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Content

1. SUMMARY

The NewFrac Global Research Plan is composed of the Individual Research Projects (IRP) plans for the Early Stage Researchers (ESRs) composing the network. The overall development of individual investigations is described in this deliverable.

2. GENERAL OBJETIVES AND TECHNIQUES

The current trend to implement a fast design-virtual testing and manufacturing cycle, automation, and data exchange in manufacturing technology will require highly efficient and reliable failure-predictive computational tools for an accurate prediction of fracture and damage phenomena but the current modeling tools are insufficient for failure prediction in heterogeneous systems with high level of complexity.

The overarching objective of the NEWFRAC network is a high-level training of a new generation of creative, entrepreneurial and innovative **early-stage researchers (ESRs)** through the development and engineering applications of a new modeling framework focused on the prediction and analysis of multi-field fracture phenomena in heterogeneous engineering systems at different scales.

The main research objective of the NEWFRAC network is the development of a new modeling and simulation framework for the fracture mechanics optimization of high-level technological products involving heterogeneous systems (materials and structures), employed in engineering fields of strategic societal and scientific impact, ranging from renewable energy production systems to biological hard tissues.

The NEWFRAC network will integrate two recent strategies of high impact for fracture modeling: **Finite Fracture Mechanics (FFM)** and a variational approach to fracture referred to as **Phase Field (PF)** approach, as well as novel methodologies for a consistent hybridization of strategies. These strategies will enable simulation of complex fracture phenomena in different engineering applications which was difficult to achieve using previous methods.

These techniques will be extended to deal with fracture in heterogeneous materials across multiple length scales and including multi-field effects. This main objective will be achieved through the two following Specific Objectives:

- Obj. 1) To make a significant step forward on the key issues in FFM and PF, that will allow developing general computational tools able to solve complex fracture problems described above.
- Obj. 2) To confront these computational tools with challenging real-world fracture problems and applications which will provide the necessary feedback to upgrade these computational tools to obtain really predictive tools, which are robust, reliable and efficient, and thus useful in strategic industrial sectors.

While **Work Package WP4** with secondments and internships in academy are aimed at accomplishing Specific Objective 1, **Work Package WP5** with secondments and an internship in industry and a hospital are aimed at accomplishing Specific Objective 2.

3. METHODOLOGIES

This scientific achievement will be carried out by training future experts, who will assimilate the required capacities and competences of analysis under the guidance of reputed researchers and professionals. To achieve these targets, **NEWFRAC will support 13 Early Stage Researchers (ESRs)** who will be trained to conduct a breakthrough research in fracture modelling engaging interdisciplinary academic and industrial activities. The NEWFRAC network has an ideal composition, providing an excellent environment and training program for future professionals in failure analysis in engineering systems.

The training plan is split into 5 **Work Packages (WPs)** as illustrated in Fig 1**.** The research and technical activities are concentrated in WP4 and WP5, which are focused on the development of tools for the study of multi-field, multi-scale and/or multi-material failure processes (WP4) and applying these methods to provide solutions to challenging industrial problems (WP5). These two WPs will solve wide-ranging interconnected fundamental issues of fracture modelling, with a flow of procedures and codes developed in WP4 towards WP5, while open problems found in solution of industrial problems will serve as an inspiration for new developments in WP4.

