Babeș-Bolyai University

Faculty of Physics

PhD Thesis Summary

A depinning approach of amorphous plasticity and dewetting

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CLUJ-NAPOCA 2016

Contents

Abstract

In the present thesis, two disordered systems are investigated from the depinning perspective. In both of them, the dynamics is governed by the competition between elastic interactions and a disordered landscape. In the first part, we use a simplified mesoscopic model to investigate the generic properties of amorphous plasticity. The yielding of amorphous materials shows universal properties similar to the depinning transition. As such, it is often described by mean field approaches. Here we show that the soft modes present in the interaction kernel have a dramatic impact on localization and result in diffusively increasing plastic strain fluctuations which ultimately lead to failure. This additional phenomenology is absent in depinning and, despite its important consequences, is disregarded in mean field descriptions. We show that shear bands are soft modes of the Eshelby interaction kernel and, besides localization, they affect the universal properties as well. At the same time, we found by testing two extreme cases that the form of disorder has no considerable impact on the universal properties. As an application, we show that the reinforcement of amorphous materials by hard inclusions is related to the percolation of shear bands in between the inclusions. In the second part, we study the morphology of a receding dewetting line on inhomogeneous surfaces. Unlike in standard depinning models, here we developed a method suitable to describe the large deformation regime of the contact line and tearing up of the layer. We show the existence of a threshold concentration of inhomogeneities. Above this concentration the line stops within at finite distance, and around the critical concentration it features critical-like properties.

1 Overview

Theoretical foundations of the mechanical properties of crystalline solids are nowadays well established. The ordered structure of these materials allowed for the development of dislocation theories that are by now confirmed by both simulations and experimental methods [12]. A considerable part of the materials, however, does not exhibit such a structural order. Examples include amorphous materials as glasses, but also larger scale amorphous systems such as pastes, foams, colloids or granular material. The mechanical response of amorphous materials, in particular, glasses is less understood, mainly because of the lack of suitable experimental devices: their intrinsic brittleness makes standard macroscopic mechanical tests extremely difficult. Another source of experimental difficulty is that in some of these materials, for instance, structural glasses, plasticity usually manifests at very small scales [33].

Mechanical properties of amorphous materials are more complex on the microscopic scale than their crystalline counterparts due to the lack of long range order. Indeed, in contrast to crystalline solids, disorder eliminates by nature the notion of isolated defects.

In the case of amorphous materials disorder excludes dislocations as an elementary plastic mechanism, moreover, makes extremely difficult to capture the statistics behind these microscopic processes, a difficulty that delayed the proposal on such an elementary mechanism 40 years after the idea of dislocations was introduced [12]. It was not until the late '70s that A. S. Argon came up with the concept of local, slip-like rearrangements of atoms as the elementary process of plasticity in amorphous materials called *shear transformations* [4].

Over the past two decades it has gradually become clearer that many amorphous systems share similar phenomenology at very different scales: model glassy systems [31], metallic glasses [3] bubble rafts [5] and colloids [34, 2]. First, they all flow above a threshold stress. Unlike in fluids however, this flow is not smooth, but is governed by sudden, avalanche-like stress drops and features scaling properties (Figure 1). This complex rheology is believed to be governed by the collective effect of the interacting local rearrangements that have been observed in all these materials. The identification of the elementary processes of plasticity at lower scales has therefore tremendously benefited from larger scale experiments [34, 2, 25, 26, 5].

This common, apparently universal phenomenology as well as the puzzling scaling behavior around yield naturally led to the conjecture that the yielding of amorphous systems is potentially a dynamic phase transition [8, 27].

