Czech Science Foundation - Part C1

Project Description

Applicant: doc. Ing. Jan Vorel, Ph.D.
Name of the Project: Time dependent behavior of thermoset polymers with application to anchors

Thermoset polymers have been experiencing a boom in special fields of civil engineering. Compared to their classical appearance in the aerospace or automotive industry, in civil engineering applications they typically do not reach a fully cured state during construction. Therefore, the material may undergo post-curing causing a significant change in material properties. At present, a well-established modeling concept addressing the temperature and curing level dependent mechanical response of the thermoset polymers is still missing. Moreover, due to post-curing effects the standard accelerated testing of polymers fails to describe the viscoelastic behavior. Hence, the estimate of a structural lifetime spanning several decades remains an unsolved challenge. In this proposal an interdisciplinary approach combining extensive experimental testing and numerical simulations on multiple length and time scales will be employed to resolve this issue. More specifically, time dependent behavior of thermoset polymers with application to adhesive anchors will be studied.

A. State of the art

At the beginning of the 21st century, civil engineers more than ever faced the often contradictory demands for designing larger, safer and more durable structures at lower cost and shorter time. This has lead to the development of new and improvement of old materials. Often, new composite materials combining the positive characteristics of typically two materials have been invented. In many cases these combine a load carrying constituent typically in the form of carbon or glass fibers bonded to the cement or polymer based matrices. Their applications can be found in many engineering disciplines including the primary and secondary structures of modern transport aircraft [10], cars [9], the wind energy [27], bioengineering [26] and civil engineering fields.

In the aerospace industry entire structural members are often made from composites whereas in the building industry the use of polymer-based composites is limited. A typical area is the field of rehabilitation and strengthening where polymer based textile composites are often used. Other ever growing application are the post-installed fastenings applied to existing concrete or masonry members such as adhesive anchors. Even though the products and applications are quite different, the commonly found polymers are of similar characteristics and face analogous challenges:

- typically utilized **exothermally reacting thermoset polymers** (e.g., epoxies or vinyl-esters) without defined post-curing
- high **filler content**, including even cement and water
- uncertain **curing level** and, hence, the mechanical properties depending on the environmental conditions (a fully cured state is usually not reached)

Moreover, a large range of working temperatures starting at freezing conditions and exceeding 50°C, is typically expected during the lifetime leading to post-curing and related changes in mechanical properties. These changes have high impact especially on the performance of the structures or elements under sustained loads or cyclic loads. The importance of this topic can be demonstrated on the two severe disasters of ceiling collapse in Boston and Sagano [22], attributed to an insufficient performance of the installed anchors under sustained load. Therefore, the characterization of this type of materials is in high demand.

In the design of engineering structures (elements), the general requirements regarding failure (ultimate load), serviceability and durability have to be satisfied. Complying with these requirements calls for extensive testing or manufacturing of actual prototypes (automotive, aerospace industry). Owing to the high cost and material variability, the civil engineering industry often relies on standard testing procedures [1, 15]. Examples with prominent relevance to this proposal is the testing of adhesive anchors, utilizing mortars composed of a thermosetting polymer (e.g., vinyl-ester based and epoxy system) combined with a higher filler content (e.g., sand, stone, and cement) of about 40% in weight of particles [14], under sustained loads [16] or fire. In such a case, the effective material properties of the used polymer are functions of space and time which are influenced by installation, curing temperature history, storage and testing conditions.

