European Cooperation
in the field of Scientific
and Technical Research
- COST -

Brussels, 24 May 2013

COST 033/13

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action MP1303: Understanding and Controlling Nano and Mesoscale Friction

Delegations will find attached the Memorandum of Understanding for COST Action MP1303 as approved by the COST Committee of Senior Officials (CSO) at its 187th meeting on 15-16 May 2013.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action MP1301
UNDERSTANDING AND CONTROLLING NANO AND MESOSCALE FRICTION

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4154/11 “Rules and Procedures for Implementing COST Actions”, or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to strengthen, organize and integrate the European multidisciplinary scientific and technological competencies and to promote innovation in the field of micro/nanotribology.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 56 million in 2013 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter IV of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

Recent years have seen widespread efforts to understand the mechanisms of friction and tribology in micrometric structures (mesoscale) down to the realm of atoms and molecules (nanoscale), with the ultimate goal of controlling friction, adhesion and wear by design. This research has generated an interdisciplinary scientific area, nanotribology, with great potential impact on technology and everyday life. Applications include safety, economy, life quality, energy and material saving, toward a sustainable development. Europe has a strong scientific nanotribology community spreading over physics, materials science, chemistry, earth and life sciences. So far, this community lacks a chance to interact closely enough: it is in urgent need of better networking, to favour collaboration among groups and exchange of complementary expertise. A COST Action, operating beyond the national horizons, can indeed mobilize and put together the critical mass of existing human and technical nanotribology resources at a modest price, thus representing a unique opportunity for an efficient scientific investment.

Keywords: Multiscale Tribological Processes, Control of Friction Wear and Adhesion, Nanotribology, Nanomanipulation, Confined Lubricants and Boundary Lubrication

B. BACKGROUND

B.1 General background

Friction is an everyday issue. At micrometric and sub-micrometric scales, interfacial forces dominate: friction and adhesion forces affect the performance and lifetime of microdevices such as magnetic-storage hard disks, micro/nano electromechanical devices (MEMS/NEMS). Durable low-friction surfaces, wear-resistant materials, and suitable liquid and solid lubricants are in demand for hi-tech applications. A fundamental understanding of the elementary nanotribological mechanisms, intimately related to both adhesion and wear, and the interrelated collective mesoscopic processes is still in its infancy, and remains a challenge. If a better understanding of atomic-scale frictional processes could be extended to the macroscopic scale of machinery, it could lead to progress in transportation, manufacturing, energy conversion, and lubricant consumption, impacting on innumerable aspects of our economy, health and environment. Methods beyond lubrication for the reduction and control of friction are needed, and promise significant industrial impact.

Europe has a highly productive and scientifically visible nanotribological community, encompassing at least 30 groups with strong expertise, covering experimental, theoretical, and

simulation approaches. This community is a patrimony, comparable to its US and Japanese counterparts. American nanotribologists are naturally pulled together by the necessity to network and to concur for funding. There are Gordon Conferences, American Physical Society (APS) March Meeting Focused Symposia, and other occasions where their community joins forces. The same can be qualitatively said for Japan. In contrast, the European nanotribology community is missing a systematic EU-funded effort supporting contacts and networking. Several COST countries contribute individually national funds to micro/nanotribology research, and so does the EU, e.g. through a number of individual European Research Council (ERC) grants. None of these covers European networking, though.
This Action will fill this gap. It will be complementary to existing national research programs, not duplicating any. Its scope will be to help all European groups active in nanotribology to network together, thus fostering a concerted scientific effort.