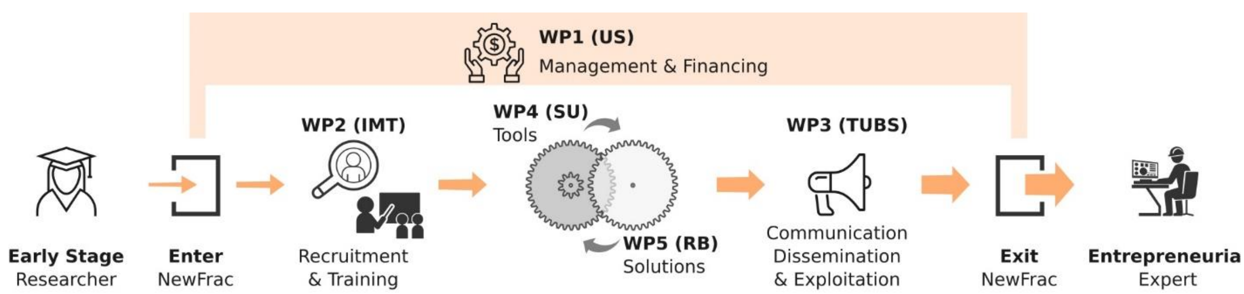

Figure 1. Work Packages illustration.

4. WORK PACKAGE 4

The objective of this Work Package 4 **"Novel tools for the prediction of fracture in heterogeneous materials"** is the development of new virtual testing techniques able to track the initiation and propagation of the fracture phenomena across the scales in the study of complex materials as composites, layered ceramics, photovoltaics, and biomaterials. Depending on the specific scale, the best-suited analysis technique must be identified. On small scales, for example, analytical or semi-analytical methods will provide evidence of the underlying physical mechanisms. Large scale structures will be examined using numerical tools that are generally applicable. Combining both approaches, scale spanning analysis techniques will be obtained.

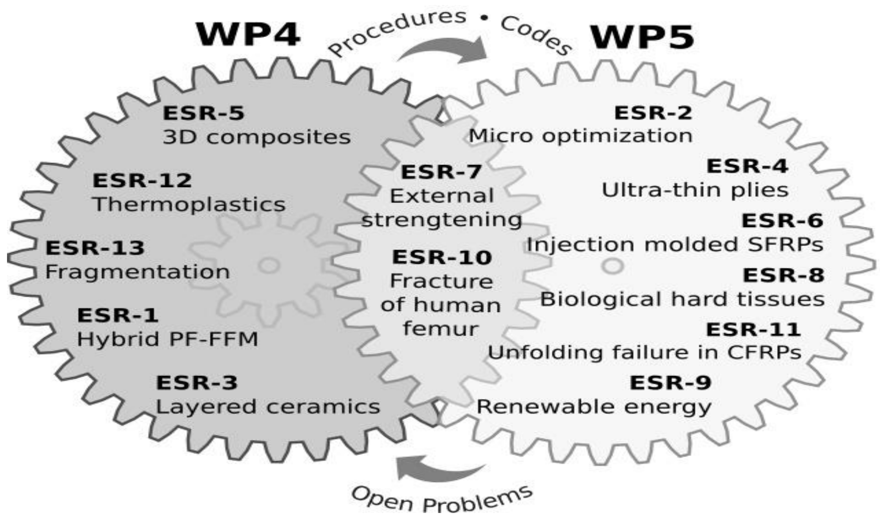

Figure 2. Individual Research Projects (IRPs) relation to Work Packages 4 and 5 (WP4 and WP5)

The main idea behind these modelling techniques is the combination of the new Phase Field (PF) approach with the Coupled Criterion of Finite Fracture Mechanics (CCFFM) to simulate fracture phenomena focusing on (sudden) crack initiation and their interactions with interfaces. The CCFFM will be especially suitable for these fracture problems, in the context of analytical and semi-analytical problems. However, the application of CCFFM is currently limited to a specialized community due to a lack of a computational implementation. Thus, the aim of the development of a hybrid approach combining the best of each method, PF and CCFFM, is to cover a relevant gap.

Additionally, an extension of the techniques for the application of PF and CCFFM to crack initiation under impacts and to dynamic crack propagation is necessary. The PF approach, very promising for the study of crack branching and fragmentation, will permit overcoming the main flaws typical for other methodologies that have been extensively used to analyse dynamic crack propagation problems. These modelling techniques will be verified against experimental results. The goal is to implement these new strategies for fracture following an application-driven approach based on their use for design and optimization in the industrial environment, because in early design stages and optimization processes, efficient models of fracture initiation and propagation are crucial.