In order to study the long-term performance of composites, a number of experiments have to be performed at various length scales. Note that small (nano/micro, meso) scale and full (structural) scale tests are distinguished. Material properties of interest include the reaction kinetics, associated curing degrees, viscoelastic properties, and standard mechanical properties such as stiffness and fracture. It is worth mentioning that the degree of cure influences the glass-transition temperature, brittleness, impact resistance, creep behavior or long term stability [39] and is dependent on both time and temperature [13]. The thermo-analytical methods such as the differential scanning calorimetry (DSC) and differential thermal analysis (DTA) can provide the necessary information about the curing process and the degree of cure of thermoset polymers [32]. Furthermore, an extensive studies in the composite community have shown (see e.g. [29, 31]) that the curing process can produce residual stresses due to differential chemical shrinkage and non-uniform curing degree throughout the structure. There are two main streams describing the curing process of composites: a) analysis of chemical reaction, heat generation and heat conduction, and, b) study of the evolution of stress and development of structural integrity. The temperature field, highly affected by the exothermic process of network formation, is usually modeled using the standard heat equation and Fourier's law. The phenomenological model proposed by Kamal [21] is generally adopted for cure kinetics. A first attempt to model the evolution of curing stresses was made by Plepys and co-workers [29] who used incremental elasticity to describe the evolution of stresses and elastic properties as a function of cure. A linear mixing rule based on the degree of cure, elastic modulus of uncured and fully cured resin was used in [6] to quantify the stress relaxation and chemical hardening. However, the foregoing contributions completely neglected the viscoelastic behavior of the polymer during network formation. This issue was addressed in [2, 24] by employing linear viscoelasticity. Recently, researchers [12] have proposed to model the evolution of the cure dependent (and therefore time dependent) material properties with the aid of integral linear elastic constitutive equations where a simple Tresca criterion is coupled to the crack band model [4] to capture the matrix microcracking.

The viscoelastic behavior of polymers is often determined by means of the dynamic mechanical analysis (DMA) allowing the characterization of the time dependence within a short testing time. The temperature dependency can be studied using a dynamic mechanical thermal analysis (DMTA) [19]. A combination of both techniques, DSC and DMTA, can be very useful to get a relationship between chemical and mechanical conversion of thermoset polymers [33]. However, the commonly used accelerated test methods based on the temperature-time superposition, allowing the testing of the long-term creep behavior in a matter of days or weeks, fail due to the post-curing effect and can be applied only for non-aging (fully cured) materials. The pioneering work in the theory of viscoelastic behavior of thermoset and thermoplastic polymers was presented in [3] and later in [7, 20]. Probably the most general nonlinear viscoelastic theory was proposed by Schapery [36]. A special case of the Schapery model called free volume approach was presented in [23]. However, to improve the prediction of the viscoelastic behavior in shear, a distortional term into the free volume in a phenomenological manner had to be introduced [30]. Note that the explicit explanation of the corresponding molecular mechanism was not provided.

To determine the standard mechanical properties of materials under consideration, a hierarchical approach has to be employed. While the materials are generally considered homogeneous on the meso-scale, they appear more like multi-phase composites on the micro-scale. To predict the material behavior in time, detailed knowledge of mechanical data at a reference time and their temporal changes are necessary. This implies a characterization of "homogenous" mechanical as well as rheological properties on the meso-scale as well as the properties of individual constituents on the micro-scale. To access these properties, micro- and nano-mechanical testing can be used, e.g., microhardness testing [5], nanoindentation [17]. The mesoscopic mechanical properties of polymers and polymer-based composites can be tested by a variety of standard testing methods. This includes classical tensile testing for the determination of Young's modulus, Poisson's ratio and tensile strength. Moreover, in combination with suitable theoretical concepts such as temperature time superposition [25], classical tension tests performed at different temperatures can also provide access to a polymer's multi-decade behavior.

Finally, it should be emphasized that the intended multi-scale modeling has the potential of improving the simulation-based design, performance and lifetime assessment of materials and structures. Such a framework would lead to a great improvement of the current approach of technical approvals for adhesive anchors based on a system level testing of products in partly standardized concrete [1, 15] which only incompletely captures the life-time performance. Multi-scale technique allows for investigating problems for which experiments are either impractical or impossible. It also enable extrapolations to unobservable duration (lifetime of structures) or untestable geometries.