B.2 Current state of knowledge

In order to develop essential advances in the field of nanofriction, and of tribology in general, fundamental research lines revolving around four critical topics are recognized as the most pressing for the current state of knowledge.
1) Bridging tribological mechanisms at different scales. Friction takes place in different phenomena that span a wide spectrum of length scales, from sub-nanometre up to kilometres as in the case of earthquakes. Diverse problems involve multiscale approaches and are being addressed by current research: biotribology (e.g. eyes and joints lubrication), bioadhesion (e.g. how can flies and lizards walk on vertical walls?) and cell adhesion, rubber sliding and rolling friction, friction of the human skin, capillary bridges, adhesion in paper and in skin friction. All these problems involve surface roughness and interfacial surface interactions over many length scales and require an accurate multiscale contact mechanics theory. While several multi-scale approaches, e.g. based on fractal methods, have been proposed, at present the molecular-level physics and rheology and the large-scale phenomenological descriptions of friction are not connected satisfactorily. One of the current challenges of tribology is to bridge the different length scales and relate the emerging laws of friction to shorter and shorter length scales, down to the atomistic processes involved. In parallel, experimental methods need to proceed a step forward toward a more precise and faster control of the dynamics at the contact interface.
2) Tuning nanofriction. Developing the ability to tune and manipulate frictional forces, adhesion and wear is a far reaching goal that can obviously be of high technological impact. Standard

lubrication techniques used for macroscopic objects are less and less effective in the micro- and nano-world, because of dominant viscous and adhesive forces. Novel alternative solutions for the control and manipulation of friction at the microscopic scales are called for. Recent preliminary experimental and theoretical studies have, for example, successfully designed efficient methods and algorithms to control tribological properties by imposing tiny mechanical oscillations or by exploiting natural, or externally optimized, interfacial mating geometries. More ideas and approaches such as electrochemical manipulation of surface interactions to control nanofriction are currently under consideration.

3) Confined lubricants under shear. One of the reasons making friction a complex task is the involvement of many degrees of freedom under a strict size confinement, which leaves very limited access to the sliding interface itself. Experimentally it is possible to shear nanometre thin lubrication films in the surface force apparatus (SFA). These films are also present in macroscopic systems so the SFA can predict processes such as wear by quantifying the squeeze-out of monolayers and friction by shearing of thin films. Theoretically, computer simulations such as Molecular Dynamics (MD) can simulate the tribological behaviour of very thin films. MD is becoming more and more sophisticated and the possibility of a direct visualisation of the sheared interface increases the probability of establishing robust models describing the tribological mechanisms in these films.

4) Controlled nano movements. The manipulation of nano-objects is an emerging nanotribology subfield associating fundamental issues and high-risk technological goals. At present, despite the indisputable success of recent experimental studies, the conventional atomic force microscopy (AFM) and friction force microscopy (FFM) setups show severe inherent limitations (e.g., unsuitability to measure real contact area dependence, generally amorphous/disordered probe ends, limited availability of good-quality AFM tip materials). Indications are emerging that these difficulties can be overcome by manipulating well-defined nano-objects (adsorbed atomic islands or crystalline clusters) with the AFM setup because the interface under study is now the contact between a nano-object and the surface. Following this approach, the interfacial friction of prototype contacts of well-characterized size and structure has been measured recently. More realistic and technically relevant interfaces are waiting to be studied: achieving the controlled manipulation of these systems may open the possibility to build directly nano or molecular suprastructures and eventually to drive single nano-clusters or molecules on a surface.

With worldwide research on friction and wear focusing on molecular interactions at the nanoscale, the coordination provided by this Action will promote a synergy of expertise, to construct a gapless chain of knowledge connecting molecular forces and machinery lifetime, fundamental mechanisms of dissipation and energy consumption, toward a rational design of future technologies.

B.3 Reasons for the Action

The field of current nanotribology is at a stage comparable to that of semiconductors thirty years ago when the advent of man-made heterostructures brought the field from engineering back to physics, leading to new fundamental discoveries like the Quantum Hall effect and to several Nobel prizes as well as to a wealth of revolutionary devices that have shaped our current society. Like then, the step from bulk materials to man-made nanoscale structures is crucial for new effects and functionalities. Being much more interdisciplinary, however, nanotribology cannot count yet on a coherent community, on established conferences and discussion forums.

This Action is mainly designed to trigger scientific/technological advances. It will complement existing national research programs, connecting all groups active in nanotribology, thus fostering a concerted European scientific effort. Highly rewarding goals of this Action are: (i) scientifically, sharing knowledge and fostering collaboration within Europe on designing methods, algorithms, and solutions to study, understand, and eventually control friction, adhesion and wear, especially at the micro and nano scales; (ii) strategically, strengthening the world leadership of Europe in this crucial field; (iii) creating a publicly visible point of contact for industrial developers and technological decision makers who need advice or consulting on friction and wear on small scales. Besides, this Action will provide Early-Stage Researchers (ESR) with a coordinated international environment, where they can develop a successful career. Appropriate gender-balance policies will make sure that equal opportunities will be given to all researchers, supporting in particular women scientists.