The Lead Beneficiary of this Work Package 4 is **Sorbonne Université (SU)** and the main participants are Universidad de Sevilla (US), Politecnico di Torino (POLITO), Eidgenoessische Technische Hochschule Zürich (ETH), University of Porto (FEUP), IMT School for Advanced Studies Lucca (IMT), Tel Aviv University (TAU), Robert Bosch GmbH (RB), Foundation for the Research Development and Application of Composite Materials, Airbus Group (FIDAMC).

This Work Package involves seven Individual Research Projects (IRP) for seven Early Stage Researchers (ESRs) along the main participants described in the sequel. The principal tasks of this WP4 and the description of role and work of partner within to them is structured at Table 1.

ESRs-Task Relation					
WP	Task Number	Task Description	ESR Collaborating	Lead Institution	Participant institutions
WP4	*4.01*	Development of total energy minimization with stress conditions and a hybrid CCFFM and PF methodology for fracture in anisotropic heterogeneous materials and structures	**ESR-1**	US	IMT, SU, SAFRAN
	4.02	Adaptation of the new techniques to the fracture of ceramics	**ESR-3**	SU	US, RB
	4.03	Methods for compressive crack analysis by PF	**ESR-5**	SU	ETH, RB
	4.04	Adaptation of the new techniques to the study of debonding	**ESR-7**	POLITO	ETH, FIDAMC
	4.05	Adaptation of the CCFFM, PF and hybrid methods to biomaterials	**ESR-10**	ETH	TAU, SU, RB
	4.06	Adaptation of the new techniques to the multiscale analysis of composites	**ESR-12**	FEUP	US, FIDAMC
	4.07	Extension of the CCFFM and PF methodologies to dynamic fracture	**ESR-13**	POLITO	US, IMT, BOTTERO

Table 1. Principal WP4 tasks details

5. WORK PLAN - WP4

Principal task of WP4 relation to Individual Research Projects (IRP) descriptions:

a. Task 4.01: Development of total energy minimization with stress conditions and a hybrid CCFFM and PF methodology for fracture in anisotropic heterogeneous materials and structures.

This task will be principal related to ESR-1 at individual project "Total energy minimization with stress conditions for mixed mode fracture in anisotropic heterogeneous materials and structures". The lead beneficiary of this project is Universidad de Sevilla (US) in collaboration with IMT School for Advanced Studies Lucca (IMT), Sorbonne Université (SU) and Robert Bosch (RB).

The main objective of this project is to use new computational methodologies based on the original formulations of Coupled Criterion of Finite Fracture Mechanics (CCFFM) with discontinuous representation of cracks and Phase Field (PF) with regularized diffused representation of cracks and the Principle of Minimum Total Energy subject to a Stress Condition will be developed and implemented in a Finite Element Method (FEM) code to provide accurate and reliable predictions for complex mixed mode fracture problems involving simultaneous crack onset, propagation, and interactions with interfaces in anisotropic brittle materials. New optimization procedures will be required, e.g., for CCFFM, a modified a staggered scheme aimed at global optimization in the feasible parameter-region given by the stress condition due to the efficiency of its computational implementation. Novel forms of the degradation and local fracture energy functions will be proposed to impose stress conditions in PF. Staggered hybrid CCFFM and PF schemes, providing necessary information to the PF algorithm in terms of suitable boundary/interface conditions or prescribed values for PF damage variable in each time step, will be explored. Validation of the computational tools developed by their application to industrial problems.

Although all ESRs working on anisotropic and piecewise heterogeneous materials will take advantage of general-purpose procedures and computational tools developed by ESR-1, these tools will be validated by ESR-3, ESR-6 and ESR-9 on multilayer ceramics, Short Fiber Reinforced Plastics (SFRP) composites and photovoltaics.