B. Fundamentals of the project, its targets and time schedule

The proposed research project attempts to provide both experimental and numerical grounds required for future developments of polymer components. With our primary interest in bonded anchors commonly found at construction sites, we focus on two highly filled thermoset polymers. Owing to their specific chemical composition resulting substantially different properties the vinyl-ester and epoxy based material systems will be examined. Both systems are representative for a large group of polymer products available on the construction market. The carefully prepared experimental program will be accompanied by the solid theory based numerical modeling. The treat these two disciplines on the same footing is indispensable for multi-decade predictions during structural design as well as extrapolations to untested environmental conditions and structural configurations.

Project targets

In the proposed project, emphasis will be placed upon the development (formulation) of a complex hierarchical material model describing the most severe processes in the thermoset polymers (time dependent behavior) based on the extensive experimental testing. In summary, the project will encompass the following mutually interconnected topics:

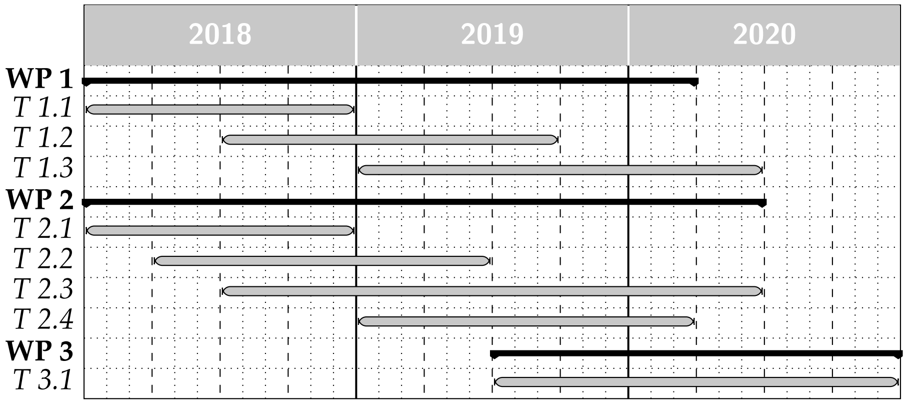
1. **General target:** An interdisciplinary approach combining experiments and simulations carried out on multiple length and time scales with the help of novel physically based multi-physics and multi-scale model.
2. **Specific tasks**
   - **Experimental investigation of thermoset polymers**: small (nano, micro, meso) scale material characterization of thermoset polymers taking into account the curing level, temperature and humidity.
   - **Numerical modeling of thermoset polymers**: theoretical and numerical framework for the prediction of temperature and humidity influence, calibrated by experiments.
   - **Lifetime prediction of bonded anchors for different loading scenarios**: validation of the developed concept against the full scale (structural) measurements such as the sustained load tests of bonded anchors at different load levels.

Validation and practical applications

An extensive experimental program concentrating on small scale experiments will be carried out at CTU in Prague to provide necessary for the validation of predictive capability of individual models developed in the course of this project. To proceed beyond the material level a close cooperation with Dr. habil. Roman Wan-Wendner, University of Natural Resources and Life Sciences (BOKU) Vienna is expected to obtain data at structural level from specific anchors' tests designed to meet the project requirements. The state of the art procedures developed in BOKU to provide specimens necessary for proper material characterization will further be exploited when preparing the specimens for small scale testing with particular attention accorded to partial curing of the matrix phase. This strong experimental support should promote the successful completion of this project. The letter of collaboration can be provided on request.

Timeliness and Work packages

The project management will be executed on the basis of 3 work packages according to the following time table:



Work package 1 (WP1): M. Šejnoha, P. Padevět, V. Hrbek, J. Schmidt, J. Vozáb
Extensive experimental investigation of thermoset polymers on different length scales.
The small scale testing of vinyl-ester and epoxy based thermoset polymers to provide information about reaction kinetics, material micro-structure, and material properties for different curing levels and temperatures. Owing to the project complexity only a limited range of humidity will be assumed.

Task 1.1: Micro-structure characterization to provide insights into the multi-phase nature of these materials.