B.4 Complementarity with other research programmes

There is at present no systematic EU funded effort supporting networking within the European nanotribology community. A past COST Action 532 ‘Triboscience and Tribotechnology: Superior Friction and Wear Control in Engines and Transmissions’ did not address the nanoscale and ended in 2007. A more pertinent earlier European collaborative effort dates back to 2002 with the ESF network ‘Nanotribo’, but it also ended in 2007 without a follow-up. Minor relief came from the ESF Eurocores ‘FANAS’, a program endorsed by the ESF where some networking was possible. However, FANAS received no direct EU support, was modestly funded by a minority of national agencies, and ended in 2011. Several COST countries individually contribute national funds to nanotribology research, but they do not cover European networking, which is still missing. The present Action will fill this gap by creating a joint network platform. Knowledge from this Action will be transferred to and from the other national/international research programmes via Action scientists who have close connections with them.

C. OBJECTIVES AND BENEFITS

C.1 Aim

The aim of the Action is to strengthen, organize, and merge scientific and technological competencies in the field of micro/nanotribology at an European level, by means of the integration of research capacities which are nowadays nationally and thematically fragmented, especially in such a wide and multidisciplinary area as friction at the micro- and nano-scale. The better coordinated research will lead to innovative solutions to, e.g., the industrial problems of hi-tech companies, such as novel coatings and molecular lubrication strategies.

C.2 Objectives

Obj 1. Coordinate the present activities and stimulate innovation. The first objective of the present Action is to overcome the fragmentation of the nanofriction community by merging diverse skills into coherent interdisciplinary approaches, to boost interactions and collaborations among scientists. This Action will certainly lead to approximately 100 joint publications in the period of the Action but, more importantly, will make new insights emerge and stimulate creativity.

Obj 2. Support gender balance and involvement of ESR. Early-stage researchers will be provided with broad international perspectives for their scientific career. The underrepresentation of women in the hard sciences is exacerbated by the fragmentation of nanotribology research: there are several women but they are scattered across the continent and across sub-areas with little contact. This Action will provide vital opportunities to network together, vigorously promoting the participation of women scientists in all Action activities. This will encourage particularly young women scientists who will have an opportunity to interact with all senior scientists, in particular women active in their field through Action events.

Obj 3. Promote dissemination and advertising within and outside the Action. Exchange and dissemination of results are crucial coordinating the research among the units, advancing the field, interacting with other communities, and for increased visibility in the global scientific arena. This is

crucial at the political level too. A problem which nanotribology research faces is that it is not adequately represented in European scientific policies and programmes. Effective dissemination and advertising of the scientific achievements in this field will improve the awareness of European policies of the role of tribological research in the advancement of science and technology.
Obj 4. Team up and prepare applications for future joint training and research projects. Europe offers several schemes for funding joint activities, e.g. the Initial Training Network (ITN), under the Marie-Curie actions of the VII Framework Programme or new actions within Horizon 2020. Since national funding schemes rarely support international events and cooperation, European funding programmes acquire in this respect a central role because they cover a much broader scale. The present Action aims at developing strategies for the successful participation in future funding programmes and for preparing future proposals, in order to give continuity and to build on the scientific success of the nanotribology network.

C.3 How networking within the Action will yield the objectives?