Expected results from this research project are:

- Validated computational tools for fracture predictions implemented in a FEM code for both CCFFM and PF based on PMTE-SC and a staggered hybrid methodology combining PF and CCFFM. The developed procedures will be available as open-source codes to encourage their exploitation in academy and industry.
- Applications of these procedures to several complex fracture problems at different scales in heterogeneous materials and structures studied in NEWFRAC.

ESR-1 planned secondment:

Scdmt	Months	Location	Comments
1	Month 10-15	IMT	Training in computational implementation of CCFFM and PF and their applications to fracture problems in photovoltaics
2	Month 35-38	RB	Validation of the developed computational tools solving industrial fracture problems in SFRP composites

Table 2. ESR-1 Secondments

ESR-1 will be registered in the Doctoral Program in Mechanical Engineering and Management of the International Doctoral School at US and included in a double doctoral degree agreement between US and IMT. In addition to network-wide training, ESR-1 will receive an extensive hands-on training in: Variational formulations of fracture mechanics; Implementation of FFM and PF; Computational optimization. ESR-1 will be enrolled into complementary courses in US and IMT.

b. Task 4.02: Adaptation of the new techniques to the fracture of ceramics

This task will be principal related to ESR-3 at individual project “Fracture analysis of advanced layered ceramics". The lead beneficiary of this project is Sorbonne Université (SU) in collaboration with Universidad de Sevilla (US) and SAFRAN.

Advanced layered ceramics are extensively applied in different engineering fields with high economic and societal impacts ranging from biomedicine, automotive engineering, aeronautic and aerospace industries, electronics, and renewable energy systems. The Phase Field (PF) approach of fracture and the Coupled Criterion of Finite Fracture Mechanics (CCFFM) proved to be reliable modelling tools in predicting crack nucleation in brittle and quasi-brittle materials. The principal aim of this ESR project will regard the consistent extension of both modelling tools for predicting crack nucleation in layered ceramics and thin films, and with special interest on shell-based structures. This methodology will allow the robust analysis of the influence of flaws and grain sizes and will focus on the role of residual stresses of various origins (thermal, chemical…) on the onset and growth of cracks. Since both methods rely on a characteristic length, which should interact with the already mentioned sizes, it is expected to provide plausible explanations for relationships between the microstructure and fracture properties at the macro-scale. Extensions to other materials with a different microstructure (amorphous: polymers, glass) could be considered.

ESR-3 will investigate fracture behaviour of advanced layered ceramics and will potentially interact with ESR-2 and 4 in a direct fashion. Further collaborations with ESR-11 and 12 regarding the development of advanced shells with damage capabilities and multi-scale techniques will be of crucial interest for the corresponding projects.

First related to the micro-scale, and then to a macroscopic and multi-field analysis focused on shells, expected results are:

- A new approach to implement the CCFFM and the PF approach of fracture at the micro-scale accounting for the residual stress effects and analysing the role of the microstructural definition.
- An explanation for the Petch law for ceramics why are there two regimes depending on the grain size and how to describe the transition between them.
- Corrections to bring to the measured tensile or bending strength to characterize the strength parameter to be used in fracture criteria.
- Formulation and numerical implementation of shell-based PF approach for advanced ceramics within a multi-field framework.

Planned secondment scheduled:

Scdmt	Months	Location	Comments
1	Month 12-15	US	Training in multilayer shells and the PF approach and for transfer of developed computational tools to industry
2	Month 35-38	SAFRAN	Fractures in injection moulded SFRP structures

Table 3. ESR-3 Secondments

ESR-3 will be registered at SU and its doctoral school SMAER and in US. In addition to network-wide training, ESR-3 will receive hands-on training in: Ceramic materials; Shells; FEM; Implementation of FFM + PF. ESR-3 will be enrolled into complementary courses in SU, US or other university. Internships are planned at University of Bordeaux (Month 10) and Montanuniversitaet of Leoben (Month 11) for training in the fracture modelling and mechanical reliability of ceramic materials, respectively.

c. Task 4.03: Methods for compressive crack analysis by PF

This task will be principal related to ESR-5 at individual project “Nucleation and propagation of compressive cracks (WP4)”. The lead beneficiary of this project is Sorbonne Université (SU) in collaboration with Eidgenoessische Technische Hochschule Zürich (ETH) and Robert Bosch GmbH (RB).