As such, it shows striking similarities with other dynamic transitions including earth quake phenomena [6] and line depinning [24]. In each of these systems the individual elements follow a stick-slip dynamics and below a critical forcing the system stops, while above the critical forcing it moves indefinitely. A dynamic phase transition then occurs at the critical forcing accompanied by scaling and cascade events. In the introductory chapter 1 we discuss the critical nature of the yielding transition and its similarities with depinning

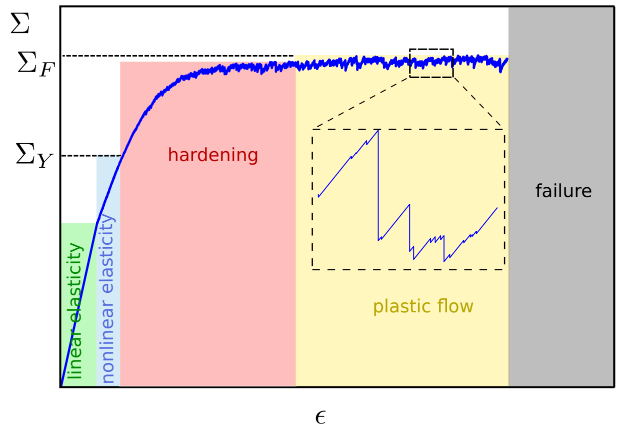

Figure 1 – Typical yielding of solids. At small strains the material deforms reversibly, at further load however it yields and eventually fails. The flow is governed by sudden stress drops and results in a serrated stress-strain curve.

[24], another system exhibiting dynamic transition.

Dynamic phase transitions thus show universal behavior, a phenomenology that is independent of the details of the particular system. Systems at very different scales ranging from charge density waves through dewetting fronts up to earthquakes can manifest in the very same behavior [7, 6]. This universality allows for the construction of simple, almost toy models that reproduce the universal properties, simply because they are insensitive to the very details of the system and thus the model.

Now, if yielding of amorphous materials is indeed a dynamic transition, can simple models reflect its universality? In particular, do the details of these models matter? Many such models have been developed [5, 16, 20, 35, 15] based on the shear transformation picture, considering a mean field interaction between the shear transformations, arguing that as long as we deal with universal properties, the actual form of the interaction is an irrelevant detail. Recently introduced mesomodels based on realistic interactions between the shear transformations started to elucidate that the actual form of the interaction affects the critical behavior [36, 37, 27, 28, 8, 32]. These mesomodels are oversimplified models of amorphous media and most of them are scalar, nevertheless, they are able to reproduce a series of generic properties of amorphous plasticity. We discuss the main idea behind these models in chapter 2.

The elastic interactions associated to the particle rearrangements are highly anisotropic. This anisotropy favors the accumulation of the plastic activity along certain direction leading to shear banding. Persistent shear banding, in turn, leads to fracture nucleation hence the failure of the material. As localization is the main obstacle of improving the strength of amorphous materials [33], its effects cannot be simply neglected by a mean field approach.

We address this issue in chapter 3, where we show that the anisotropy of the interaction indeed leads to the localization of the plastic activity which has a dramatic impact on the fluctuations. We show in particular, that the peculiar interaction between the shear transformations allows for deformation modes at no energy costs. These modes can then develop indefinitely and their diffusion governs the dynamics of amorphous systems. In chapter 4 we further explore the way localization affects scaling properties including finite size fluctuations in amorphous systems and relate the scaling to molecular dynamics simulations. Localization and diffusion are features that are completely absent from the standard depinning phenomenology.

In amorphous systems, localization of plastic activity along shear bands is associated to the brittleness and failure of the material [25] and this failure is a serious limitation of the usability of amorphous materials, in particular, the newly developed metallic glasses as structural materials [29, 14, 30]. Recently it has been shown that the nucleation and propagation of shear bands can be controlled by introducing inclusions of a different composition into the amorphous bulk [1, 21, 19], the potential applications of these composites are thus countless. While several homogenization techniques are available to predict the effective mechanical properties of such composite materials [13, 39, 38], they all focus on the averages properties. Due to the underlying dynamic transition however, close to criticality, the importance of fluctuations is crucial. These fluctuations lead to considerable finite size effects that cannot be captured by standard homogenization methods. On the other hand, the newly developed family of mesomodels [36, 37, 27, 28] has been inherently designed to account for fluctuations, hence they are good candidates in investigating such finite size effects. In chapter 5 we use a mesoscopic model to investigate finite size scaling in an amorphous composite and we show that reinforcement is related to the percolation of shear bands through the inclusions, as well as that hard inclusions may block the propagation of shear bands, reinforcing the material.