The objectives of the Action will be achieved through regular meetings, Short-Term Scientific Missions (STSMs), workshops and training schools, international conferences and knowledge dissemination. More specifically, individual objectives will be achieved in the following way.
Obj. 1. Working Groups (WGs), described in section D.2 and E.2, will be responsible for establishing and consolidating collaborations and for boosting research through exchange of ideas, results, and people. The periodic Management Committee (MC) meetings, workshops, and the dedicated website will provide an overall coordination.
Obj. 2. The STSMs will support mobility especially of ESR. The training schools will provide with training that cannot be given at the local level. Meetings, workshops, and the Action website and newsletters will keep ESR up-to-date on science, activities/initiatives within the network and job openings in the field, and provide direct interaction with world leading scientists in their field. The objective of promoting a broader representation of women in nanotribology will be achieved throughout the Action by means of an active gender-balance policy activities managed by a Gender Balance Coordinator.
Obj. 3. Dissemination will be achieved through regular conferences, workshops, scientific publications and reports. A dedicated website of the Action will be set up, where the scientific achievements will be promoted. Specific incentive will be put on making the main scientific results publicly accessible even to non-experts in the field, in order to promote science to a wider audience.
Obj. 4. The best strategies and funding programmes will be discussed at the MC and WG meetings

and the planned conferences.

C.4 Potential impact of the Action

The expected benefits of this Action joining under one common umbrella the scientific and complementary human resources spread all over Europe will have long-lasting effects on (i) the scientific community itself; (ii) fundamental science, technology, and hi-tech industry; (iii) environment and safety; (iv) young researchers and women scientists; (v) the general public. Specific benefits include: 1. Defragmentation of tribology-related research efforts across Europe, with joint involvement of leading experts from complementary disciplines such as physics, chemistry, material science, and engineering. 2. Strengthening the leading role of Europe in an international, worldwide context of nanotribology research. 3. Addressing the main current challenges in the field. 4. A transfer of scientific and technological knowledge to the European industry, fostering industrial competitiveness of Europe in hi-tech applications. 5. Paving the way for a reduction of consumption and waste of materials and energy toward a sustainable development. 6. Preparing highly professional and competitive young researchers. 7. Production of outreach material and activities for universities, schools, and the general public.

C.5 Target groups/end users

This Actions targets: (i) the nanotribology scientific community itself. The Action will have a significant impact on the individual members and teams, in terms of their research profile and scientific production quality. (ii) Related broader scientific communities including solid-state physics, chemistry, engineering, and material science, whose overlap will increase as a result of this Action. (iii) The future generation of scientists, and women scientists in particular. (iv) European industry. Several companies were involved and have expressed their support for this initiative. (v) The general public, through a specific dissemination effort. In addition, over a longer time scale, society as a whole will benefit of the faster technological advances promoted by better science through networking.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

A better microscopic understanding and control of friction guides the scientific focus of this Action, which addresses the following tasks: 1. Drawing bridges between friction at different scales and properly relating the atomistic processes with the macroscopically observed effects. 2. Controlling the tribological behaviour by imposing, e.g., tiny mechanical oscillations or by exploiting either natural surface geometries or externally induced interfacial nanostructures. 3. Exploring confined interfaces under shearing. These tribological systems exhibit intriguing boundary lubricated regimes, whose tunability represents a priority for a variety of micromechanical devices where the early stages of motion and the stopping processes are often dominated by highly dissipative stick-slip dynamics. 4. Understanding the diffusion, adhesion and friction mechanisms of atomic or molecular aggregates on surfaces. Single-cluster manipulation can serve as an ideal method to measure the interfacial friction of structurally well-defined contacts of controlled sizes and material pairings.

D.2 Scientific work plan methods and means

The scientific work plan is organized in four interrelated Working Groups (WGs), reflecting the four general themes sketched in section B.2.

WG1: Bridging tribological mechanisms at different scales. Today, the phenomenological macroscopic or mesoscopic description of sliding friction cannot be linked yet to the fundamental mechanisms occurring at the molecular level. Bridging the different length scales by properly relating the atomistic processes with the macroscopically observed effects is the challenge of modern tribology which WG1 will address.

Main objectives:

- Enrich the description of mesoscopic sliding fiction by overcoming the single-asperity level description, addressing tribological problems in relevant multi-contact systems, where both single-asperity dynamics and collective interaction mechanisms should play a crucial role.
- Analyse the complex variation in the interfacial separation between rough surfaces, extending over several decades in length scales and its effects on friction and on the flow of a fluid in between the surfaces.
- Investigate and control the mechanism of energy dissipation due to wear and plastic deformations.
- Correlate atomistic studies of friction and the macroscopic friction and wear tests.
- Study the behaviour of nanowires/nanotubes as candidate objects (micro/mesoscale in one dimension and nanoscale in others) for bridging the tribological properties at the small length

scales.
- Elucidate the origin of certain friction laws (rate-and-state), which yield a good phenomenological description of systems as different as granular media and solid on solid.
- Address the microscopic origin of interface "ageing" and of slow relaxations.
Methods A. Experimental: *Tribological test methods, from nanonewtons to newtons, to explore lubricated and dry systems where roughness size scale varies continuously over many orders of magnitude. *Combined microtribometry and surface analytical techniques. *On-line topography and wear measurements for friction experiments at micro/macroscopic scales. *In-situ friction measurements between nanowires/nanotubes and substrate in longitudinal/lateral directions. *Experiments on granular media and solid-on-solid friction, measuring the time/length scales involved, and the influence of disorder on the parameters of rate-and-state laws. *Direct measurements of single-particle and cooperative motion in molecules in contact with a surface; benchmark data on energy landscapes and dissipative mechanisms.
Methods B. Theoretical: *Implementation of specific approaches to model dynamics in multicontact systems, linking descriptions of single contact, discrete arrays and extended systems. *Development of unconventional multiscale/hybrid simulation techniques to bridge the atomic level of investigation with coarse-grained or continuum analysis at larger scales.

WG2: Tuning nanofriction. The aim here is to develop the fundamental nanoscale design enabling friction control, by causing the tribological properties to vary at will under some external action. Focus will be on exploiting novel methods and solutions, since standard (macroscopic) manipulation and lubrication techniques are much less effective or impractical in the micro- and nano-world.
Main objectives:
- Control nanofriction by the application of mechanical, electrochemical, and electrostatic actuation.
- Investigate the robustness of superlubric effects and ultra-low friction operative conditions against a variety of energy dissipation mechanisms, e.g., dislocation formation, plastic deformation, wear…
- Address the effects of electronic vs. phononic friction.
- Probe superlubricity of liquids at solid surfaces.
- Understand the influence of surface treatments on nanoscale friction and wear.
- Exploit surface pattern geometries to control/suppress highly dissipative regimes of motion.
- Exploit the effect of phase transitions, either in the sliders or in the intervening lubricant, on sliding fiction.
Methods A. Experimental: *FFM (ambient, liquids and ultrahigh vacuum) in combination with

mechanical and electrostatic actuation, and with a variety of probing tips, different geometry, sample structures and patterns. *Standard and pendulum-type AFM to investigate dissipation across phase transitions like the metal-superconductor transition. *Design of a hierarchical macro to nanofluidic experimental device with a single carbon nanotube as nanofluidic system.
Methods B. Theoretical: *Molecular dynamics (MD) simulations methods to analyse the detail of the internal rates of surface structural rearrangement during sliding. *Implementation of reliable single- and multi-contact models to correlate the tribological behaviour recorded in experiments and the dynamics of microscopic events at the sliding interface. *Search for simpler models capturing the general features of the multifaceted tribological processes observed in experiments or realistic MD simulations. *Development of new approaches to control nanofriction on substrates whose properties are affected by electronic quantum-mechanical transitions, e.g. magnetic and superconducting ones.

WG3: Confined systems under shear. The goal is to explore and understand the dynamical response of tribological systems sheared in confined geometries, where critical boundary-lubricated regimes and highly dissipative intermittent sliding may take place. An efficient control of friction in such systems represents a formidable challenge of great practical relevance for a broad class of nanotechnological devices.
Main objectives:
- Investigate the mechanisms of contact formation and energy dissipation in AFM in liquids.
- Understand the relation between friction, adhesion, load, and number of molecular layers in ionic liquid lubricant films, and nanometer-thin polymer films.
- Understand the flow behaviour of water and organic fluids in nanometrically bounded spaces, in particular inside carbon nanotubes, and probe the possibility of a superlubric behaviour.
- Explore the transition from molecular to hydrodynamic behaviour.
- Investigate the conditions for the possible generation of solitonic motion of a confined lubricant.
- Address the potentiality of lamellar lubricants (graphite, MoS_2,...) for creating superlubric interfaces.
- Explore/compare friction dynamics of granular systems and colloids with that of confined fluid lubricants.
Methods A. Experimental: *SFA measurement of the shear stress between two atomically smooth surfaces across films of ionic liquids, while also controlling the number of molecular layers and applied load. *Design of a hierarchical macro to nanofluidic device with a single carbon nanotube as nanofluidic system. *Perform transport measurements using patch-clamp techniques and single-