Task 1.2: Micro-mechanical properties of individual phases of the studied materials measured on the nano/micro-scale.

Task 1.3: Meso-scale experiments for the material model validation.

Work package 2 (WP2): J. Vorel, M. Šejnoha, J. Sýkora , T. Janda, J. Havelka, S. Valentová, J. Vozáb
Development of numerical tool based on the multi-scale modeling for the aging thermoset polymers.
Implementation and basic validation of the most suitable modeling approach. Modeling of the long term, time dependent behavior of thermoset mortars needs the identification of suitable models for the cure kinetics, heat transfer, internal stress development and the non-linear viscous damage behavior.

Task 2.1: Extensive literature review of viscoelastic polymers followed by the implementation and basic validation of the most suitable model(s).

Task 2.2: Cure kinetics described phenomenologically by Kamal's equation. Adaptation of standard heat equations with internal heat generation, caused by curing, to get the temperature profile.

Task 2.3: Multi-scale modeling of thermoset polymers, calibrated and validated by experiments. Novel computational framework based on the idea of the microplane model in combination with nonlinear viscoelastic model(s).

Task 2.4: Identification/calibration of constitutive models.

Work package 3 (WP3): J. Vorel, J. Sýkora , T. Janda, J. Havelka, S. Valentová, J. Schmidt
Application of the developed predictive tools based to bonded anchors in different loading scenarios.
The capabilities of the proposed computational framework will be showcased by analyzing complex engineering problems which require a thorough understanding and accurate modeling of the curing process and creep behavior of thermoset polymers.

Task 3.1: Validation of the developed concept against the results of the sustained load tests of bonded anchors at different load levels.

C. Relevance of the project

Industrial aspects. Thermoset polymers are currently experiencing a boom in the construction sector and are increasingly used for special civil engineering purposes. Moreover, the outstanding properties of thermoset composites are boosting their application in primary and secondary structures of modern transport aircraft or cars. In particular, the proposed methodology has the potential to improve the design rules for these materials without the risk of cut-back in bearing capacity and other undesirable phenomena. A better understanding of the complex behavior can also be utilized by industry for the optimization procedure, design of experimental setup and uncertainty quantification of structures.

Scientific aspects. Present experimental program together with advanced constitutive models offers a valuable tool towards understanding and prediction of time dependent behavior of thermoset polymers. This research topic has become increasingly important in the last decade, and more and more research groups are focusing on structures made from these polymers. Without any doubt, this will remain an active field of research for years to come, and we believe that our team has the potential to contribute to its development.

Education aspects. Bearing in mind the extensive backgrounds of all team members and the expected participation of Ph.D., MSc. and Bc. students, it is obvious that this project will favorably influence students in both the undergraduate and postgraduate studies and will allow for the incorporation of the methods and techniques resulting from the project in courses within the Czech Technical University in Prague, specifically those specialized in advanced materials models. It is believed that the theoretical quality of the research team will also ensure that the proposed targets will be successfully completed as scheduled.

D. Conceptual and methodical approaches

The following paragraphs briefly outline the methods and theories which will be employed to achieve the project goals provided already in Section B (**Project targets** and **Work packages**).

Work package 1: Experimental investigation of thermoset polymers on different length scales.
leader: M. Šejnoha, personnel: P. Padevět, V. Hrbek, J. Schmidt, J. Vozáb

In the spirit of multi-scale computational framework addressed in WP2, a complex experimental program will be executed to provide necessary data on both micro- and meso-scale.