From the material science point of view, there is a constant need for newer techniques in tailoring structural materials with imposed mechanical qualities. Understanding localization and the intrinsic universal properties is thus the first step towards the development of structural materials with enhanced mechanical characteristics.

The present thesis has been carried out within the framework of a joint program between ESPCI Paris and UBB Cluj and extensive collaboration with NEU Boston. Accordingly, it consists of two parts. In the first part (chapters 1-5), we investigate the universal properties of amorphous materials at the yielding transition from the depinning perspective, a phenomenology arising from the competition between elasticity and disorder.

The second part of the thesis introduces a new disordered system. In chapter 6 we investigate the dynamics and roughening of a receding dewetting line on inhomogeneous surfaces. The phenomenology of dewetting on a disordered surface is often related to depinning since the roughening of the contact line is a result of the competition between the pinning of inhomogeneities and the long range elastic forces acting on the line. These elastic forces originate from the surface tension and are usually accounted for in a perturbative treatment [17, 11, 23, 22, 9, 18] under the approximation that the deformations of the contact line are small. While such a framework has been successful in reproducing some features of the contact line morphology, for instance, roughness exponent [10], it does not aim to address the phenomenology associated to large deformations.

Unlike in the standard depinning approach of dewetting [17] where long range elastic interactions are considered along the contact line, here we consider a soft line that allows for large deformations and even the tearing up of the layer. We develop a novel, simplified model of dewetting to investigate the contact line dynamics and morphology when the line can undergo large deformations. Although the method is not a standard depinning model, we find that the system exhibits critical-like properties around a threshold concentration of inhomogeneities.

The work behind this thesis lead to the following publications in peer-reviewed journals: [41, 40, 42]. In the following we summarize the content of each chapter and our conclusions regarding the results.

2 Chapter 1: Introduction

The introductory chapter aims to present the phenomenon of plastic deformation of amorphous materials through the review of previous scientific results. First, we examine the most relevant phenomenology to our subsequent work regarding the plasticity of amorphous materials, in particular, glasses. We then introduce the main ideas and methodologies behind the multiscale modeling strategy of amorphous plasticity starting from molecular dynamics methods, through coarse grained models up to constitutive models. Finally, we review the scaling properties of amorphous systems underlining in particular the links between the phenomenology of amorphous plasticity and the depinning transition. Emphasizing at every stage of this literature review the questions that are still open, we justify our approach and the methods that will be implemented in this thesis.

In this chapter, we introduce the general phenomenology of amorphous plasticity. We discuss that plasticity in amorphous materials takes place under the form of localized rearrangements of several particles. The large scale dynamics is governed by the collective behavior of the rearrangements. The phenomenology is then the result of the competition between elasticity and disorder. In this context, yielding of amorphous materials is very similar to the depinning transition. In addition to depinning however, amorphous materials show striking localization which ultimately leads to fracture nucleation. Constitutive laws focus on effective properties, disregarding the importance of localization. Molecular dynamics methods on the other hand do not allow for fine-tuning between the nature of disorder and the elastic interactions. The newly developed family of mesomodels was designed to address this issue, by coarse graining the material, yet keeping the elastic interactions. These models thus allow for fluctuations and localization, they are therefore promising in modeling the shear banding behavior and the associated brittleness of amorphous materials. The next chapter is dedicated to presenting the idea and methodology behind these mesomodels.

3 Chapter 2: Mesoscopic models

In the previous chapter we discuss the phenomenology of amorphous plasticity and we conclude that the yielding transition shows critical behavior, similar to the depinning transition. Nevertheless, localization is a key feature in amorphous plasticity that is completely absent in depinning. In the following chapters we investigate the localization of the plastic activity in amorphous systems and the effect of this localization on the universal properties. Since we are interested in generic properties that are independent of the very details of the system, we use mesoscopic models that are expected to reflect such a universal behavior. Nevertheless, as we show, some of the details of these models, in particular the form of the elastic interaction does have a considerable impact on the generic properties. In this chapter thus we review the main ingredients of mesomodels with emphasis on what of these ingredients impacts universal properties.

