN), Laboratoire Gulliver – ESPCI ParisTech, France

We investigate the drainage of a 2D microfoam in a vertical Hele-Shaw cell, and show that the Marangoni stress at the air-water interface generated by a constant temperature gradient applied in situ can be tuned to control the drainage. The temperature gradient is applied in such a way that thermocapillarity and gravity have an antagonist effect. We characterize the drainage over time by measuring the liquid volume fraction in the cell and find that thermocapillarity can overcome the effect of gravity, effectively draining the foam towards the top of the cell, or exactly compensating it, maintaining the liquid fraction at its initial value over at least 60 s. We quantify these results by solving the mass balance in the cell, and provide insight on the interplay between gravity, thermocapillarity and capillary pressure governing the drainage dynamics. Finally we use this model system to provide insight in the drainage dynamics for a more complex interfacial rheology, using insoluble surfactants inducing a solutocapillary effect.

B12. Bio-inspired undulatory swimmers

Ramiro Godoy-Diana, Benjamin Thiria

PMMH – ESPCI ParisTech, France

Swimmers in nature use body undulations to generate propulsive and manoeuvring forces. The fish-swimming kinematics is driven by muscular actions all along the body, involving a complex temporal and spatial coordination of all the local actuations. Such swimming motion, in particular the anguilliform kinematics, can be reproduced artificially, in a simpler way, by using the elasticity of the body passively. I will give a brief review of our recent work on such flexible swimmers.

C. VENDREDI @ 9h30-10h45 / 11h15-12h30

C1. Reversible covalent associative polymers in water

Rémi Fournier,[1] Stéphane Jouenne,[2] Michel Cloitre[1]

1 Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

2 PERL, TOTAL E&P, 64170 Lacq

Polymer flooding is one of the prevailing technologies used in enhanced oil recovery. It consists of injecting an aqueous polymer solution which sweeps the reservoir and pushes the oil to the production well. High molecular weight water-soluble polymers like hydrolyzed polyacrylamide (HPAM) are commonly used although they exhibit serious drawbacks due to their propensity to break and degrade at high shear rates. To circumvent these limitations, the use of hydrophobically associative polymers has been proposed. The advantage is that small polymer chains can now assemble together into clusters, which increases the viscosity and that can be reversibly broken and reformed by hydrophobic association, thus maintaining the efficiency of the system. Unfortunately, low viscosities are not precisely tuned because of the competition between intra- and inter-chains associations. Here we present a new concept of reversible covalent associative polymers, based on commercial polymers, available in large quantities, and already used in oil recovery. An adequate functional group was grafted on a HPAM backbone. The grafted HPAM chains react with shorter polyvinyl alcohol chains through a molecular recognition mechanism. The mixture exhibits remarkable visco-elastic properties which depend on polymer concentrations, grafting rate, ionic force, temperature and pH. The binary covalent association of the two complementary moieties prevents cluster and loop formations, encountered in conventional associative polymers, thus providing a large increase of water viscosity even at very low polymer concentrations. We will present the rheological properties of this new class of associative system. Significant viscosity enhancement, even at very low concentrations (<0.4wt%), is obtained. Actually, a marked transition between a viscous-like and a gel-like regime is witnessed, upon increasing the polymer concentration. Flow experiments provide us with information about a non-newtonian behavior, similar to classical telechelic associative polymers. Rheo-PIV measurements could help us understand the microscopic processes at play during the flow of these reversible covalent associative polymers.

C2. Foams in porous media for oil enhanced recovery

Annie Colin,[1] Virginie Hourtané,[2] Hugues Bodiguel[2]

1 Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

2 Laboratory of the Future, UMR 5258, 178, avenue du Dr Schweitzer F-33608 Pessac, France

Foams are dispersions of a gas in liquid. We meet aqueous foam every day in many manufactured products such as shampoos, foods, leverages or in industrial processes such as solid extraction or heterogeneous catalysis. Some of these processes involve the injection of a foam into earth' subsurface, in particular to enhance oil recovery or to clean polluted soils. These latter applications are recent and particularly promising. Injecting foams into rocks present numerous advantages over water flooding as the needed volumes of water for a given volume of the injection fluid are considerably lowered and the specific rheological properties of the foam allow a better invasion of the injection fluid into small pores. Foams improve reservoir sweep efficiency because of their high effective viscosity, which reduces both channelling flows (flows of gas in the high permeability streaks) and viscous fingering. For these reasons, foams now are also getting used for in situ cleaning/remediation of polluted soils. Understanding how foam flows in porous media is thus of great importance an has been the purpose of many studies in the past. These experimental studies typically focus on macroscopic flows in realistic porous materials such as packed grains or porous solids. Tang and Kovscek have shown that the high effective viscosity is due to trapped gas. They claimed that size heterogeneities may be at the origin of the creation of preferential paths. Although they provide important insight into the dynamics of draining in the pore network as a whole, flow at the level of the pore cannot be accessed and at this stage we have only a poor description of the mechanism ruling foam flows in porous media. One of the major difficulties in describing foam flows in interconnected network is to account for the large number of parameters potentially involved such as interfacial tension, wetting properties, relative flow rate of the two phases, viscosities, coalescence of bubbles, detailed features of the porous medium used, creation of preferential path. Full visualisations of foam flows in model porous media are therefore urgently needed to validate and improve theoretical approaches. To achieve a better understanding of foam flows through porous media, we investigate here a basic situation. We consider a stable foam and we take advantage of microfluidics to fabricate micromodels with well-defined surface and geometric features. Micromodels are useful by allowing a direct observation of the displacement mechanisms of fluids in porous media . Recent advances permit good control of their geometrical properties and give access to quantitative in situ measurements. We start from the simplest configuration: a channels network with no size heterogeneities. Coupling drop of pressure, velocimetry and liquid fraction in situ measurements, we show that the measured high effective viscosity of foams originates from the creation of preferential path and from filtration. Strikingly, and contrary to classical belief, we point out that preferential paths do not arise only from size heterogeneities. They may be created by clogging occurring at the nodes. Separated experiments on single loop confirm this picture.

C3. Structured layers on glass substrate for new functionalities: the example of super-hydrophobic surfaces

J. Teisseire,[1] M. Rivetti,[1] E. Barthel[2]

1 Surface du Verre et Interfaces, UMR 125 CNRS/Saint-Gobain, 39 Quai Lucien Lefranc, F-93303 Aubervilliers, Cedex, France

2 Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

Surface modification and coating deposition are the major path for the functionalization of glass substrates. During the last 30 years, innovation relied mainly on silver-based functional coatings deposited by magnetron sputtering, leading to very complex stacks in the last products. It appears now that the future innovation in glass or flexible substrate may come from surface micro- and nano-patterning to control the path of light or modify surface properties. We will present strategies developed in the joint laboratory CNRS/Saint-Gobain to functionalize conventional glass substrates. Thanks to these coated structured layers we will present an example of new physical properties added to the glass substrate: the super-hydrophobicity. To understand the relation between wetting and surface roughness, contact angles were measured on periodic super-hydrophobic surfaces. Investigating different types of lattices, including anisotropic ones, we found that effective adhesion scales with surface fraction (and not with line fraction). This surprising behavior is closely related to the deformations of the contact line which can be by studied by direct observation. Numerical and analytical modeling demonstrates that the relevant mechanism is pinning through triple line defects which we interpret in term of propagation of kink along the lattice.