molecule fluorescence.
Methods B. Theoretical: *Combined ab-initio, classical MD simulations and potential of mean force calculations for grand canonical ensembles including single-asperity interactions with surfaces in liquids. *Large scale MD calculations to unravel the detailed tribological mechanisms which play a role in shearing confined thin polymer films. *Multi-scale techniques from density-functional theory (DFT) to force field MD to coarse-grained approaches.

WG4: Controlled nano movements. The aim is a predictive understanding and control of the fundamental processes underlying nanofriction and adhesion by exploiting nano-object manipulations. This strategy can serve as a complementary method to study interfacial friction as a function of parameters difficult to access and modify in a standard FFM set-up. For example nanoparticles allow a broader choice of structurally well-defined material pairings at the interface and /or permit to vary the contact size over a wide range.
Main objectives:
- Control the dynamics of nanoparticles using AFM, understanding the influence of friction forces on translational and rotational motion on the nanoscale.
- Clarify the role of size, shape, geometry, and electronic structure in the manipulation of nanoparticles.
- Explore the detailed mechanisms at the onset of sliding as a function of cluster size, to obtain new insight in the yet unsolved issue of how friction depends on the contact area and age.
- Investigate the mechanisms of controlled AFM manipulation of atoms/molecules at insulating surfaces.
- Understand single-atom manipulation mechanisms depending on the adatom-surface binding character.
Methods A. Experimental: *Protocol implementation for AFM controlled nanomanipulation in controlled atmosphere, liquids, ultra-high vacuum. *Optimizing in-situ friction measurements during crystalline nanoparticle manipulation on amorphous or well-ordered substrates. *Exploiting multichannel multi-frequency AFM acquisition protocols for the simultaneous observation of manipulation process.
Methods B. Theoretical: *Analysis of the contact-area, interfacial shear-stress, and shear-strength dependences on the shape of gold nanoparticles. *MD simulations of the detailed depinning mechanisms and the most effective energy dissipation processes in the dynamics of deposited nanoclusters. *DFT simulations and STM/AFM measurements of single-atom manipulation in ultrahigh vacuum. *Developing simplified models based on classical mechanics and reaction-rate

theory to interpret nanomanipulation experiments.

The European groups, most of which have already expressed an interest in this Action, will carry out this work plan, keeping open possibilities for other groups to join the network during the course of the Action.

E. ORGANISATION

E.1 Coordination and organisation

The Action will be supervised and coordinated by a Management Committee (MC), presided by a Chair and a Vice-Chair, according to document COST "Rules and procedures for implementing COST Actions". All research activities of the Action members will be carried out and funded by internal resources of the participating groups, with COST supporting only the coordination, networking, and dissemination activities. To achieve the Action objectives effectively, coordination will involve:

- Action management. The MC will set up the network, discuss the achievements and the problems encountered, and plan future activities. It will report to the COST Office on a yearly basis. The MC will appoint a Core Group (CG) to assure rapid, efficient and flexible coordination of the Action. The CG will consist of the MC Chair and vice-Chair, the WG Leaders, the STSM Coordinator, and the Gender Balance Coordinator. The CG will prepare all relevant documents for the MC meetings.
- Outreach Coordination. The MC will appoint a Coordinator responsible to create and update monthly the Action web site according to COST rules, and to publish a periodic newsletter, with scientific highlights, joint publications, and job advertisement. The Outreach Coordinator will also supervise the other activities described in section H.
- Gender balance and mentoring. The MC will appoint a Gender Balance Coordinator to promote an appropriate gender balance in all Action-related activities and coordinating the mentoring scheme for early-stage researchers.
- STSMs Coordinator: she/he will coordinate the STSMs. She/he will be responsible of overseeing the STSM-implementation plan, prepare the annual selection and review process of the STSMs. Operative decisions on the STSM will be taken by the CG and reported to the MC.