The micro-scale experiments should provide the basic morphological details exploited in the construction of the computational model discussed in WP2 as well as the material properties at the level of individual constituents. As for the micro-structure characterization the scanning electron microscopy (SEM) will be utilized. The subsequent processing of SEM-EDX analysis data combined with image analysis of SEM diagrams will allow for the discrete evaluation of chemical composition, representation and shape of different filler particles. Investigation of time dependent material properties will follow two streams. With reference to individual phases of the material (micro-scale) the nanoindentation measurements will be carried out to acquire basic data such as hardness and Young's modulus of filler particles and referential polymer matrix using standard grid indentation with statistical deconvolution of the measured data. The dynamic mechanical analysis (DMA) performed with modulus mapping technique of the indenter will be then performed to identify the viscoelastic behavior of the polymer matrix. The accuracy of measured storage and loss modulus will be checked using the SEM measurement of the resin shrinkage at the micro-scale together with the direct observation of incompatible strains and potential delamination development determined by digital image correlation (DIC).

At the level of composite (meso-scale) the DMA measurements employing the dynamic shear rheometer at a sufficiently wide frequency range will be carried out to provide data for the necessary validation of computational homogenization in WP2. These will be accompanied by standard creep tests at various strain rates and stress levels to classify the nonlinear viscoelastic properties of the composite (mortar phase). The results will also be adopted in the validation step of the selected viscoelastic model(s) similar to [40]. This will particularly be important when addressing the issue of different curing levels. While the temperature impact on material properties will be thoroughly investigated, the influence of humidity will be limited to small range.

Finally, to capture the expected volume changes during curing, free shrinkage tests starting with the specimen production and supported by DIC will be performed. The temperature evolution as a product of curing inside the specimen will be measured in parallel.

It is worth mentioning that all experimental results can be effectively exploited within Bayesian updating described in WP2.

Work package 2: Development of numerical tool based on the multi-scale modeling
leader: J. Vorel, personnel: M. Šejnoha, J. Sýkora , T. Janda, J. Havelka, S. Valentová, J. Vozáb

To describe the complex behavior of thermoset polymers at different length and time scales, the multi-scale modeling technique will be exploited. This approach can extend the understanding about the material behavior and allows us to investigate the behavior of bonded anchors for different loading scenarios if the concrete (masonry) properties are known and can be captured by the well-established material model, e.g., concrete damage plasticity model [18], LDPM [11], see WP3. In general, the multi-scale approach is based on the analytical micromechanical approach as proposed in [37, 40] or, if necessary, finite element methods [38]. The multi-scale multi-physics modeling of polymers has to take into account not only the direct and indirect mechanical loading by curing related eigenstresses but also the time evolution of the material properties caused for example by temperature.

The result of such complex multi-scale material models will be the necessary inputs for the simulation of structural components (full scale) made of a thermoset polymer such as the mortar layer in adhesive anchor systems. The mechanical behavior of the material model will be based on the microplane model [8] and the time, temperature and humidity influence will be taken into account based on the free volume approach [23]. It is believed that the coupling of microplane model and free volume approach will effectively capture the local dilatation strain and no artificial term as presented in [30] will be needed. Moreover, following [40] utilization of the generalized Leonov model [38] is planned to verify the aforementioned procedure. Implementation of this model either into OOFEM [28] or MARS (`http://www.es3inc.com`) softwares, see part G, is expected.

The input information for model setup, calibration and validation will be provided by the appropriate experimental tests found in the published reports or provided through additional experimental investigations including but not limited to nanoindentation (see *Task* 1.2), mesoscopic tension/compression tests, and compact tension test (*Task* 1.3). Moreover, to cope with the principal goal of this project specified in part B, the model (epistemic) uncertainties should be reduced. In particular, when dealing with the viscoelasticity problem, several input parameters of the constitutive model need to be identified/calibrated. In the classical approach, the deterministic identification strategies are used to achieve such goal, see e.q. [34]. Nevertheless, more valuable information about the material parameters can be obtained using different strategy known as Bayesian inference, see [35]. It involves both expert knowledge of the material, such as limit values of physical parameters, and information from experimental observations and measurements. In other words, it uses experimental data to update the prior uncertainty in the material description and results in a posterior probabilistic description of the material performance. In addition, unlike traditional identification techniques that aim at regularizing the ill-posed inverse problem to achieve a point estimate, the Bayesian identification process leads to a well-posed problem in an expanded stochastic space.