C4. Activity induced phase separation

J-F. Joanny,[1] A. Grosberg

1 ESPCI ParisTech, France

We consider a new type of active systems made of two types of particles in contact with themostats at different temperatures and analyze the stability conditions of either uniformly mixed or phase segregated steady states consisting of phases enriched with the two types of particles. We show that in sufficiently dilute mixtures, the system can be described within a second virial approximation neglecting three body and higher order collisions. Within this approximation, we define non-equilibrium "chemical potentials" whose gradients govern diffusion fluxes and a non-equilibrium "osmotic pressure", which governs the mechanical stability of the interface.

C5. Pénétration d’objets flexibles dans des milieux réorganisables

Nicolas Algarra,[1] Tristan Deleplanque,[1] Pascal Kurowski,[1] Damien Vandembroucq,[1] Arnaud Lazarus,[2] Evelyne Kolb[1]

1 PMMH – ESPCI ParisTech, France
2 IJLRA

L’enfouissement d’objets (pieux, tiges, pénétromètres..etc) dans un sol est une problématique bien connue en génie civil et dans l’industrie pétrolifère. Cependant lorsque le sol est peu cohésif (l’exemple type est le sol sableux) et que la taille caractéristique de l’objet qui s’enfouit devient comparable à la granularité du sol, les calculs par éléments finis de résistance à la pénétration de milieux continus sont difficilement transposables. En effet, dans un sol granulaire, la distribution des contraintes mécaniques est hétérogène et tous les chemins de pénétration ne sont pas équivalents. De plus, la réorganisation possible des grains sous l’effet de la pénétration de l’objet conduit à une modification des propriétés mécaniques du milieu environnant, donnant lieu à un couplage et à une rétroaction entre la force sur l’objet qui pénètre et la réorganisation du milieu. Notre thématique est de comprendre les mécanismes de pénétration d’un « intrus » dans un milieu poreux réorganisable, comme un milieu granulaire ou un sol. L’intrus peut être un objet rigide, une tige flexible ou même un objet biologique comme une racine de plante qui croît dans la porosité entre les grains d’un sol ou d’un milieu modèle, et qui peut les réorganiser.

C6. Shape matters in protein mobility within membranes

F. Quemeneur[1], J. K. Sigurdsson[3], M. Renner[2], P. J. Atzberger[3], P. Bassereau[1] and D. Lacoste[4]

1 Institut Curie, UMR 168, F-75248 Paris, France

2 Université Pierre et Marie Curie, F-75252 Paris, France

3 University of California Santa Barbara, CA 93106, USA

4 Ecole Supérieure de Physique et Chimie Industrielle, F-75231 Paris, France

The lateral mobility of proteins within cell membranes is usually thought to be dependent on their size and modulated by local heterogeneities of the membrane. Experiments using single-particle tracking on reconstituted membranes demonstrate that protein diffusion is significantly influenced by the interplay of membrane curvature, membrane tension, and protein shape. We find that the curvature-coupled voltage-gated potassium channel (KvAP) undergoes a significant increase in protein mobility under tension, whereas the mobility of the curvature-neutral water channel aquaporin 0 (AQP0) is insensitive to it. Such observations are well explained in terms of an effective friction coefficient of the protein induced by the local membrane deformation.

C7. Multilayer assembly of polymers on liquid interfaces for encapsulation

Corentin Trégouët[1,2], Sandrine Le Tirilly[3], Stephane Bone[3], Gerry Fuller[4], Patrick Perrin[1], Nadège Pantoustier[1], Mathilde Reyssat[2], Cécile Monteux[1]

1 SIMM, ESPCI, 10 rue Vauquelin, 75005 Paris

2 Gulliver, ESPCI, 10 rue Vauquelin, 75005 Paris

3 Givaudan, 55 Rue de la Voie des Bans, 95100 Argenteuil

4 Stanford, Via Ortega 443, Stanford, CA 94305-4125, USA

Microencapsulation offers a solution to protect, transport and deliver active substances. The efficiency of microcapsules depends on their thickness and mechanical properties. The goal of our study is to produce model capsules with controlled mechanical properties. We developed a microfluidic method to produce capsules based on layer-by-layer assembly of polymers directly on oil droplets and to study their deformation in constrictions. In parallel we perform surface rheological measurements to characterize their shear and compression properties of the membranes assembled in model geometry. We show that the mechanical properties of the capsules depend on the type and strength of the interactions involved between the polymer layers. Using an interplay of hydrogen bond and hydrophobic interactions we obtain a wide range of behaviours, from purely viscous to viscoelastic, where the elastic modulus and relaxation time can be varied over orders of magnitude.

C8. Crack propagation of filled polymer materials during processing

Guillaume Foyart, Michel Valtier

Manufacture Française des Pneumatiques MICHELIN, Centre de Technologie 63060 CLERMONT-FERRAND

New polymer nanocomposite materials are introduced in the tire treads in order to reduce the rolling resistance of vehicles. To ensure a rapid market release of these innovative tires, the processing steps must be as adaptive and flawless as possible. It is not always straightforward to predict the materials behavior during the calendaring and extrusion steps. One of the main issues that hindered the industrial performance is crack propagation of uncrosslinked filled polymer materials. Crack propagation can lead to several costly disagreements like band breaking and decohesion at the edges of the tire tread during the manufacturing process. In this talk, we will present the methodology we're setting up to predict, at a semi-lab scale, the risk for a new material to be non-cohesive at the plant scale. Not surprisingly, a deeper understanding of the physics that lies underneath is the key toward a better design of materials and/or processing tools in order to keep both rolling and industrial performance at a cutting edge.

C9. A new high throughput technique of mechanical measurements applied to cytoskeletal actin networks

Pierre Bauër, Joseph Tavacoli, Olivia du Roure, Julien Heuvingh

Physique et Mécanique des Milieux Hétérogènes, ESPCI, CNRS UMR 7636, UPMC, Université Paris-Diderot, 10 rue Vauquelin, 75005 Paris, France

Actin filaments play a fundamental role in cell mechanics: assembled into networks by a large number of partners, they ensure cell integrity, deformability, and migration. Their mechanical characteristics and force production mechanisms remain elusive and deciphering them would lead to a deeper understanding of cell properties specially during embryogenesis or development of cancers. Such networks of semi-flexible polymers are also of great interest for material science. Techniques such as AFM or micropipette have been used to probe such materials, but due to their low throughput the results lacked systematic measurements to challenge the theories. Our team developed a setup allowing to mechanically probe reconstituted actin networks grown around colloidal superparamagnetic beads. The magnetic dipolar forces, that develop between beads in an homogenous magnetic field, are used to deform the actin network in a controlled way. The optical observation of the deformations, through a microscope, gives quantitative data with a high throughput allowing systematic studies (by changing the concentrations of the proteins used in the network assembly). A strong effect of the network architecture on its elasticity has been evidenced. However, to measure the elasticity of the networks a Hertz model is used to obtain the area of contact which changes with the indentation. As a consequence non-linear measurements cannot be performed. Moreover, the spherical geometry of the beads constraints the polymerization as it occurs at the surface of the beads. Indeed the 'new' gel pushes the 'old ' gel outward creating tension in the gel. As a result the gel grown around a bead has internal tension and force velocity measurements are not possible. Those issues would be solved if the networks were grown on colloids with flat surfaces. We therefore developed a new method to engineer monodisperse, superparamagnetic, micron-sized cylinders of arbitrary geometrical shapes with high magnetic susceptibility. This process combines soft lithography and reticulation methods by molding a suspension of magnetic colloids in UV-curable monomers. We achieve high homogenous content of magnetic materials by carefully choosing the surface chemistry of the colloids and curable matrix in order to prevent aggregation. The growth of actin gels on these flat surfaces and the measurements of their mechanical properties provide direct force-velocity measurements, stress-strain curves and non-linear measurements. This innovation provides an efficient tool to characterize dense actin branched networks (Poisson's ratio, Young's modulus, stress stiffening and softening, force generation with force-velocity curves, visco-elastic measurements ...) that will pave the way to understand the microscopic origin of cells' elasticity.