Recent results have proved that Phase Field (PF) approaches can quantitatively predict crack nucleation for mode-I loading. However, current models do not allow for a faithful prediction of the crack nucleation event in more complex loading conditions and materials. A further important limitation of PF models is their difficulty in reproducing fracture propagation under compressive loadings, despite the important amount of work on the subject. The principal aim of the ESR-5 project will be to investigate crack nucleation and propagation under compressive loadings and to propose novel extension of the PF approach to overcome the current limitations. The project will include theoretical and numerical developments. The new methodologies for PF applied to fracture in compression will imply the development of coupled damage-plasticity and multi-field models. The numerical procedures, based on the FEniCS framework, will be released into the NEWFRAC collaborative computational platform to benefit other ESRs. These procedures will be applied to compressive crack onset and propagation in LFRP laminates in aeronautical applications, layered ceramics with residual compressions, and bones.

To model inelastic deformation by PF, ESR-5 will collaborate with ESR-12, and for multi-field modelling with ESR-3, 9 and 12. For applications of the numerical codes developed to fracture under compression in LFRP composites ESR-5 will strongly interact with ESR-4, 7, 11 and 12, for fracture under compression in bones with ESR-8 and 10, and in ceramics with ESR-3.

Expected results from this research project are:

- A critical assessment of the existing approaches and the analysis of their limitations in reproducing experimental results.
- Theoretical formulation of coupled damage-plasticity models to account for fracture in compression, including the semi-analytical solution of simplified test cases in 1D and 2D.
- Numerical implementation of the above models in the FEniCS framework and development of the associated HPC solvers.
- Quantitative comparisons between simulations and experimental results at disposal from other ESRs and through the secondment in FIDAMC.
- Application to study fracture in LFRP composites, ceramics and bones.

Planned secondment scheduled:

Scdmt	Months	Location	Comments
1	Month 12-17	ETH	Development of PF applied to fracture in compression
2	Month 35-38	RB	Fractures in injection moulded SFRP structures under compression

Table 4. ESR-5 Secondments

ESR-5 will be registered at SU and its doctoral school SMAER. In addition to network-wide training, ESR-5 will receive extensive hands-on training in: Fracture Mechanics, FEM calculations, Damage, Plasticity. ESR-5 will be enrolled in complementary courses in SU and ETH.

d. Task 4.04: Adaptation of the new techniques to the study of debonding

This task will be principal related to ESR- 7 at individual project "Debonding of the reinforcement in LFRP and FRCM externally strengthened beams". The lead beneficiary of this project is Politecnico di Torino (POLITO) in collaboration with Eidgenoessische Technische Hochschule Zürich (ETH) and Foundation for the Research Development and Application of Composite Materials, Airbus Group (FIDAMC).

Externally reinforced structures are composite structures where the heterogeneity is due to the application of an external reinforcement to an existing structure in order to restore it or to increase its bearing load. The main objective of this ESR project is the analysis of the delamination of the external reinforcement in rectilinear and curved beams strengthened by thin Long Fiber Reinforced Polymer (LFRP) or Fiber Reinforced Cementitious Matrix (FRCM) composite. The problem has a great relevance since external bonding of Fiber Reinforced Composites is nowadays a common practice in strengthening of existing structures in general and in restoring of stone and masonry arches in particular. Furthermore, among the different failure mechanisms of strengthened structures, the reinforcement debonding is probably the most important one to be investigated because of his typical brittle and catastrophic character. A first goal of the project is to develop an analytical approximate solution for the interfacial stresses between the structure and the reinforcement, under different mechanical and thermal loading conditions. A second goal is the application of LEFM, FFM and its comparison with the numerical solution of the problem by means of the Cohesive Crack Model (CCM). A third goal is to understand the effect of cyclic loads by assessing the fatigue behaviour of LFRP-to-concrete joints.