Throughout this chapter we show that an increasing number of mesoscopic approaches have been implemented. These mesomodels intend to model the universal behavior of amorphous systems. While some of the implementation details are irrelevant to the phenomenology (loading type, lattice type) other details do matter.

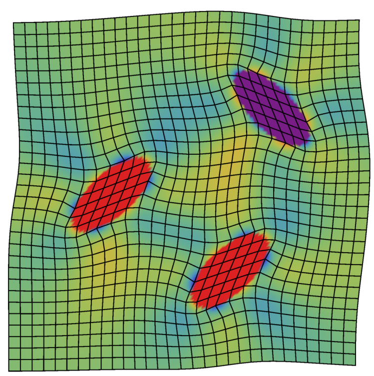

Figure 2 – Interacting ellipsoidal Eshelby inclusions. On the figure, the main direction of the eigenstrain is the same for each inclusion. Colors indicate the shear stress. Note the quadrupolar symmetry in this particular arrangement: the induced stress is positive along the 0 and $\pi/2$ directions, but is negative along the $\pm\pi/4$ directions. Moreover, the stress induced by an ellipsoidal inclusion undergoing a homogeneous deformation is homogeneous within the inclusion.

In particular, the key concept behind any of these models is the elastic interaction between the elastoplastic blocks and disorder resulting from the amorphous structure. The former is usually modeled via material Eshelby inclusions, as shown on Figure 2.In the subsequent two chapters we focus on the effect of these two ingredients. The topic of the next chapter is the impact of the elastic kernel on the universal properties of amorphous systems, focusing on fluctuations. We have shown that disorder is related to the distribution and spatial correlations of the underlying potential landscape. The effect of disorder on scaling properties will be investigated in chapter 4.

4 Chapter 3: Building elastic kernels: all about Eshelby

In the previous chapter we address the two key concepts associated to the mesoscale description of amorphous plasticity: elastic interactions and disorder. The aim of this chapter is to study the first one: we show that the usage of a particular kernel has a dramatic impact on the universal properties. Consequently, the yielding transition does not fall into the mean field universality class. The reason for this difference lies in the inner properties of the elastic kernel that allows for localization. These properties, namely the possibility of soft deformation modes are particularly sensitive to the construction of the kernel. In this chapter thus we first review the various strategies used to build such a kernel and then test the impact of the actual kernels to the fluctuations. Fluctuations are traditionally downplayed in engineering studies and only effective properties as considered. The yielding transition however shows critical properties, including correlated, large-scale fluctuations. The importance of these fluctuations cannot be disregarded as these are the ones leading to material failure. In this chapter we show that the peculiar form of the Eshelby kernel

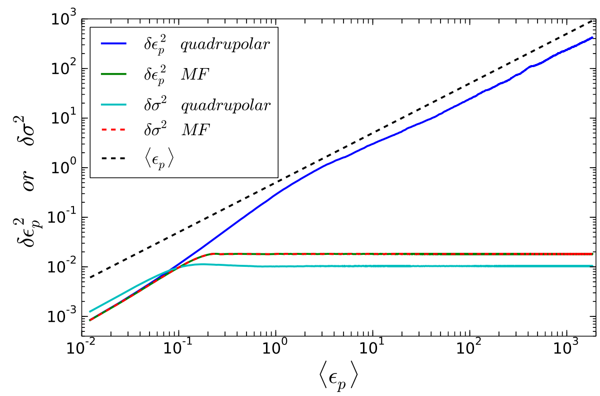

Figure 3 – Strain and stress variances for the mean field and the Fourier quadrupolar kernel. Straight dashed black line indicates diffusion. Stress fluctuations saturate for both the mean field and the Fourier quadrupolar kernels, as well as strain fluctuations for the mean field kernel. On the other hand, strain fluctuations converge towards a diffusive regime for the quadrupolar kernel.

associated to the atomic rearrangements in the mesomodels gives rise to the localization of the plastic activity and a diffusive increase of strain fluctuations (Figure 3). At short time scales, localized plastic events rule the dynamics, at longer scales however shear bands develop. The localization along shear bands takes place because these bands can form at no excess energy cost. Deformation can thus be trapped for long times along the bands giving rise to constantly increasing fluctuations. The dynamics is then governed by the loose coupling between the individual bands. It is therefore likely that, one step further from the Eshelby inclusions, amorphous plasticity can be regarded in the new framework of the interplay between disorder and the loose elastic coupling between individual shear bands.