C10. Colorimetric monitoring of nanometer distance changes in DNA-templated gold nanoparticle dimers

Laurent Lermusiaux, Vincent Maillard, Sébastien Bidault

ESPCI ParisTech, PSL Research University, CNRS, Institut Langevin, Paris, France

The nanometer-scale sensitivity of plasmon coupling allows the translation of minute morphological changes in nanostructures into macroscopic optical signals. In particular, single nanostructure scattering spectroscopy provides a direct estimation of interparticle distances in gold nanoparticle (AuNP) dimers linked by a short DNA double-strand. We demonstrate here that this spectroscopic information can be inferred from simple widefield measurements on a calibrated color camera. This allows us to analyze the influence of electrostatic and steric interparticle interactions on the morphology of DNA-templated AuNP groupings. Furthermore, polarization-resolved measurements on a color CCD provide a parallel imaging of AuNP dimer orientations. We apply this spectroscopic characterization to identify dimers featuring two different conformations of the same DNA template. In practice, the biomolecular scaffold contains a hairpin-loop that opens after hybridization to a specific DNA sequence and increases the interparticle distance. These results open exciting perspectives for the parallel sensing of single specific DNA strands using plasmon rulers. We discuss the limits of this approach in terms of the physicochemical stability and reactivity of these nanostructures and demonstrate the importance of engineering the AuNP surface chemistry, in particular using amphiphilic ligands.

C11. Morphology and dynamics of a crack front in a disordered interface

Julien Chopin,[1,2] Laurent Ponson,[2] Elisabeth Bouchaud[1]

1 Laboratoire Gulliver, équipe EC2M – ESPCI ParisTech, France

2 Institut Jean le Rond d'Alembert, Equipe MISES, UPMC

An interfacial front (wetting contact line, crack front, magnetic domain wall, ...) propagating in a heterogeneous landscape exhibits morphological and dynamical properties whose understanding remains imperfect. We designed an experiment where a crack front propagates at the interface of a thick slab of elastomer and a flexible plate (printable transparency). An arbitrary pattern (lines, random distribution of disks, ...) is initially printed on the transparency using a regular printer allowing a spatial modulation of the fracture energy of the interface. With this simple process, an optimal control of the heterogeneities is achieved, allowing to investigate the statistical properties of the crack front. In particular, we studied the dependence of the roughness exponent of fronts with the average speed of propagation as well as the emergence of an intermittent dynamics.

C12. Nanoparticles are always polydisperse - Let subpopulations crystallize!

Bernard Cabane

LCMD – ESPCI ParisTech, France

Functional nanomaterials are often made through self-assembly of nanoparticles dispersed in a liquid phase. So far it has been assumed that well-controlled functions can be obtained only with materials that are crystalline arrays of such nanoparticles. In turn, it has also been assumed that such regular arrays can be built only by using dispersions of nanoparticles that are all the same, i.e. monodisperse in sizes. Consequently, enormous efforts have been devoted to developing synthetic routes that end up producing populations of particles that are as monodisperse as possible. Here we demonstrate that such efforts may not always be necessary, and that, to the contrary, polydisperse populations of nanoparticles may *selfselect* to produce the same colloidal crystals that have been produced through delicate and elaborate synthesis of monodisperse populations.

D. 14h30-15h45 puis 16h15-17h15

D1. A study of the wetting ridge on soft gels

Menghua Zhao[1,2], Matthieu Roché[2], Tetsu Narita[1], Laurent Royon[2], François Lequeux[1] and Laurent Limat[2]

1 Sciences and Engineering of Soft Matter, UMR 7615 of CNRS and ESPCI

2 Matière et Systèmes Complexes, UMR 7057 of CNRS and University Paris Diderot.

Wetting phenomena exist widely from the nature to industry applications, such as sliding drops on lotus leaf, industrial coating. While many investigations have been done in illuminating either the droplet static or dynamic behaviors on rigid surfaces, a further understanding on soft substrates is still lacking. Here in the current studies, the wetting ridge, which is caused by the out-off plane surface tension in the vicinity of the contact line, is quantitively studied by a home made Schlieren setup. Silicone elastomers are employed here as candidates of soft gels. Aqueous glycerine droplets are applied to those surfaces in order to match the refrective index of a surrounding liquid, which allows us to visualize the ridge irrespectively of the drop configuration (that is made completely transparent by the index matching). The profiles of the surface deformations both inside and outside the droplet are recovered and further compared with theoretical predictions.

D2. Liquids of Active Disks : a review of recent experimental and theoretical results

Olivier Dauchot

EC2M, Laboratoire Gulliver – ESPCI ParisTech, France

Vibrated polar grains have proven to be an excellent system for investigating experimentally model systems of self-propelled particles. In this talk I will review well established as well as more recent experimental results, together with numerical simulations and theoretical analysis of this system. I will show how one can gain physical insight into the transition to collective motion of such system and finally present some new exotic behavior of such active particles.

D3. Real-time PIV for closed-loop flow control experiments and rapid investigation of a flow

Eliott Varon,[1, 2] Nicolas Gautier,[1] Jean-Luc Aider[1]

1 Laboratoire PMMH, CNRS, ESPCI, Paris, France
2 PSL, Paris, France

A high-speed implementation on a GPU (Graphics Processor Unit) of an optical flow algorithm is used to compute in real time 2D2C (2-Components in a 2D plane)velocity fields. It is called real-time PIV (Particle Image Velocimetry). The principle of the Lukas-Kanade algorithm used in these experiments is recalled. Its high scalability and flexibility are illustrated. Computation speed and accuracy are discussed. With a very simple and cheap setup (continuous 2W CW laser and low-cost 2M pixels high-speed camera) it is possible to compute 2D velocity fields in real time at a rate larger than 100 Hz. Much better performances can be obtained with a better GPUand / or a faster camera. Using this setup, it is possible to compute in real-time any quantities derived from an instantaneous 2D velocity field: velocity components, vorticity fields, Q-criterion, recirculation bubble of a separated flow, turbulent kinetic energy, etc. The instantaneous state of the flow can then be estimated in real time and used as an input for closed-loop flow control experiments. This novel approach has been applied to two types of shear flows: the Backward-Facing Step (BFS) flow and a boundary layer growing over a flat plate. It is shown that real-time PIV opens new perspectives for flow control but also for experimental fluid mechanics because of its instantaneous access to the properties and dynamic of a flow.

D4. Vitrimers a New Class of Plastic Materials

Max Rottger, Renaud Nicolaÿ, Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

A novel class of materials, coined vitrimers, has recently been discovered in the Soft Matter and Chemistry Laboratory. Vitrimers are unique networks capable of reorganizing themselves without altering their crosslinking density. These novel materials go from the liquid to the solid state or vice versa, yet they are insoluble. Most importantly, vitrimers are reshapeable at will and can be repaired and recycled under the action of heat. This property means that they can undergo transformations using methods that cannot be envisaged either for thermosetting resins or for conventional plastic materials. The first vitrimer materials developed in the laboratory were epoxy networks whose unique processing and recycling properties were relying on transesterification reactions. In order to extend the concept of vitrimers to a broader range of polymer matrices as well as to optimize processing and recycling conditions of these materials, the Soft Matter and Chemistry Laboratory is developing and testing new

dynamic covalent reactions compatible with vitrimer technology. In this lecture we will present our work on the synthesis and characterization of the next generation of vitrimers. The healability and recyclability of these materials will also be presented.