A summary of the main Action Milestones includes:
Year 1: Kick-off Meeting with setting up of Action Management (MC, CG, WG, etc.) and Networking Coordination; Setup of web site & mailing-list; Launch of Mentoring Scheme and

STSM-implementation plan; Workshop 1; Training School 1.

Year 2: Mid-term review of the scientific strategies and outreach activities; First International Conference; Training School 2.

Year 3: Workshop 2; Training School 3.

Year 4: Final reports and strategies for the future; Second International Conference; Training School 4.

Additionally, a regular networking activity will involve scientific publications, reporting, the newsletter, outreach activity, and STSMs.

The following table details the **Milestones and Deliverables of this Action.**

Year	Milestones	Deliverables
1	Months 1-6 Kick-off Meeting with setting up of Action Management (MC, CG, WG, etc.) and Networking Coordination; Work Plan established; Call for Training School 1; Months 7-12 Organization of Workshop 1; Call for the First International Conference; Launch of the Mentoring Scheme and STSM-implementation plan; MC meeting 1; WG meetings; Organization of Training School 1.	Web site & mailing-list service fully operational; Half-yearly Newsletters 1 & 2; WGs reports; Scientific publications, highlights; STSM report; Mentoring Scheme set up; Workshop 1; Training School 1; Outreach Activities; Annual Report.
2	Months 13-24 Call for Training School 2; Organization of the First International Conference; MC meeting 2; WG meetings; Mid-term review of the scientific strategies and outreach activities; Organization of Training School 2.	Half-yearly Newsletters 3 & 4; WGs reports; Scientific publications, highlights; STSM report; Mid-term report on gender balance and mentoring; First International Conference; Proceedings of the First International Conference; Training School 2; Outreach Activities; Annual Report.
3	Months 25-36 Call for Training School 3; MC meeting 3; WG meetings; Organization of Workshop 2; Call for the Second International Conference; Organization of Training School 3.	Half-yearly Newsletters 5 & 6; WGs reports; Scientific publications, highlights; STSM report; Workshop 2; Training School 3; Outreach Activities; Annual Report.
4	Months 37-48	Half-yearly Newsletters 7 & 8;

	Call for Training School 4; MC meeting 4; WG meetings; Organization of the Second International Conference; Organization of Training School 4; Final reports and strategies for the future.	WGs reports; Scientific publications, highlights; STSM report; Assessment of gender balance and young researcher activities; Second International Conference; Proceedings of the second International Conference; Training School 4; Outreach Activities; Final Report.

E.2 Working Groups

The four WGs detailed in section D.2 will target the four main investigation streams outlined in section B.2. Each WG will be coordinated by a chair and a vice-chair appointed by the MC, with the responsibility for organization, coordination, networking and reporting. WGs will also provide the scientific input to the annual reports and the periodic outreach activity.
The scientific programmes of the four WGs will be carried out in close cross-correlation. The participation of groups in more than one WG will be encouraged. The existing cross-links between WGs will extend in the course of the Action, thus maximizing the impact of the Action itself. An upgrade of the WG structure may be implemented at the mid-term meeting, if the MC identifies clear benefits for the on-going Action plan.

E.3 Liaison and interaction with other research programmes

To establish fruitful possible interactions with future interrelated COST Actions and other European or worldwide research programmes, the following means will be exploited: 1. organization of seminars and joint workshops/meetings, as an effective means of exchange; 2. invitation of leading academic and industrial partners of other programmes to talk at the annual Action conferences/workshops; 3. establishment of research collaborations, especially through joint European projects to study specific topics of common interest; 4. invitation to join this COST Action, directed to groups of those projects with relevance for the tribology field.
An objective of the Action is to promote the participation of its members in future research programmes, in particular, those launched within the European Framework Programmes.

E.4 Gender balance and involvement of early-stage researchers

This Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will also be committed to considerably involve early-stage researchers. This item will also be placed as a standard item on all MC agendas.

As the number of women working in tribology is traditionally small, this Action will devote an extra effort in supporting a gender balance in all its activities. The MC will implement a mentoring programme; the website and the newsletters will highlight events concerning gender issues and women in science. This Action will also encourage and support the participation of young researchers to all Action activities as well as in its management and administration.