Such a localization is not possible in classical depinning problems with mean field or isotropic interactions. While shear bands are soft modes of the Eshelby kernel, we show that their presence may be erroneously suppressed in the kernel by the particular discretization. Soft modes of the elastic kernel allow for strain localization and constantly increasing strain fluctuations which ultimately leads to crack nucleation and material failure. Controlling shear band formation is therefore the first step in suppressing crack nucleation and reinforcing fragile amorphous materials.

5 Chapter 4: Scaling properties and finite size effects

The mesoscale description of amorphous plasticity results from the interplay of elasticity and disorder. In the previous chapter we play with the elastic interaction and put in evidence the importance of soft modes and we conclude that they have a dramatic effect on strain localization, plastic strain fluctuation and their presence may even affect the universality class in the depinning picture. Here, besides the kernel, we explore the impact of the disorder on the scaling properties. We focus on the avalanche rate distribution and displacement fluctuations and relate the results to former athermal quasistatic molecular dynamics studies, with special attention to finite size effects.

As the ultimate goal of mesomodels would be to provide a quantitative upscaling, quantitative connection to molecular dynamics is indispensable in the long run. The extent to which the details of the various mesomodels matter is yet unclear and the first step towards the elucidation of the question is to test the way the model details affect universal properties. If the universal properties seen in experiments or molecular dynamics simulations are not reflected in the mesomodels, there is no way they could give quantitative results on non-universal properties, hence mesomodels cannot serve as the Ising model of amorphous plasticity until the effect of various details is well understood.

In this chapter thus we emphasize the impact of disorder on fluctuations and scaling properties. We consider two extreme cases of the disordered landscape: distributed height but fixed width or distributed width but fixed height of the potential barriers. Moreover, we focus on relating critical exponents describing the finite size scaling of avalanche statistics and diffusion coefficient in these mesomodels to their MD counterpart.

We find that the hypothesis that avalanches in amorphous media follow slip line (narrow shear band) like patterns is consistent with the observed finite size scaling. Short term diffusive behavior is governed by the rare kicks of individual slip lines, which is confirmed by the finite size scaling of the diffusion coefficient. At long times, diffusion is governed by the collective effect of diffusing shear bands which leads to non-trivial scaling of the diffusion coefficient. The next step would be to carry out a systematic spatial correlation analysis on the strain or displacement patterns in individual avalanches.

Long time behavior is sensitive to the kernel (no soft modes - no diffusion), however the proper symmetry of the kernel and soft modes alone are not enough to reproduce the right universality class. On the other hand, all the universal properties are robust with respect to the protocol. While a realistic disordered landscape (threshold and slip amplitude distribution) has yet to be gathered from MD, we do not expect that it would have considerable impact on the universal properties.

6 Chapter 5: Application to amorphous composites

In the previous chapters we show that the elastic interaction kernel associated to rearrangements in amorphous materials features soft modes that lead to localization and anomalous strain fluctuations. This shear banding and the associated increased fluctuations are at the origin of the brittleness of amorphous materials, for instance, glasses. Recent experiments have shown that shear banding can be controlled by the introduction of a second phase into the amorphous bulk [21]. The role of this second component is to block the development of shear bands. Such composite materials then become reinforced. In this chapter we use the mesomodel with extremal dynamics and the Fourier stress redistribution kernel to model the reinforcement of amorphous materials by hard inclusions. Hard inclusions are modeled as any other lattice site, but with higher yield thresholds. With this simple modification we investigate the flow stress increase with the hard inclusion concentration and explain the observed finite size effects by a simple analytical model based on strain localization, more precisely the percolation of shear bands in between hard inclusions.