D5. The Role of Dynamical Heterogeneities on the Mechanics of Polymer Glasses

P. Shi, H. Montes, F. Lequeux*

Soft Matter Science and Engineering (SIMM, - UMR 761, ESPCI/CNRS/UPMC/ PSL Research University

If dynamical heterogeneities in glasses have been evidenced about 20 years ago, their roles on the mechanical properties of polymer glasses remain unclear. Here we study the mechanics of polymer glasses in their glass transition regime, and we reveal the importance of dynamical heterogeneities on their non-linear mechanics.

D6. Washing Wedges: a capillary instability

Ludovic Keiser, Rémy Herbaut, José Bico, Etienne Reyssat

PMMH – ESPCI ParisTech, France

When oil is introduced into a confinement gradient (two glass plates forming a horizontal sharp wedge), capillary forces drive it towards the most confined area, where the solid-fluid contact area is maximal. A soap solution subsequently introduced into the wedge follows the same steps until it makes contact with the oil previously added. If the aqueous phase wets the solid preferentially, a complex exchange process between oil and water occurs. The water-oil interface destabilizes, oil droplets form and migrate away from the tip of the wedge. The whole oil phase is eventually extracted. We present a linear stability analysis to describe this instability and use it to explain the size of the oil droplets formed. This model experiment may constitute a useful tool to select optimal systems for oil recovery processes.

D7. Fouling and Clogging in Microfluidic Channels

Cesare Cejas,[1] Fabrice Monti[1], Jean-René Authelin,[2] Jean-Pierre Burnouf,[2] Patrick Tabeling[1]

1 Laboratoire MMN, CNRS Gulliver, ESPCI, Paris, France

2 Département des Sciences Pharmaceutiques, Sanofi Recherche et Développement, Vitry sur Seine, France

Fouling is a phenomenon that results from the adsorption of protein molecules on microfluidic channel walls. The agglomeration of particles on the wall reduces the effective surface area for continuous suspension flow, thereby inducing clogging. Clogging not only significantly decreases the efficiency of delivery and administration of various suspensions but may also render microfluidic devices completely useless. Although it is a widely encountered problem, surprisingly physical mechanisms of this complex phenomenon are not very well understood. Therefore, it is important to characterize its behavior to improve relevant applications. Using model systems, we elucidate various subtle mechanisms that trigger

clogging events and develop a phase diagram of dominant clogging behavior as a function of controlled physical parameters such as concentration, pressure, particle size, and channel height. We describe these results using a simple physical model that takes into account particle motion near the wall. These results are first steps in acquiring an increased understanding of the events that cause clogging and hopefully provide insights into new techniques for optimum delivery of suspensions in microfluidic devices.

D8. Elastic Vitrimer Composites

Aurélie Legrand, Corinne Soulié-Ziakovic, Szilvia Karpati, Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

One of the current challenges of numerous industries such as aeronautics or automotive industries is to replace metals with lighter materials presenting similar mechanical properties. Composites based on thermosetting resins are currently widely used. However, once the resin is cured, it is impossible to reshape or repair them. Finding alternative systems has become a necessity and one possible solution could be provided by vitrimer based composites. Vitrimers, a new class of polymer materials, are made of molecular networks that can rearrange their topology by catalyzed exchange reactions without altering the number of links between their atoms. These materials are insoluble and exhibit dimensional stability of thermosets; yet at high temperatures when exchange reactions are fast they can flow like thermoplastics. Even more importantly, these networks show Arrhenius-like gradual viscosity variations. Their topology can be quenched and the material behaves as a solid even above a classical glass transition. Depending on the chemistry chosen, vitrimers at room temperature can resemble either hard or soft elastic solids. Our goal is to investigate the effects of dispersing colloidal particles on mechanical properties of vitrimers such as fracture resistance, elastic modulus, abrasion resistance, etc. This study focuses on reinforcing a soft vitrimer network by nano-sized silica fillers. The polymer matrix is an epoxy network undergoing catalyzed transesterification reactions and behaves like an elastomer at room temperature. In this poster, we present the synthesis and the functionalization of silica fillers, the processes and the characterization of their dispersions in the soft vitrimer matrix, and the mechanical properties of the so obtained nanocomposites.

D9. Traffic of E. coli bacteria in a confined flow

Nuris Figueroa Morales,[1,2] G. Miño,[3] A. Rivera,[3] R. Caballero,[3] E. Altshuler,[3] E. Clément,[1] A. Lindner[1]

1 PMMH, UMR 7636 CNRS-ESPCI-Universités Pierre et Marie Curie and Denis Diderot, Paris, France

2 "Henri Poincaré" Group of Complex Systems and Superconductivity Laboratory, Physics Faculty-IMRE, University of Havana, 10400 Havana, Cuba

3 Environmental Microfluidics Group, MIT, U.S.A.

We study quantitatively the migration of E. coli bacteria near the walls of confined microfluidic channels, and in more detail along the edges formed by the interception of two perpendicular walls. Our experiments establish the connection between bacterial motion at the surface and at the edges under varying applied flow rates and show the robustness of upstream motion at the edges. We quantify the bacteria fluxes along the bottom walls and edges and show that they result from both the transport velocity of bacteria and the decrease of surface concentration with flow rate. To do so, we measure the bacteria concentrations as a function of the applied flow rates at the bottom and top walls and at the edges of the channel. We discuss the typical erosion rates in terms of the hydrodynamic attractive forces and the

local values of the shear rate in a rectangular channel. We show that erosion of bacteria moving on the edges is slower compared to erosion from the bottom and top walls, due to the smaller local shear rate experienced by the bacteria at the edges and the stronger hydrodynamic interactions at the intersection between two walls. We show that the population of bacteria swimming upstream at the edges increases rapidly with increasing flow rate, and soon most of the bacteria are found to swim upstream. While bacteria transport at the bottom and top walls is dominated by the local shear flow, bacteria transport at the edges is mainly dominated by interaction between bacteria. At the edges, we find significantly higher velocities in bacteria swimming upstream than for the downstream swimmers. We are able to explain this phenomenon as a result of the frequent alignment process while bacteria switch direction from downstream to upstream, in addition to the decrease of speeds that takes place during collisions in this unidimensional corridor. As the population of upstream swimmers at the edges is larger compared to the downstream swimmer, the collisions are more frequent for the downstream swimmers, leading to a decrease of the mean velocity of the population. We show that upstream motion is possible not only at the edge, but takes place in an "active boundary layer" who's size varies with applied flow rate.

D10. Composite ceramic-hydrogel coatings for hydrogel implant

David Moreau[1,2], Arthur Villain[2], David N Ku[3], and Laurent Corté[1,2]

[1] Laboratoire Matière Molle et Chimie, CNRS UMR 7167, ESPCI-ParisTech, Paris, France

[2] Centre des Matériaux, CNRS UMR 7633, Mines-ParisTech, Evry, France

[3] George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA USA

The replacement of soft osteoarticular tissues by synthetic implants is often limited by a weak anchorage to bone tissues. One approach to reduce the encapsulation of the implant by a loose fibrous tissue and thus strengthen the bone-implant interface consists in functionalizing the surface of the implant by a coating of calcium-phosphate ceramics. To be efficient, these coatings should adhere firmly to the implant and resist to surgical handling and physiological solicitations during the implant lifetime. Here we propose a simple process to coat poly(vinyl alcohol) (PVA) hydrogel implants with hydroxyapatite (HA) microparticles. By means of a combination of dip-coating and physical cross-linking, a dense and homogeneous composite coating of HA particles embedded in a PVA matrix is produced at the implants surface. Microscopic observations and mechanical experiments show that it is possible to adjust the surface exposure of hydroxyapatite, the thickness and the robustness of the coating by varying the composition of coating solutions and the soaking conditions.

