SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CA 17107
STSM title: Advancements in smart textile reinforced concrete, geotextiles and lighting
STSM start and end date: 04/12/2020 to 24/12/2020
Grantee name: Aleksandar Petrovski

PURPOSE OF THE STSM:

(max.200 words)

This STSM research is oriented to investigation of smart geotextiles and smart textiles for concrete, which are topics that are becoming more extensively researched, considering their application potential. Smart Textile Reinforced Concrete has proven as an outstanding building material. It enables versatility in its application for casting new structures as well as retrofitting. It has high sustainability performance in terms of reduced greenhouse emissions by minimizing use of cement, has the ability to be casted as thin-walled structural elements with complex geometries, and has flexible design possibilities, which designate this material system as an excellent candidate for many applications. Several studies show the correlation between the piezoresistive change of the electrical properties of the carbon tow and the change of mechanical properties under repeated loading representing the response to service live loads, thus showing its great application potential. Further, smart textile reinforced concrete structural elements are shown to have inherent sensing capabilities based on embedding metallic yarns in the textile mesh. Also, studies examine intelligent textile-reinforced concrete structural elements with sensing capabilities, a concept based on dual use of glass and carbon fiber textiles as reinforcement and, at the same time, as a sensory agent. The response to wetting, which is conditioned by the cracking of the beam and the exposure to ionicconductive solutions, provides a mean to monitor the functionality and the structural health of the textile-reinforcedconcrete beam.

Smart geotextiles have found wide application in the construction indistry. In geomechanics, the soil movements are hard to predict in natural environments. Hence, the application of smart textiles may offer a solution for manmade slopes and embankments. Additionaly, smart geotextiles are used in monitoring of sea dikes, which is commonly performed visually after storms.

The smart textiles can be greatly advanced by integrating monitoring functionalities within the existing reinforcement textile. Furthermore, integrated monitoring and real time information regarding the structural state of the TRC element can conceptually compensate for the reduction in material use gained by the unique thin walled structural layout.

Hence, the objective of this STSM is to broaden the knowledge and to identify the possibilities of smart materials and textiles for the creation of smart textile reinforced structures. The aims of this STSM are: to examine the advancements, to broaden the knowledge base and to identify the possibilities of application of smart textiles in concrete structures, as well as geotextiles and smart lighting.

The output results of the STSM will provide a solid knowledge base regarding the possibilities of smart textile materials for their implementation in new concrete buildings as well as retrofitting of existing ones.

By disseminating the findings, the STSM will contribute towards an increase of knowledge in the construction industry and the architects and an increase of the implementation of smart materials in the buildings and product design. The findings for the STSM research will be published in a relevant conference or journal, for which the CONTEXT Action will be greatly acknowledged.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