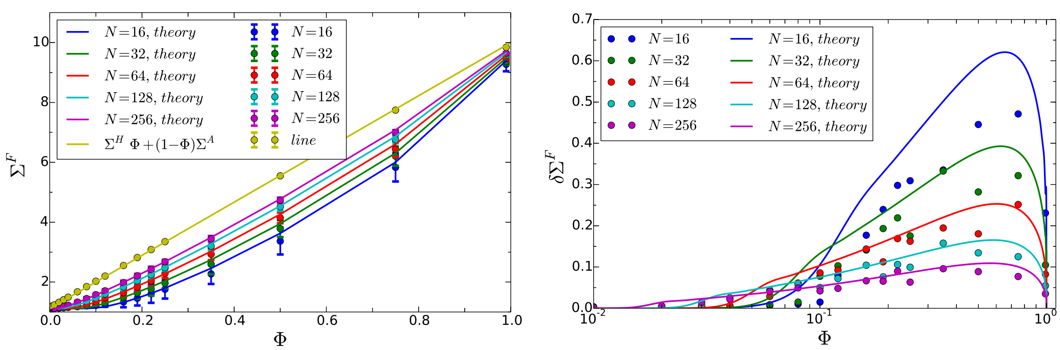

Figure 4 – Left: Exact analytical predictions of the flow stress concentration dependence based on the weakest band model. The linear mixing law describes the reinforcement of a one dimensional depinning line. Right: Analytical predictions of the flow stress fluctuations. Since our approach assumes that the positions of the inclusions are independent, it tends to overestimate fluctuations. As the system size (and thus, at constant concentrations, the number of hard sites) increases, the hypergeometric distribution of dependent draws converges towards our assumed binomial distribution of independent draws, consequently the estimation works better for larger systems.

We find that the plastic behavior in amorphous composites shows two types of system size dependence: one associated to the amorphous matrix as described in [37] and another one associated to the hard inclusions. While the former results in an $1/N$ dependence of the flow stress with the system size, the latter predicts a size dependent threshold concentration below which no reinforcement is observed. The threshold concentrations corresponds to the percolation of shear bands through the system within the hard inclusions. Above the threshold concentration, the distance of the flow stress to a linear mixing law scales as $(\log N/N)^{1/2}$ and the flow stress increases with the system size. The linear mixing law then gives an upper bound to the flow stress. We show that the increase in the flow stress is associated to the breakthrough of the weakest shear band over hard sites and the flow stress value is governed by the accumulation of plastic activity along the weakest band. Finally, we develop a simple model based on the weakest shear band hypothesis that turns out to predict well the flow stress value, its size dependence and even the flow stress fluctuations.

7 Chapter 6: Soft line in quenched disorder

In the first part in the thesis we show that the yielding transition of amorphous materials has many features in common with the depinning transition of elastic lines. Both phenomena are a result of the competition between disorder and long range elastic interactions. In that sense, many systems can be modeled in the depinning framework. For example, the roughening of a moving dewetting contact line on inhomogeneous surfaces is governed by the competition of the surface tension forces and the pinning-like interactions with the inhomogeneities of the surface. This roughening process has been intensively studied in the depinning framework. As we show however, the depinning framework is limited to linear interactions, thus small deformations only. Moreover, standard depinning methods do not allow for the eventual tearing up of the layer due to large deformations.

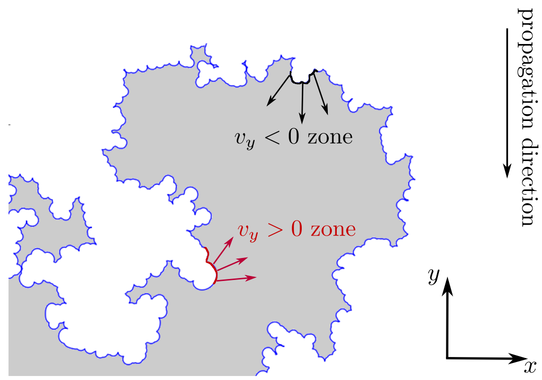

Figure 5 – An example from computer simulations where local backward movement of the interface occur. The liquid layer sketched in gray contracts by moving in the bottom direction (negative direction of the y axis). Due to the highly deformed shape of the interface, there will be parts of the interface where the velocity vector of the interface will have a positively oriented y component.