F. TIMETABLE

The time scale of this Action is 4 years. After an initial kick-off Meeting where the WGs are set-up, the Action will be carried out according to the following plan:

Work Plan	Year 1				Year 2				Year 3				Year 4			
Quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
WG1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WG2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WG3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WG4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MC CG WG meetings				x				x				x				x
Mentoring Programme			x	x	x	x	x	x	x	x	x	x	x	x	x	x
STSM Programme			x	x	x	x	x	x	x	x	x	x	x	x	x	x
Training schools				x				x				x				x
Workshops				x								x				
International Conferences								x								x
Website	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Newsletters		x		x		x		x		x		x		x		x
Outreach Activities			x	x	x	x	x	x	x	x	x	x	x	x	x	x

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, CH, DE, DK, ES, FI, FR, IE, IL, IT, NL, PT, TR, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 56 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The MC will oversee the outreach and dissemination strategy of the Action and direct the dissemination activities to the following target groups:

1. Researchers in the field of friction and tribology directly involved in the Action;
2. Researchers (academy/industry) active in the same and related fields not involved in the Action;
3. Undergraduate and PhD students;
4. Opinion formers, European-level and regional-level Research Policy decision-makers;
5. National and European funding agencies;
6. Media: scientific and non-scientific press, digital media and TV;
7. Other European Cooperation projects, Networks of Excellence;
8. International channels such as, e.g., ICTP/UNESCO which reach researchers of developing countries;
9. The general public, including high-school classes.

H.2 What?

The content of the dissemination activities will be adapted to the needs of these specific groups:

a. Highly specialized and technical scientific contents: this category encompasses all scientific achievements of the Action research groups and especially the research highlights, whose dissemination will be crucial for tribology researchers (targets 1 and 2 in sect. H.1).

b. Technical news and highlights: news concerning the opening of new positions, the organization of conferences, schools and workshops, highlights of the freshly published papers in the field will

constitute a basic tools for the everyday work of the Action researchers.
c. Selected scientific contents for training and education: a selection of key works and seminal papers accompanied by other introductory material will focus target 3.
d. Statistical data: this information will characterize several aspects of the output of the Action and will be an excellent self-evaluation tool. Some statistics about the participants of the meetings, the published papers, the collaborations among the Action groups and contacts with other communities will be helpful for targets 4 and 5 to size and evaluate the tribology community.
e. Broad impact information for general audience: non-technical articles treating the hot topics in tribology will help people pertaining to targets 6 to 9 to get the flavour of the activities carried out by the researchers and their potential impact on industry and society.

H.3 How?

The key tools for disseminating the scientific achievements (item a in section H.2) are the joint publications in peer-reviewed journals, book chapters, symposia proceedings, and communications to international conferences.
The website will be a central pillar of the dissemination plan, providing information about the Action itself, the management structure, contact details, and documents about events, training schools, publications, job/project opportunities, reports, and manuals. Statistical data, including item d, will be available in the open-access part of the web site.
Mailing lists for the committees and members of WGs will allow information exchange at each level. Technical news and highlights (item b), will be delivered as a periodic newsletter.
Training will be covered by schools plus lectures given by leading scientists during the Action meetings. Training in advanced techniques of science communication will be included in the activities targeting early-stage researchers. The material of the lectures will be available on the Action website. All researchers, and especially young researchers, will be strongly encouraged to contribute actively to WikiVersity, the academic open-access part of Wikipedia, still missing a satisfactory coverage of tribology.
Non-technical articles, press releases and invitations for media exposure (when appropriate) will contribute to dissemination to the general public (item e).
The progress of the Action will be evaluated periodically during the MC meetings, using intermediate brief reports on the dissemination activities and outcomes presented by the Outreach Coordinator. The annual reports will cover the dissemination activities. These reports are in fact dissemination tools themselves and will be made publicly available through the Action website.

The dissemination plan will be updated periodically, to strengthen specific methods, as well as to introduce new measures. Moreover, the outreach strategy will be adapted to arising needs, like that to improve internal and external communication processes. In particular, according to the COST rules, at the end of the third year, the MC will produce a revised dissemination plan to be included in the annual report.