(max.500 words)
The topic of this STSM research is relevant to the work of Working Group 4 Smart textiles for building and living applications, of the CONTEXT COST action. Therefore, the work performed during this STSM research aims to contribute towards achieving the research objectives of the CONTEXT Action, regarding wider acceptance of the smart textiles among different stakeholders, especially the architects and the construction industry.
The topic of smart geotextiles is exciting and rellatively novel in terms of reserch as well as application in the construction industry. During the STSM stay several relevant state-of-the-art research studies have been examined, followed by investigation of comercial products and manufacturers such as: Pegase, Sylex, Tencate etc. The desk analysis and literature review started of with the analysis of smart textiles and geotextiles in the construction industry, followed by their application in reinforced concrete structures.
Further, the production process of smart geosynthetics, smart geotextiles, geogrids was investigated, such as knitting, weaving, embedding, coating etc. As shown in a research study, the knitted PET geogrids are carriers of fiber optic cable, where in the manufacturing process the PET warps thread are replaced by the fiber optic cable which is woven together in a double-axis warps-knitting machine. The geogrids are polymer coated for prevention of stripping of the fiber optic from the geogrids. Such smart geogrids are integrated with the fiber optic and have high stiffness, resistance to corrosion making them applicable for reinforcement, monitoring and measurement in civil enginneering.
Several light scatering technologies, systems and sensorsand their application are examined, such as: Raman scattering for temperature sensing, Distributed temperature sensing (DTS) , Rayleigh scattering detection techniques and OTDR, Distributed Fiber Optic Sensing (DFOS), Fiber Bragg grating (FBG), Brillouin scattering for strain and temperature sensing, Spontaneous Brillouin scattering and BOTDR, BOTDR, Stimulated Brillouin scattering and BOTDA, as well as sensors, such as: interferometric fiber optic sensors, which have four types (Fabry–Perot, Mach–Zehnder, Michelson, and Sagnac interferometer); FBG point sensors etc. Further, a literature review was performed of the state-of the art of available ITC technologies applied in smart textile concrete, smart geotextiles and lighting. Smart sensing technologies have been examined which can provide monitoring and the health condition of structures thus enabling prediction and prevention of their damage or failure. Such technologies and methods which have been investigated are: fiber optic sensing (FOS), global position system, wireless sensor network, particle image velocimetry, time domain reflectometry, microelectromechanical system, acoustic emission and laser scanning.
Several case-studies were examined regarding the application of smart textiles in civil engineering structures. The application ranges from sea dikes, tunnel shaft, embankments, mines, beams, pile foundatis, structural Health Monitoring of bridges, roads etc.
It can be concluded that smart textiles, have great potential due to their applicability, light weight, adaptable geometry, antielectromagnetic interference, excellent insulating characteristic, high sensitivity and monitoring, especially in long structures and distances. Downsides are the installation of the product and the need for trained workforce, as well as cost. Smart textile illumination were investigated, which, so far, are mostly developed for the wearables market.
Studies show that the future research should be in the direction of: cost-effective demodulation techniques for distributed fiber optic sensing technology; special opto-electronic sensors for geo-engineering monitoring and installation methods as well as advancing real-time monitoring data processing and early warning systems.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Geosynthetics is the generic term for a series of sheets or fibroid materials that are primarily applied in geotechnical and environmental engineering. Geotextiles are used in geotechnical engineering for: separation, filtration, drainage, reinforcement, stabilization, barrier, and erosion protection. They can appear in multiple forms such as geogrids, geotextiles, geomembranes etc., all made of polymers, and which are extensively used in civil engineering structure for reinforcement applications, notably in stabilization of highway slopes and embankments, reinforcement of foundations, reinforcement of paved roads to mitigate cracking and rutting, reinforing beams and columns etc.
The integration of fiber optical sensors give the smart geotextiles the advantages of superior electrical insulation, strong anti-electromagnetic interference, high sensitivity, etc. The monitoring smart geotextiles can provide is regrading the changes of mechanical deformation, temperature, humidity, pore pressure,