ESR-7 will strongly interact with ESR-4, 7,11,12 and 13 dealing with layered structures. Especially, ESR-11 will benefit from the analytical results by ESR-7, while ESR-7 will exploit the knowledge acquired by ESR-13 about FFM and dynamics to assess the strength of FRP-reinforced structures under impact loads.

Expected results from this research project are:

- A deeper understanding of the edge debonding and intermediate-crack induced debonding mechanisms, gathering information about how to design the external reinforcement of beams to prevent failure. The study is expected to clarify the essential differences in behaviour between joints with flat and curved substrates and between reinforcements made by LFRP and FRCM during debonding.
- To develop analytical formulae, under suitable simplifying assumptions, providing the load causing debonding that will be useful in engineering practice. A good agreement between CCM and FFM approaches is expected. A successful comparison between the FFM and the CCM solutions would be an important goal since FFM would provide a useful tool for preliminary sizing of externally strengthened structures, limiting the use of the computationally expensive CCM to the final stage in the structural design.

Planned secondment scheduled:

Scdmt	Months	Location	Comments
1	Month 12-17	ETH	Training about the unfolding problem in curved laminates
2	Month 35-38	FIDAMC	Industrial applications of the tools developed for challenging unfolding problems in curved laminates used in CFRP aeronautical structures

Table 5. ESR-7 Secondments

ESR-7 will be registered in the PhD Program in Civil and Environmental Engineering of ScuDo the Doctoral School at POLITO. ESR-7 will be enrolled in complementary courses of his/her choice in POLITO, in Structural engineering and Applied mathematics and physics, among others. The host department, the Department of Structural, Building and Geotechnical Engineering at the Politecnico di Torino, holds excellent expertise in Structural and Fracture Mechanics.

e. Task 4.05: Adaptation of the CCFFM, PF and hybrid methods to biomaterials.

This task will be principal related to ESR-10 at individual project "PF modeling of fracture in the human femur". The lead beneficiary of this project is Eidgenoessische Technische Hochschule Zürich (ETH) in collaboration with Sorbonne Université (SU), Tel Aviv University (TAU) and Robert Bosch GmbH (RB).

ESR-10 will work at the development, implementation and testing of a Phase Field (PF) model for fracture of anisotropic biological tissues, with specific reference to the human bone, especially to the proximal part of the femur. First, ESR-10 will develop a suitable energy functional to account for anisotropic effects and for asymmetry between tension and compression, investigating the mathematical properties of different options and carrying out both homogeneous and localization analyses. ESR-10 will thus develop the macroscopic anisotropic PF model, carry out the theoretical analysis and numerical implementation phases, and test the model on simple geometries before extending it to the geometry of the proximal part of the femur. Subsequently, ESR-10 will work in cooperation with ESR-8 to formulate a scale transition procedure between the microscale, where ESR-8 will have developed local fracture initiation criteria based on FFM, and the macroscale, where crack propagation will be described. Again, in cooperation with ESR-8 ESR-10 will carry out numerical simulations of the experiments performed by ESR-8 to validate the developed tools.

ESR-10 will work with ESR-8 on the formulation of a scale transition procedure. ESR-10 will also interact with ESR-8 in the comparison of numerical simulation results with experimental results. ESR-10 will also collaborate with ESR-4, 6, 9 and 12 working on multiscale analysis by interchanging procedures and codes.

Expected results from this research project are:

- A family of PF models for anisotropic materials with asymmetry between tension and compression.
- A specific PF model for fracture of the human femur; 3) An experimentally validated computational multiscale framework for fracture in the human femur.