Work package 3: Application of developed predictive tool to bonded anchors
leader: M. Šejnoha, personnel: P. Padevět, V. Hrbek, J. Schmidt, J. Vozáb

The capabilities of the proposed computational framework will be showcased by analyzing complex full scale engineering problems which require a thorough understanding and accurate modeling of the curing process and creep behavior of thermoset polymers obtained by means of the procedures described in WP1 and WP2. Especially, the developed concept will be validated against the results of sustained load tests of bonded anchors at different load levels, i.e., comparison of blind predictions (no a posteriori adjustment of the parameters allowed) of the time-dependent behavior of the structural problem with experimental results. The data necessary for this task will be obtained from literature or from BOKU in Vienna which is approved for anchor testing. Bear in mind that concrete will be represented by the state of the art discrete multi-physics model LDPM [11] or concrete damage plasticity model [18] which will be independently calibrated using standard laboratory specimens. The ability to predict the structural response for different load levels does not only confirm the quality of the model but also provides major insights into the mechanisms and phenomena on lower scales.

E. Expected results of the project

The major deliverables of the projects will be publications in peer reviewed journals. In particular, five manuscripts are planned to be submitted. One manuscript is planned to be submitted to a peer reviewed journal within the first year, other manuscript within the second year and remaining manuscripts within the last year. Moreover, two articles will be submitted to peer reviewed journals indexed by Scopus such as Acta Polytechnica and two Ph.D. theses are also expected. The project results will also be presented at national and international conferences and in the form of invited talks at foreign universities. Moreover, the work in this project will provide several interesting conclusions applicable to industrial utilization and scientific developments:

- **Direct results**. Advanced tools for computational simulations of problems related to applications of bonded anchors. Determination of effective material properties at several structural material levels with respect to time and curing level. This should improve the predictions of long-term behavior of anchor systems in general with emphases on the service life.
- **Indirect results**. Novel multi-scale modeling strategy and material description will provide efficient and reliable estimates of complex response of entire structural members made from composites utilized in aerospace and automobile industry or structural rehabilitation. Specific applications include, e.g., window frames, fuselage, wings and engine casing of Boing 787 or Airbus 350; wind turbine blades; prostheses in bioengineering field.

F. International collaboration

The research activities within the project will be further complemented by ongoing international collaborations of the team members. In particular, we expect a close cooperation with the following scientist:

Dr. habil. Roman Wan-Wendner University of Natural Resources and Life Sciences (BOKU) Vienna, Austria. He is member of several technical committees of *fib*, ACI and RILEM, and is the chair of ACI 209-D on numerical methods in creep. His research activities fall in the field of fastening systems, numerical and experimental investigation of concrete.

G. Readiness of the applicant and departments

To fulfill the intended targets of the proposed project a well-balanced research team, consisting of one full professor, one associated professor, three assistant professors, three Ph.D. students, one MSc.

student and one Bc. student, is proposed. The team involves members who have a long-time experience in the field of experimental investigation and numerical modeling of heterogeneous materials on different length-scales.

The scientific activities of the Department of Mechanics at the Faculty of Civil Engineering, CTU in Prague encompass a wide variety of topics, such as solid, soil and structural mechanics, computer science and applied mathematics, reliability of structures and nano-scale modeling and simulation of cementitious materials. The research questions addressed in the project perfectly fit and further extend these activities. The computing infrastructure of the Department of Mechanics includes a powerful multi-processor cluster as well as the "standard" set of commercial scientific software (MATLAB - image analysis, data processing) and in-house open source codes (e.g., OOFEM - **O**bject **O**riented **F**inite **E**lement Solver (`http://www.oofem.org`)).