D11. Modelling 2D droplet displacement in a Hele-Shaw Cell

Benjamin Reichert,[1] Axel Huerre,[1] Isabelle Cantat,[2] Marie-Caroline Jullien[1]

1 Laboratoire de Microfluidique, MEMS, Nanostructures (MMN) – ESPCI ParisTech, France
2 Institut de Physique de Rennes (IPR) UMR CNRS 6251

Droplet-based microfluidics is a growing field often requiring an accurate synchronization for automated systems. It has been showed that confinement plays a crucial role in setting the droplet velocity. We have performed rational experiments for developing an accurate model. Indeed, the role of different experimental parameters (viscosity ratio, interfacial rheology, geometry of the Hele-Shaw Cell) has been addressed in order to elaborate a complete model that can be used as a reference to predict droplet velocity.

POSTERS

Auto-patterning on acrylate films

Jérémie Lacombe, Corinne Soulié-Ziakovic, Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

It has been found that some acrylate films obtained by photopolymerization possess some unique patterning at their surface. This patterning at a lengthscale of few hundred of micrometers appears spontaneously during the UV irradiation. Different kinds of patterns (random, lamellar, peanut, hexagonal) have been obtained by changing some relevant parameters such as the thickness of the film, the irradiation time, the monomer/crosslinker ratio…It is also possible to adjust the size of the patterns. Some factors have been identified to play a key role on the patterning process, including oxygen inhibition, reaction kinetics as well as the transfer reactions during the photopolymerization.

Toughening elastomers with sacrificial bonds

Pierre Millereau,[1] Etienne Ducrot,[1] Meredith Wiseman-M,[2] Markus Bulters,[2] Costantino Creton[1]

1 Laboratory of Soft Matter Science and Engineering, ESPCI ParisTech UPMC-CNRS

2 DSM Research, P.O. Box 18, 6160 MD Geleen, The Netherlands

Elastomers are widely used in the aeronautic and the automobile industries. They are often subjected to many mechanical stresses hence the desire to study and improve their mechanical properties. Nowadays, elastomers are commonly used with fillers to introduce large-strain reversible deformability. On the contrary, unfilled elastomers are known to present very poor mechanical properties. With the goal of using pure polymers in order to maintain specific properties such as transparency and resistance to temperature, we present a generic method to reinforce weak elastomers. In the past decade, Gong *et al.* have synthesized hydrogels formed with two interpenetrating networks with very different levels of crosslinking. Those double networks have significantly enhanced fracture toughness compared to a single network. This improvement is due to the breaking of the bonds of the more crosslinked and highly stretched minority network while avoiding crack propagation through the less crosslinked and unstretched majority network. This method has been applied to acrylic elastomers and has permitted reinforced double and triple networks with sequential swelling/polymerization steps. Those samples contain prestreched chains called sacrificial bonds that can break and dissipate energy before the material fails. The use of chemoluminescent cross-linking molecules, which emit a photon as they break, has allowed the mapping of the internal bond break ahead of the propagating crack. Here we propose to focus on the different mechanical properties that are given by those elastomers. Single-edge notch tests under different traction speeds and temperatures have been performed to give a better understanding of the properties of these materials. These systems are less sensitive to a change in respect to these parameters compared to what was observed in a common filled elastomer. Studies on different ratios of first to second network highlight the prominence of the prestreched parameter in the properties of the studied system. These results will be presented and developed on the poster.

Adhesion and self-adhesion of hydrogels filled by nanoparticles

Marie Gracia, Alba Marcellan, Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

Dispersing nanoparticles into hydrogel matrices is known to greatly enhance the stiffness and toughness of hydrogels. The reinforcement and toughening in these nanocomposite gels are related to the adsorption/desorption processes of gel strands onto nanoparticles, which then act as additional physical cross-links. The same principle of chain adsorption on nanoparticle surfaces was recently used to glue together two pieces of gel. Here, we investigate how this mechanism is involved in the adhesive properties of nanocomposite gels. Model nanocomposite hydrogels were prepared by dispersing silica nanoparticles into covalently cross-linked poly(*N,N*-dimethylacrylamide) (PDMA) hydrogel. The adhesive properties were quantified using a lap-shear experiment by pulling apart two ribbons of gel that were previously pressed together along a given length. For nanocomposite PDMA gels containing 0.2 volume fraction of silica nanoparticles, the adhesion energy to peel the ribbons is much higher than for unfilled PDMA gels. Measurements at various speed show that viscoelastic losses due to bulk rearrangement is a significant part of this energy. The interfacial contribution of adhesion is explored using a mixed geometry where a ribbon of nanocomposite gel is pressed onto a ribbon of unfilled gel. We find that adhesion significantly increases with contact time. Moreover, post-mortem observations of the peeled areas by scanning electron microscopy show that silica nanoparticles remained embedded into the unfilled gel. These results demonstrate that adhesion comes from a progressive reorganization of particles at the interface through dynamic adsorption/desorption processes and for high speed amplified by visco-elastic dissipation in bulk of nanocomposite gels.

Reinforcement mechanism of polymer modified bitumen

Lise Devès, Renaud Nicolaÿ, Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

In 2013, 112 million tons of bitumen was consumed worldwide. The consumption of emerging countries is still growing and thus, the global bitumen consumption is also expected to increase. Around 80% of the total volume of bitumen is used for paving. Pavements have to support a heavy traffic and their performances have to remain high on a wide range of temperature. Especially high stiffness at high temperature and flexibility at low temperature are requested. Several additives can improve the bitumen properties. Among them, polymers are well known to allow a better elastic recovery, a higher cracking resistance at low temperature and a higher rutting resistance at high temperature. Elastomers and plastomers are the main polymer modifiers used for pavements. The mechanism of bitumen reinforcement and the pros and cons of each polymer type will be discussed in this poster.

Curie transition in PVDF copolymers

François Bargain,[1] Sylvie Tencé-Girault,[1] Fabrice Domingues Dos Santos[2]

1 Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

2 Arkema- Piezotech CRRA, rue Henri Moissan 69493 Pierre-Benite

Among piezoelectric materials, polymers have the advantage of being easy to process compared to inorganic materials (single crystals, ceramics). They also allow manufacturing light, thin and flexible

devices. The thermoplastic semi-crystalline polymer Poly(vinylidene fluoride), -(CH2-CF2)n-, is the most studied piezoelectric polymer. It presents a polymorphism (α, β, γ and δ phases) but the ferroelectric and piezoelectric properties are characteristic of the β phase (all trans conformations along chains) which can be obtained only after stretching. This phase can also be obtained from the melt or by solvent cast of Poly(vinylidene fluoride – trifluoroethylene) -[(CH2-CF2)–(CHF-CF2)]n-. In this copolymer, the macroscopic polarization at room temperature, characteristic of ferroelectric material, disappears at the Curie transition around 100°C. This transition is a crystal-crystal transition from the ferroelectric phase (β phase) to a paraelectric phase (conformational disorder along chains). The study of the Curie transition is a way to understand the organization of copolymers in terms of chain conformations (trans/gauche) and crystallization and then a way to improve their performances. To do that, we performed in-situ Infrared spectroscopy (IR) and X-rays diffraction experiments (SAXS and WAXS) during the Curie transition in thin films of P(VDF-TrFE) 70/30 %mol obtained by solvent cast. We can correlate the trans/gauche conformations of the chains with the crystalline structure (crystalline ratio and cell parameters) with the morphology and with the thermodynamic parameters (transition enthalpy and heat capacity).