Planned secondment scheduled:

Scdmt	Months	Location	Comments
1	Month 13-15 & 25-27	TAU	Discussing, developing and implementing the micro-macro scale transition procedure.
2	Month 35-38	FIDAMC	Validation of the computational framework against experiments performed at TAU for developing and implementing scale transition procedures and validation of modeling approach

Table 6. ESR-10 Secondments

ESR-10 will be enrolled as doctoral student in the Department of Mechanical and Process Engineering at ETH. ESR-10 will be a member of the graduate school at the ETH. Specific training in advanced modelling and simulation techniques as well as training of PF modelling of fracture will be arranged at the group of Prof. De Lorenzis, where extensive know-how and experience on this topic is available

f. Task 4.06: Adaptation of the new techniques to the multiscale analysis of composites

This task will be principal related to ESR-12 at individual project "Fracture in fibre-reinforced thermoplastics (FRTPs) across the scales". The lead beneficiary of this project is University of Porto (FEUP) in collaboration with Universidad de Sevilla (US) and Robert Bosch (RB).

The advent of new manufacturing capabilities for manufacturing LFRP composites has introduced the possibility of producing highly efficient fibre-reinforced thermoplastics (FRTPs). Due to their inherent characteristics, thermoplastic matrices can overcome the brittle character and difficult recyclability of thermoset matrices. These aspects are of special interest in industrial applications since they encompass higher strain-to-failure, higher fracture toughness and damage tolerance and the ability to reshape and reuse/recycle. The objective of this project concerns the analysis of fracture in FRTPs across the scales, i.e., from the scale of the constituents (micro-scale level) to the scale of the laminate (meso-/macro-scale level). Specific aspects concerning the behaviour of different thermoplastic matrices, such as visco-elasto-plasticity and ductile fracture, and the interaction with the reinforcing fibres in terms of damage tolerance will be addressed at the micro-scale level. These aspects will be taken into account in the formulation of the appropriate constitutive models for the homogenised orthotropic material at the ply level for meso-/macro-scale analyses.

ESR-12 will interact with ESR-2, ESR-4, ESR-6 and ESR-9 concerning the development of multiscale approaches of fracture of heterogeneous materials, and with ESR-3, ESR-7 and ESR-11 by interchanging procedures, codes, and common perspectives in the analysis of fracture of different multi-layered composites. Additionally, it is expected that ESR-12 will collaborate with ESR-4 in the definition of robust characterization techniques for advanced composite systems across the scales (from the constituent materials to the multi-layered composites) and to validate the developed models in an industrial context.

Expected results from this research project are:

- Development and validation of PF models to predict the inelastic deformation and ductile fracture of thermoplastic matrices and thermoplastic-based composite materials.
- Study of the effect of different constituents on the meso-/macro-mechanical behaviour of thermoplastic-based composites. 3) Study of ply- and coupon-size effects on thermoplastic-based composites.

Planned secondment scheduled:

Scdmt	Months	Location	Comments
1	Month 10-15	US	Performing the formulation and numerical implementation of the ductile PF strategies
2	Month 24-27	FIDAMC	Training regarding to the application of FRTPs in the aeronautical industry and for testing of the developed computational procedures on industrial fracture problems in FRTPs

Table 7. ESR-12 Secondments

ESR-12 will be included in a double doctoral degree agreement between FEUP and US. In addition to network-wide training, ESR-12 will receive extensive hands-on training in Advanced analysis of composite materials and anisotropic elasticity, Constitutive modeling of thermoplastic polymer resins, Damage Mechanics and Plasticity in layered composite materials, Implementation of the FEM and a PF model coupled with plasticity, Experimental techniques for characterizing FRTPs

g. Task 4.07: Extension of the CCFFM and PF methodologies to dynamic fracture.