The laboratory at CTU is sufficiently equipped to fully support the necessary experimental program both on nano/micro-scale (e.g., SEM - Zeiss Merlin, Phillips; nanoindentation, SPM, DMA - Hysitron Instruments T700i) and meso-scale. Most of the meso-scale experiments at elevated temperatures will be executed using the MTS Alliance RT/30 testing device allowing for tensile, compressive, three-point and four-point bending tests with the maximum applied force of 30 kN. It is equipped with a thermal chamber with a temperature range -80°C to 350 °C and internal dimensions 60x25x20 cm. Plate-plate based Dynamic shear rheometer HAAKE MARS will be used for DMA testing on meso-scale. The preparation of samples as well as the full scale experiments will be conducted in cooperation with BOKU in Vienna.

H. Complementarity of the research team

The team as a whole will be led by the principal investigator Jan Vorel, whose profile is presented in Part D1 of this proposal. The remaining team members are:

prof. Ing. Michal Šejnoha, Ph.D., DSc. (*December 5, 1966, Prague, *h*-index 14, 531 citations)
Full professor since 2008. His research activities include geometrical and constitutive modeling of ceramic, metal and polymer matrix composites with random microstructure, constitutive modeling of soils, and modeling of transport processes in soils and composites and stochastic analysis of timber structures. He participated in modeling, testing and developing new ceramic and metal matrix composite materials; he developed and implemented several micromechanical models to accurately study material behavior of composite materials. In the project, his expertise in the micromechanical homogenization and viscoelastic behavior will be essential for a successful completion of WP1 and contribution to WP2. He is the author and co-author of 55 publications listed in Web of Science database.

Ing. Pavel Padevět, Ph.D (*June 6, 1971; *h*-index 4)
Assistant Professor, Department of Mechanics, Faculty of Civil Engineering, CTU in Prague. Specialization: Experimental methods with focus on investigation of material properties of the materials. Material science in the fields of cement, admixtures to the cement, creep of materials, unfired clay for building construction and other building materials. He will contribute to WP1.

Ing. Jan Sýkora, Ph.D. (*March 15, 1982; *h*-index 6; 84 citations)
His research activities include numerical modeling of heterogeneous materials (such as numerical homogenization, analysis of transport processes in heterogeneous materials, image analysis-based probabilistic characterization of random media), uncertainty quantification and updating in material modeling based on stochastic finite element method and polynomial chaos expansion. He will contribute to WP2 and WP3.

Ing. Tomáš Janda, Ph.D. (*January 23, 1980; *h*-index 3)
Research Associate at the Department of Mechanics, whose expertise is mainly in the development of non-linear constitutive models for cohesive-frictional and viscoelastic materials and Bayesian inference for general purpose stochastic models. Dr. Janda has a long-term experience in finite element method programming in C/C++. He will contribute to WP2 and WP3.

Ing. Jan Havelka (*March 20, 1988; supervisor: J. Sýkora)
A Ph.D. candidate, planned defense date is 06/2018, research activities in Bayesian identification, boundary inverse problems, and stochastic finite element method. He will contribute to WP2 and WP3.

Ing. Vladimír Hrbek (*September 8, 1988; supervisor: J. Vorel)
A Ph.D. candidate at the Department of Mechanics, with research interests in experimental evaluation of material properties at nano-, micro- and macro-level. He will contribute to WP1.

Ing. Soňa Valentová (*October 12, 1987; supervisor: M. Šejnoha)
A Ph.D. candidate at the Department of Mechanics, with research interests in numerical modeling and applied mathematics. She will contribute to WP2 and WP3.

Bc. Jaroslav Schmidt (*April 1, 1993; supervisor: T. Janda)
A MSc. student of Civil Engineering, who is currently collaborating on experimental program focused on the time dependent behavior of polymer based materials and related calibration of viscoelastic models. After the defense of his MSc. thesis, he plans to continue as a doctoral student. He will contribute to WP1 and WP3.

Jan Vozáb (*April 26, 1995; supervisor: J. Vorel)
A bachelor candidate of Civil Engineering, who is currently collaborating on viscoelastic characterization of polymers. After the defense of his bachelor thesis, he plans to continue in the collaboration. He will contribute to WP1 and WP2.

I. References

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