Vibrationnal and Elastic properties of a Faraday wave lattice

Lucie Domino, Malo Tarpin, Sylvain Patinet, Emmanuel Fort, Antonin Eddi

PMMH – ESPCI ParisTech, France

Faraday waves that appear at the surface of a vibrated liquid bath form an ordered 2D lattice of standing waves. Investigating the secondary instabilities of this regular pattern, we observed that the pattern oscillates slowly (compared to the forcing frequency) and that a single transverse mode, with a prescribed wavelength, growths over the entire lattice. This suggests that the selected mode is only one amongst a continuous collection of all the phonons that can present a 2D periodic lattice. We thus force the vibrations of the wave structure and reveal that a entire branch of phonons can be excited in the Faraday lattice. The striking point is that the phonons dispersion relation does not agree with surface wave propagation, revealing that a new physical mechanism is at play.

Turbulent bands in a planar shear flow without walls

Matthew Chantry,[1] Laurette Tuckerman,[1] Dwight Barkley[2]

1 PMMH – ESPCI ParisTech, France

2 University of Warwick

The banded structure of turbulence is observed immediately beyond transition in shear flows with two unconstrained directions. Yet despite its ubiquitous nature, the mechanisms underpinning bands are not understood to the level of localized turbulence in pipe flow. To this aim we investigate turbulent bands in Waleffe flow, a sinusoidal shear flow, U(y)=sin(pi/2 y), with stress-free boundary conditions at y=+-1. The existence of turbulent bands in this system demonstrates that walls are not necessary to induce the phenomenon. The structure of the bands in Waleffe flow closely matches those found in PCF. Utilizing the simple Fourier dependence of the Waleffe forcing we construct a model flow which uses only 4 Fourier wavenumbers in the wall-normal direction. This simple model captures the phenomenon of bands both in tilted and untilted domains.

Digital microfluidic for growing unculturable micro-organisms

Mathieu de la Motte Saint Pierre

LCMD – ESPCI ParisTech, France

99% of all the micro-organisms on earth are unculturable. That is to say that it is not possible to cultivate them in normal laboratory condition (in bulk in a rich media). We cannot make them grow because we do not know what conditions are needed for them to grow, maybe they need the presence of a specific molecule or they are outgrown by other species or they need to have an interaction with another micro-organism for them to grow. Until now it was the micro-organisms we wanted to grow that had to adapt to our culture media but now if we want to be able to cultivate other microbes we need to adapt our media to the specific micro-organism. Been able to cultivate pure culture of new micro-organisms is really needed to characterize them, "reading" their DNA is not enough to know them well. Growing new micro-organisms could make us understand what are the relations between different microbes in a given ecosystem as a lot of them grow only in such media. It could also lead to significant discovery in the medical field like new antibiotics as antibiotics can be found in metabolites made by microbes. To make this happen we will use two technologies that have been made up in the laboratory. The first one is a device that allow us to observe on the long term micro-droplets containing micro-organisms of interest. With this we can monitor up to 500 000 micro-reactors (the micro-droplets) to study the result of competition between micro-organisms. The second one is the production of micro-beads of alginate with micro-organisms inside that will allow us to co-culture the one we are interested in and therefore study the cooperation between different species.

Functional branched polymers by radical polymerization and thiochemistry

Coralie Teulère, Morgane Le Neindre, Renaud Nicolaÿ and Ludwik Leibler

Matière Molle et Chimie (MMC) – ESPCI ParisTech, France

The Soft Mater and Chemistry Laboratory recently developed a methodology that allows controlling the functionality and topology of copolymers using a single molecule. This approach relies on a monomer carrying a xanthate group that can be used to introduce both branching points and pending functional groups. The rational design of the xanthate monomer, as well as the synthesis and characterization of functional linear and branched copolymers will be presented. Parameters allowing to precisely control the degree of branching and functionality will discussed. An example of functional branched polymer carrying polymerizable units will also be presented.

Dynamics and mechanics of a dual cross-link gel

Jingwen Zhao, Costantino Creton, Tetsuharu Narita

Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

Self-healing dual cross-link poly(vinyl alcohol) (PVA) hydrogels can be synthesized by incorporating transient physical cross-links (borate ion) in a chemically crosslinked gel network. Previously the stress-strain relationship of their linear tensile properties was studied over a wide range of extension ratios and strain rates, based on which we proposed a new analysis method to separate the stress into strain- and

time- dependent terms. The connection between rate dependent mechanical behavior and kinetics of breaking and reattachment of temporary cross-links was quantified using a three-dimensional finite strain constitutive model. Reattachment of the chains contributes significantly to the overall stress of the dual cross-link gel and was described accurately in our model: the rate of healing is much faster than the rate of breaking. Here we report the linear viscoelastic properties of the hydrogels by oscillatory shear measurements in order to study quantitatively the breaking and healing dynamics experimentally. The storage and loss modulus obey the time temperature superposition principle, and the apparent activation energy and cross-linking enthalphy were calculated. The value of the breaking time is 20 times larger than the healing time, confirming the prediction by the constitutive model analysis.

Interdiffusion and Adhesion of Polymers at Short Contact Times

Robert Gurney

Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

The study of adhesion between soft polymers offers a means to understand contact formation, chain interdiffusion dynamics and interfacial separation mechanisms. The energy required to separate the interfaces is directly related to the contact time. While behavior at long (>1s) contact times is well understood, precise mechanisms for the initial moments of contact, and interdiffusion at very short times, remain unclear. In this work, we use a carefully controlled, custom-built adhesion testing device which allows a precise, short dwell time on the order of milliseconds to be applied during a contact adhesion experiment. The advantage of our experimental setup is precise control of many parameters, such as contact force, velocity, and control of dwell to times as short as 10 ms. This study is relevant for industrial applications in which surfaces must be adhered and a strong bond formed within just a short time of contact. The adhesive strength of uncrosslinked styrene butadiene rubber (SBR) is tested as a function of dwell time, molecular weight and filler content. The results will be discussed in relation to the rheological properties of the materials and the evolution of the separation mechanism with interfacial contact time.

Optical trapping reveals that the dynamics of hairpins is closer to equilibrium for DNA than for RNA

Mathilde Bercy

Laboratoire de Nanobiophysique – ESPCI ParisTech, France

Nucleic acid hairpins are common elements of complex secondary structure. Studies of their kinetic and thermodynamic properties can contribute to a better understanding of RNA assembly and of gene regulation processes that often involve DNA and RNA hairpins. In this work, we compared four different hairpin molecules, two DNA and two RNA ones, exhibiting a 13 base pair stem of identical sequence (Uracil replacing Thymine) and a single-stranded loop of 10 or 18 nucleotides. Using high-precision optical trapping, we measured force as a function of mechanical tension at various pulling velocities. The RNA hairpins unfold at higher force, as expected from the known fact that RNA is more stable than DNA. The force hysteresis increases with pulling speed for all hairpins, in accordance with theoretical prediction. Surprisingly, we observe that the RNA hairpins exhibit a much larger force hysteresis than their DNA counterparts. Attempt frequencies fitted to the DNA data exceed the corresponding frequencies of the RNA hairpins by an order of magnitude. Both DNA hairpins can flip with sub-second

dwell-times between folded and unfolded states when held under constant extension, while force flipping was not observable for the large-loop RNA hairpin.