In this chapter, we precisely address these two issues. We develop a depinning-like model which aims to capture large deformations and eventual tearing up of the liquid layer (Figure 5). We show that there exist a critical concentration of inhomogeneities below which the line stops within a finite distance, and above this concentration it moves indefinitely. Right at the critical concentration however large deformations of the line occur with long correlations which may be the footprint of a peculiar depinning-like transition.

A novel and efficient off-lattice simulation method, resembling the classical molecular dynamics, is introduced for investigating the dynamics of thin and viscous liquid layers, dewetting on inhomogeneous surfaces. By using this simulation method the existence of an unusual depinning-like transition is revealed. This transition is governed by large deformations of the interface and the breaking up of the layer. The two-dimensional parameter space of the investigated system is explored, and the obtained results are discussed in view of available experimental observations. We learn that the contact line's dynamics is a result of an interplay between the capillary forces and the substrate disorder, however, with the appropriately introduced adimensional form, both relevant parameters are related to the inhomogeneities. In such an approach, the universal properties of the contact line can be viewed as a result of the competition between the inhomogeneities strength and their density. The difference between the dynamics of a receding and an advancing contact line (dewetting vs. wetting), other than the contact angle hysteresis, remains an open question and could be investigated in the future by rigorously introducing pressure in our model.

8 Conclusions and perspectives

Throughout this thesis, we study two disordered systems from the depinning point of view. The complex phenomenology in these systems stems from the competition between disorder and the elastic interactions between regions in the system.

In the first part, we examine the generic plastic properties of amorphous systems via a simple mesoscopic model. We show that the threshold dynamics is a natural consequence of the multistability arising from the competition between elasticity and the underlying disorder and local thresholds are related to the heights, whereas plastic slip amplitudes are related to the widths of the disordered potential wells. Accordingly, we consider two extreme cases of the disorder (distributed barriers or distributed positions of wells), and we find that generic properties are unaffected by the particular form of the disorder. This has yet to be confirmed by intermediate cases, namely by gathering the precise distributions of thresholds and slip amplitudes from molecular dynamics, however, based on our results, we do not expect considerable change in the universal properties.

While the yielding of amorphous materials is, in many aspects, similar to the depinning transition, we found that plastic yielding is not depinning. Consequently, mean field approaches are insufficient to fully describe the yielding transition. Amorphous plasticity shows additional phenomenology compared to depinning such as localization and diffusive fluctuations. We show that the existence of soft modes in the anisotropic elastic interactions at play in amorphous plasticity are at the origin of these extra features. Soft modes allow for the constant increase of fluctuations and thus the ultimate failure of the material. We found that, in amorphous plasticity, the soft modes of the elastic interaction kernel are nothing but percolating shear bands. In this context, soft modes explain not only the diffusing fluctuations but the localization behavior as well. Moreover, we provided a new framework to describe amorphous plasticity as the interaction between loosely coupled shear bands. The weak interaction between shear bands results from the inhomogeneity of the plastic strain along the band.

However weak this coupling may be, it still matters on the long run. A simple independently diffusing shear band model for instance is unable to predict the finite size scaling of the diffusion coefficient on the long run. A detailed investigation of the statistical properties of the mechanical noise induced by the inhomogeneous plastic deformation along the shear bands could help to elucidate the role of this coupling in the long term dynamics. In the meantime, localization on short times follows slip lines as predicted by scaling and observed in molecular dynamics. However, a more thorough analysis of the spatial correlation of the plastic activity induced by the individual avalanches is necessary to firmly confirm that avalanches indeed follow slip line patterns.

Diverging fluctuations and the associated shear banding in amorphous materials ultimately lead to failure. Understanding the shear band formation mechanism is therefore the first step in developing materials with enhanced mechanical characteristics. The next step in the process is to control the nucleation of shear bands. We found that shear band nucleation is affected by adding hard inclusions to the amorphous matrix. We show that the reinforcement of amorphous materials by hard inclusions shows finite size effects and a linear mixing law gives an upper bound to the flow stress. Furthermore, we found that reinforcement is related to the percolation of shear bands in between the hard inclusions. Although we carried out simulations with soft inclusions as well, the reinforcing mechanism there is less clear. This is a work under progress and not discussed here, however, we expect soft sites to contribute in suppressing permanent shear band formation.