This task will be principal related to ESR-13 at individual project "PF and FFM for fragmentation and dynamic crack propagation in brittle materials and composites". The lead beneficiary of this project is Politecnico di Torino (POLITO) in collaboration with Universidad de Sevilla (US), IMT School for Advanced Studies Lucca (IMT) and Bottero.

The objective of this project is the study of fragmentation and delamination in brittle materials and composites under impact loads. The originality of the project is not in the topic, which has been the object of study for many years, but it resides in the numerical and analytical approaches used to tackle such a complex problem. The goal is to develop numerical and analytical approaches that are robust and devoid of the flaws typical of other methodologies, like the mesh dependency affecting the cohesive method, and the difficulty managing crack branching and coalescence characterizing the X-FEM. At that purpose, the PF approach will be applied to study fragmentation of materials subjected to high strain rates. Specific applications concern the optimization of the shape of glass products and of the microstructure of multigrain materials to improve their performance in a dynamic regime. Besides the study of fragmentation, the extension of FFM to dynamics will be an important objective of the present project. The dynamic FFM will allow one to investigate the crack initiation under impact loads. The goal is to provide a useful tool for preliminary sizing of materials and structures, limiting the use of computationally expensive approaches to the final stage in the structural design, while preserving a physical insight into the fracture mechanics problem due to semi-analytical relations. Such an approach will be mainly applied to the problem of delamination of multi-layer materials. Experimental impact tests will be also carried out in the Laboratory of Materials and Structures of POLITO in order to produce a reliable set of results useful for the validation of the numerical and analytical models.

Strong collaboration is foreseen with ESR-1, 7 and 9. In particular, ESR-13 will take advantage, for his studies on fragmentation, of the tools for CCFFM and PF developed by ESR-1; and will collaborate with ESR-7 for the development of a FFM approach suitable for dynamic conditions of loading. Interactions with ESR-9 will concern the analysis of the performance of materials for renewable energy applications in dynamics.

Expected results from this research project are:

- Implementation of computational methods and Finite Element procedures in research software, such as FEAP and Akantu.
- Generation of a large set of results on fragmentation for many different input data (material properties, microstructures, impact velocities etc.) to be critically analysed to investigate the effects of the microstructure on fragmentation.
- Parametric studies on simple problems with the purpose to shed light on the phenomenon of crack branching, for which a fully exhaustive explanation is still missing.
- Extension of the FFM to dynamics to provide a reliable tool suitable for preliminary sizing also for impact loads.

Planned secondment scheduled:

Scdmt	Months	Location	Comments
1	Month 13-15	US	Receive training on the PF approach both from the theoretical and computational points of view
2	Month 25-27	IMT	Get knowledge on practical problems related to fracture and delamination of heterogeneous materials in dynamic regime
3	Month 35-38	BOTTERO	For industrial applications of the developed tools to glass technologies

Table 8. ESR-13 Secondments

ESR-13 will be registered in the PhD Program in Civil and Environmental Engineering of ScuDo the Doctoral School at POLITO. In addition to network-wide training, ESR-13 will receive extensive hands-on training in computational fracture mechanics methods and high-performance computing. The study of fragmentation, in fact, requires the use of codes optimized for parallel computing to be run on big clusters of computers, for this aim ESR-13 will attend specific courses delivered by ScuDo as well as by other specialized institutions like the International Centre for Mechanical Sciences in Udine. M. Corrado will supervise ESR-13 for all aspects related to computational modeling, while P. Cornetti for analytical methodologies needed to handle FFM approach.

6. CONCLUSIONS

This Overall Research Plan describes in detail the general objectives of Work Package 4. It summarizes all the Individual Research Projects (IRP) of ESRs related to Work Package 4, focusing on the specific objectives to be achieved and on the methodologies and techniques to be used by these ESRs. This Overall Research Plan has been updated to consider the results of the presentations and discussions we had at our first extended Webinar (four 2-hour sessions) on November 2020.