The dynamics of semiflexible actin filaments in simple shear flow

Yanan Liu, Anke Lindner, Olivia Du Roure

PMMH – ESPCI ParisTech, France

In order to understand the relationship between microscopic structure of polymer and macroscopic properties of polymer suspension, we aim at observing the dynamics of individual deformable filament in different flow geometries as a first step. Semiflexible polymers can show various dynamics when submitted to flow-induced stresses, such as bending, stretching and tumbling whereas rigid fiber will only experience tumbling. Actin filament is a semiflexible polymer with a persistence length around 20 microns which can be fluorescently-labelled for observation. Thus we can have a direct visualization of the transport and deformation of single filament in the flow. This allows us to study the dynamics of semiflexible actin filaments in simple shear flow controlled through microfluidics tools. The intrinsic mechanical properties of polymers is given by the ratio of the contour length and the persistence length. Polymers are semiflexible when the contour length is comparable to the persistence length. Until now, we precisely measured the persistence length of actin filaments in solutions of increasing viscosities. We found, as expected, that this value does not depend on the viscosity and is 18.5_1 microns, in agreement with previous results. We expect the viscosity to have an influence on the timescale of the fluctuations. This study will be the basis to understand the complex behavior of such a deformable object in viscous flows. Previous works on the motion of actin filaments in simple or complex flows have described very interesting behaviors, which aroused our great interest to quantitatively study the transport and deformations, and their coupling, of filaments in simple shear flow.

Biocompatible stimuli-responsive emulsions stabilized by an amphiphilic copolymer for drug delivery systems

Marine Protat,[1, 2] Nadège Pantoustier,[2] Patrick Guenoun,[1] Patrick Perrin[2]

1 LIONS (Laboratoire Interdisciplinaire sur l'Organisation Nanométrique et Supramoléculaire), CEA Saclay

1 SIMM (Sciences et Ingénierie de la Matière Molle) – ESPCI ParisTech, France

Emulsions are very important phases in applied science due to the fact that they bring together two incompatible liquids and hence often lead to original dual properties. Multiple emulsions, water-in-oil-in-water or oil-in-water-in-oil, have potential industrial applications in pharmaceuticals, cosmetics or foods as drug delivery systems. For these applications, the control of both emulsion phase inversion and stabilization/destabilization processes under the action of stimuli is a major issue. Our team has recently developed a biocompatible emulsion system stabilized by amphiphilic diblock copolymers for which both emulsion type and stability can be controlled using pH, ionic strength or temperature as a stimulus. With this system, multiple water-in-oil-in-water emulsions are obtained in one emulsification step and stabilized by only one emulsifier. This leads to an enhanced stability of our multiple emulsions that are stable over several weeks and resistant to a significant increase of temperature. We now aim at using these emulsions to do encapsulation and controlled release of drug species.

Chemotaxis microfluidic chamber for the study of 3D migration of cancer cells

Koceila Aizel

LCMD – ESPCI ParisTech, France

The aim of this work is to enable the observation of the migration of cancer spheroïds in a 3D collagen matrix embedded in a PDMS microfluidic chamber undergoing a stable concentration gradient of growth factors to better understand the underlying mecanisms of metastasis.

Texture driven bouncing

Thibault Chastel, Anne Mongruel, Philippe Gondret

1 LCMD – ESPCI ParisTech, France
2 FAST

The dynamics of a sphere impacting a textured wall in a viscous fluid are investigated using high frequency laser interferometry. The wall is decorated with square micro-pillars. We show how the micro-textures affect the critical Stokes number for the bouncing transition. The contact is characterized by an indentation depth that depends on the texture's geometrical parameters. An elastic contact model is developed to describe this dependency.

Influence of the cross-linking density of PNiPAM microgels on the drainage dynamics of thin-liquid films

L. Keal,[1] V. Lapeyre,[2] V. Ravaine,[2] V. Schmitt,[3] C. Monteux[1]

1 Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France
2 ENSCPB, Bordeaux
3 CRPP, Bordeaux

Pickering emulsions stabilised with microgels formed from the thermosensitive polymer PNiPAM are both very stable and able to be destabilised on demand. The stability of microgel emulsions is linked to the properties of the thin films separating neighbouring droplets, but the dynamics within these films are not well understood. In order to study adsorption and drainage dynamics of these films a single thin film in air was examined with white light interferometry. Using a hydrostatic thin film balance setup the time evolution of the film thickness was studied for a set applied pressure. Softer microgels, those with a lower cross-linking density, have been shown to stabilise better than harder microgels, so two cross-linking densities of microgels were examined to explore the origin of this difference. Concentration was varied to control surface coverage. The influence of time allowed for adsorption before pressure drop was also explored. Results recover the increased stability of films formed from soft microgels, and of those with higher surface coverage. Mechanical stability of emulsions is reduced by adhesion between film surfaces. Films formed from lower concentrations or with harder microgels were more likely to exhibit sudden nucleation to adhesive bilayer or monolayer under pressure, accompanied by a large increase in plateau border contact angle. Film reswelling experiments confirmed adhesion for nucleated layers.

Real time tracking of metabolism and growth of single cells into a populations of engineered microbes within controllable and adjustable microenvironments using a microfluidic device

Krzysztof Langer, Adilya Timmers, Catherine Bonhomme, Laurent Boitard, Véronique Le Berre, Denis Pompon and Jerome Bibette

LCMD – ESPCI ParisTech, France

Observations made by Tao, Sylva and Morton suggest that engineered microorganisms frequently self-adapt. Such adaptations generally result in different growth rates and can have dramatic effect on microorganism behavior and productivity. From a molecular point of view, a wide range of mechanisms can be involved, including accumulation of mutations on engineered or endogenous genes, genome rearrangement or amplification, epigenetic shifts (including metabolic switches), but also can involve changes in non-genomic genetic elements like plasmid copy number. Traditional ways of analysis of these phenomena involves repeated dilutions and batch or continuous cultures followed by genetic and metabolic characterization of isolated clones. Developed at ESPCI, of innovative microfluidic device allows for real time and clonal (down to single cell) evaluation of metabolic and energetic balance shifts in microbes within easily controllable and adjustable microenvironment. It also offers a new and innovative approach to the question of real time tracking of metabolism and growth rate changes of cell populations. Most recent results on the topic will be discussed.

Crystallization of polar active disks

Guillaume Briand

EC2M, Laboratoire Gulliver – ESPCI ParisTech, France

Vibrated polar disks have been used as one of the first experimental system to investigate the transition to collective motion in active liquids. Here we consider the crystallization transition in such systems and compare it systematically to that of a system of isotropic vibrated disks, in the same experimental conditions. We will show that, while the isotropic disks exhibit a transition akin to the equilibrium crystallization of hard disks in two dimension, the polar self-propelled disks present a completely different transition scenario. We observe a phase coexistence between a liquid and a very dense, almost ordered closed-pack crystal and the complete crystallization apparently only happens for packing fractions very close to Ordered Closed Packings.