The mesomodels we used are meant to capture the generic phenomenology of amorphous plasticity. In this spirit, they are oversimplified caricatures of real world amorphous systems and the effect of these simplifications has yet to be clarified. For instance, we were using scalar models with the strong hypothesis that the plastic slips follow the symmetry of the external loading. Stresses and strains however are tensorial quantities, and a tensorial model is necessary to support this hypothesis. Another, related simplification is that we did not account for densification. This assumption probably applies to dense amorphous systems such as metallic glasses. On the other hand, even a pure shear plastic deformation of an Eshelby inclusion induces a pressure component in the stress field, and the consequences may be nontrivial.

In the second part of the thesis we considered another depinning-like system. We developed a novel approach to model the dynamics of thin liquid layers on inhomogeneous surfaces. In our simplified picture we considered the layer as flat, and followed the motion of the contact line only. We found that in this approximation, interactions are short ranged, hence the line is soft. The roughening of the line is governed by the competition of these short range interactions and the disorder of the surface. We revealed the existence of a critical concentration of inhomogeneities below which the line stops within finite time, and above this concentration it moves indefinitely. Around the threshold concentration the line shows critical-like properties such as fractal-like structure and long spatial correlations. This is a peculiar transition: although depinning-like in the sense that it results from the competition of short range interactions and the pinning forces of the disorder, it is associated to the large deformations and tearing up of the layer. Large deformations and tearing up are not accounted for in standard depinning models, we therefore hope that our method may open a new perspective in the study of jerky interface motion.

9 Publications

Publications related to the thesis

- B. Tyukodi, C. Lemarchand, J. Hansen, D. Vandembroucq, "Finite size effects in a model for plasticity of amorphous composites", Physical Review E, 93, 023004 (2016)
- B. Tyukodi, S. Patinet, D. Vandembroucq, S. Roux, "From depinning transition to plastic yielding of amorphous media: a soft modes perspective" (2015, submitted)
- B. Tyukodi, Y. Bréchet, Z. Néda, "Kinetic roughening of a soft dewetting line under quenched disorder - a numerical study", Physical Review E 90, 052404 (2014)

Conferences

- B. Tyukodi, W. Zhu, D. Vandembroucq, C. Maloney, "Diffusion and localization in elasto-plastic models of amorphous plasticity", Materials Research Society fall meeting (2015, Boston, talk)
- B. Tyukodi, Y. Bréchet, Z. Néda, "Kinetic roughening of a soft dewetting line - a novel computer simulation method ", Physics Conference TIM14 (2014, Timişoara, co-author of plenary talk)
- B. Tyukodi, C. Lemarchand, D. Vandembroucq, "Plasticity of strongly heterogeneous materials", Condensed Matter in Paris (2012, Paris, poster)

Other publications

- B. Bresson, C. Brun, X. Buet, Y. Chen, M. Ciccotti, J. Gateau, G. Jasion, M. Petrovich, F. Poletti, D. J. Richardson, R. Sandoghchi, G. Tessier, B. Tyukodi, D. Vandembroucq, "The long memory of glass surfaces" (2016, in preparation)
- Sz. Boda, Z. Néda, B. Tyukodi, A. Tunyagi, "The rhythm of coupled metronomes", The European Physical Journal B 86, 263 (2013)
- B. Tyukodi, I. A. Chioar, Z. Néda "A kinetic Monte Carlo study for stripe-like magnetic domains in ferrimagnetic thin films", Central European Journal of Physics 11, 487 (2013)
- B. Tyukodi, Zs. Sárközi, Z. Néda, A. Tunyagi, E. Györke, "Boltzmann constant from a snifter", European Journal of Physics 33, 455 (2012)
- Z. Néda, B. Tyukodi, Á-E. Kacsó "Foundations of classical statistical mechanics" (textbook, 2014, in Hungarian, ISBN 978-973-114-187-9)

Keywords

plasticity, amorphous materials, depinning, yielding transition, dynamic phase transition, dewetting, disordered media, interface roughening.

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