Influence of elasticity on superhydrophobicity

Martin Coux, Raphaële Thévenin, Christophe Clanet, David Quéré

PMMH–ESPCI, Laboratoire d'Hydrodynamique de l'X - Ecole polytechnique, France

When laid on a lotus leaf, a drop of water is very mobile: adhesion on the surface is very low. It also keeps the spherical shape it has during a free fall. It has been shown that these phenomena express superhydrophobicity, which is due to the hydrophobic microstructures on the leaf. The surface of the leaf presents textures, in the order of magnitude of 10 to 20 microns. Materials with micrometric hydrophobic pillars can be created; for almost twenty years such artificial superhydrophobic surfaces have been fabricated and studied. Playing on the geometry of the textures is a way to tune the water-adhesion

properties of the surfaces. For instance, a drop on a higher pillar density will tend to stick more to the material. In this study, we examine the influence of the elasticity of the surface. For this purpose, we produce materials made of PDMS with different crosslinking degrees. PDMS is a silicone-based organic polymer, which elastic modulus can be tuned over one order of magnitude, from 100kPa to 1MPa. Surprisingly, our results show that water presents the lowest adhesion on softer surfaces. Furthermore, the Cassie-Baxter state is as stable on these surfaces as on tougher ones. SEM observations and fluorescent tagging on these different materials allow us to show that the change of adhesion properties is mainly due to the evolving shape of the surface textures: more elastic structures tend to bend, and to present blunt edges on which the contact line grips less.

Hydrogel fibers for ligament reconstruction

Laurent Corté

Laboratoire Matière Molle et Chimie, CNRS UMR 7167, ESPCI-ParisTech, Paris, France

Centre des Matériaux,CNRS UMR 7633, Mines-ParisTech, Evry, France

Rupture of the anterior cruciate ligament (ACL) is one of the most common injuries of the knee and several 100,000 ACL reconstructions are performed each year in the World. A prosthetic device could alleviate various drawbacks associated with the current replacement options, specifically autografts and allografts. Still, most previous prosthetic ACLs have been unsuccessful due to mechanical failure or chronic inflammation and the clinical gold standard remains autograft reconstruction. An interesting new perspective for soft-tissue reconstruction is offered by hydrogels, which exhibit unique biocompatibility and self-lubrication performances. In particular, hydrogels of polyvinyl alcohol (PVA) form non-degradable biocompatible hydrogels and have already shown a high potential in several soft-tissue replacement applications including cartilage or vein-valve. For ligament implants however, they are limited by insufficient tensile properties and their use is usually restricted to embedding or coating of a “dry” polymeric fibrous construct. In this work, we take advantage of the strong macromolecular orientation of PVA fibers and show that pure hydrogel implants can be achieved exhibiting a water content (~40-60wt%) and a mechanical behavior close to those of native ligaments. Both pure PVA ropes and composite ropes made up of PVA and ultrahigh molecular weight polyethylene (UHMWPE) fibers exhibited a tensile behavior close to that of the native ACL. Composite ropes of PVA and UHMWPE fibers provided a safety factor with tensile strength over 2000N. Moreover, the design of the construct can be adjusted to reproduce the non-linear elasticity with a toe region that is preferred for ligament reconstruction. This promising mechanical performance and other preliminary results provide a strong incentive to pursue more extensive evaluation including the in-vivo resistance to fatigue and anchoring to bone tissues.

An investigation into the mechanical behavior of PVA hydrogel fibers

Julien Caroux, Laurent Corté

Laboratoire Matière Molle et Chimie, CNRS UMR 7167, ESPCI-ParisTech, Paris, France

Centre des Matériaux,CNRS UMR 7633, Mines-ParisTech, Evry, France

Hydrogels of polyvinyl alcohol (PVA) have shown excellent biocompatibility and functional capacity in several soft-tissue replacement applications like the replacement of articular cartilage for example. Recently, it was shown that spun fibers of PVA can swell to form PVA hydrogel fibers that match closely the water content (50wt%) and mechanical behavior of ligaments. In this study we characterize the mechanical behavior of PVA hydrogel fibers and explore how it can be tuned by thermo-mechanical

treatments. Combining microscopic measurements and tensile testing in water on single fibers, we analyze the effect of spinning conditions and annealing on the swelling and tensile properties. Under repeated loading-unloading cycles, PVA hydrogel fibers exhibit a rubbery behavior with elasticity up to large strain (>60%). Furthermore, we find that the stiffness of hydrogel fibers can be significantly increased by the proper combination of annealing and stretching. This effect is attributed to changes in the macromolecular orientation and swelling ratio. These results support ongoing studies aiming at the design of artificial ligament substitutes from assemblies of PVA hydrogel fibers.

Stimuli responsive hydrogel with host guest complex

Matthieu Fumagalli,[1] Dominique Hourdet,[1] Alba Marcellan,[1] Khaled Behlal,[2] Patrice Woisel,[2] François Stoffelbach[3]

1 Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

2 UMET Université Lille

3 LCP UPMC

Hydrogel – polymer networks swollen in water – include a wide number of biological and industrial materials with interesting rheological and mechanical properties. The developpement of stimuli responsive materials, whose properties can be tuned by an external trigger, is an important challenge in this field. In the present work, we have introduced onto a polydimethylacrylamide backbone, naphtalene lateral groups that can act as a guest molecule into a cyclobis(paraquat-p-phenylene) host molecule. We highlight how such host guest complexation is able to modify the swelling level of reticulated hydrogels and the rheological properties of polymer solutions.

Adhesion and Fracture of Soft Materials

Costantino Creton, Matteo Ciccotti, Dominique Hourdet, Yvette Tran, Alba Marcellan

1 Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

Soft polymeric materials are materials with a low shear modulus relative to their bulk modulus and where elastic restoring forces are mainly of entropic origin. A sparse population of strong bonds connects molecules together and prevents macroscopic flow. In this poster we show some examples of how these soft materials break and detach from solid surfaces. We focus on how stresses and strains are localized near the fracture plane and how elastic energy can flow from the bulk of the material to the crack tip. Adhesion of pressure-sensitive-adhesives, fracture of gels and rubbers are specifically addressed. The most important length scale in these problems is the elasto-adhesive length G/E where G is the fracture energy and E is the elastic modulus. The ratio between sample size and G/E controls the fracture mechanisms and we investigate them by using theoretical concepts bridging solid mechanics, polymer physics and polymer chemistry.

Fabrication and applications of new magnetic micro-objects and patterns

Julien Heuvingh

PMMH – ESPCI ParisTech, France

Rigid-body behavior of "softly interacting" elements

Ken Sekimoto

MSC-Paris7/Gulliver-ESPCI

Cavity-averages in the presence of polydispersity and incomplete data

Michael Schindler

Laboratoire de Physico-Chimie Théorique, Laboratoire Gulliver – ESPCI ParisTech, France

Pénétration d'une tige flexible dans un milieu granulaire

Nicolas Algarra,[1] Tristan Deleplanque,[1] Pascal Kurowski,[1] Damien Vandembroucq,[1] Arnaud Lazarus,[2] Evelyne Kolb[1]

1 PMMH – ESPCI ParisTech, France
2 IJLRA

Pénétration d'une racine dans un tube élastique

Tristan Deleplanque,[1] Nicolas Algarra,[1] Pascal Kurowski,[1] Damien Vandembroucq,[1] Arnaud Lazarus,[2] Evelyne Kolb[1]

1 PMMH – ESPCI ParisTech, France
2 IJLRA

Polymer assembly at liquid interfaces: one-step encapsulation

Julien Dupré de Baubigny

Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France

Non local rheology for dense granular flows in avalanches

Adrien Izzet

PMMH – ESPCI ParisTech, France

A molecular level improvement of N_2/CH_4 separation by polyimide membranes

Ioannis Tanis, David Brown, Sylvie Neyertz

Laboratoire de Physico-Chimie Théorique, Laboratoire Gulliver – ESPCI ParisTech, France

Présentation du pôle de compétitivité Elastopôle

Jean-Louis Halary

Soft Matter Sciences and Engineering (SIMM) – ESPCI ParisTech, France