health of the structures, temperature, vibration, early detection of high failure and failure risk etc.
Fiber Bragg grating (FBG) is the first sensor applied to geotextiles, which can monitor small structures, but is not suitable for large structures such as dams, railroads etc., while also it is costly. However, the development of distributed optical fiber sensors enabled monitoring large-area geotechnical structure. Optical fibers usins Brillouin scattering (interaction between the light wave incident into the fiber and the elastic sound wave in the fiber) sensor enable the measurement of the external physical quantities. Further, polymer optical fiber sensor integrated geotextile provides a solution for a distributed measurement of high strain.Additionaly, graphene coating is used for the production of smart geotextiles, that enhances geotextiles thermal conductivity, high strength, weight reduction, stability, self repair, hydrophobicity, antibacterial performance (to prevent filter plugging), and temperature/pressure/humiditysensing function (temperature, pressure change, and leakage location detection) etc.
Application of smart geotextiles has been investigated in several research projects. A project regarding detecting failures or damages for river dikes “sensorbased geotextiles” employed fiber optical sensing technology integrated in geotextiles and installed in different test dikes, in which the sensors showed high measurement accuracy. Additionally, it has been shown that smart geotextiles with fiber optic cables can be reliably used for early detection of failure by identifying deformation and water leakages.
Smart textiles application in beams has been investigated considering that the carbon fibers have linear piezoresistive behavior and the required strain sensitivity. Therefore, researchers have embedded Torayca T-300-1K carbon strands in glass-fiber-reinforced plastics in order to monitor and measure the slope of the bending of a concrete strucutral cantilevered beam. However, certain production difficulties are noted.
Smart geotextiles have been examined regarding their application in reinforcment of strucutures in buildings. In that regard, piezo resistive fibrous sensors have bee inserted in carbon fiber composite based on three-dimensional woven reinforcements. The sensors provide mapping of compression and traction at the top and bottom of the reinforcement when bending thus monitoring the deformation patterns and mapping its stress-strain history. The manufacturing process is promising as it was shown that the sensors can be inserted during the weaving process thus forming network of sensors inside the reinforcement.
In the interdisciplinary research project EarlyDike a monitoring system of sea dikes is developed for the detection of changes in humidity and deformation, measured by smart geotextiles produced by yarn-based carbon sensors placed on a geotextile substrate. For the monitoring of the humidity and deformation, sensors consisted of two parallel fiber bundels attached to the geotextile are used without any conductive medium in-between. The benefit of the smart geotextiles for monitoring of sea dikes, compared to conventional monitoring strain gages is that the smart geotextile sensor can monitoring the full length of the structrue which can be up to several kilometers as in the case-study of sea dikes. For such smart geotextiles, parallel sensors have been used with a narrow stitching width for the increase of the contact surface of the filaments. The sensors are laminated by warp-knit threadsor stitching threads for the protection of the sensoring filaments. More specifically, Tailored Fiber Placement (TFP) is used for the application of the sensors on the geotextile. The sensors are stainless steel fibers and Polyacrylnitril based carbon fibers. Other researchers examined the sensor-enabled geogrid (SEGG) to add a self-sensing function to conventional geosynthetics enabling meausrement of their tensile strain. Researchers propose Fiber Bragg grating sensor incorporated into GFRP, a sensing network of fiber Bragg grating wavelenght division multiplexing (WDM)/spatial division multiplexing (SDM) mixing array composed of 18 fiber gratings. It is used for monitoring the settlement of uncompacted hydrous strata and can detect strain in a safe and stable manner. In order to ensure measurement accuracy, a new smart geosynthetic is developed by high-density polyethylene filled with carbon black used in landfills, deep foundations, and waste disposals. Smart geogrids embedded within FBGs are applied as reinforcement in tunnel excavation and it is concluded that they can be effectively used to measure strains. The fiber optic is protected PVC sleeve which has better strain transfer performance compared to nylon. The tensile experiment has shown that the wavelength of FBGs geogrids varies linearly and has a good consistency. The temperature experiment shows that FBG geogrids has slightly higher temperature sensitivity than normal FBG.
Sylex uses DTG manufactured fibers in their own sensing solutions for the monitoring of mechanical parameters such as strain, vibration, pressure, displacement and temperature. Therefore, strain gauges, extensometers, displacement, pressure and temperature sensors are manufactured based on robust Draw Tower Gratings from FBGS. Other research companies such as Com&Sens (Composites & Sensing), which is a spin-off company at Ghent University, specializes in applying fiber optic sensors to monitor composite structures; The University of Reading participates in the "Eureka project", where FBGS fibers re embedded within an innovative new design of composite train bogie; similar researh is conducted at the Institute of Building Structures and Structural Design (ITKE) at the University of Stuttgart.
The tendency towards sustainability drives change in the proudction of geotextiles. Considering that most geotextiles consist of polymers which induce environmental issues, there are possibilitis for the production of natural geotextiles.
The conventional sensors used in construction monitoring are applied after the structure is constructed.

However, in the smart textile production process the integration of sensors can be done in one production step, by placing the sensor in the textile. Such yarn-based sensors based on optical fibers have different mechanical properties from the remaing fibers of the textiles. Due to the different stiffness and diameter they should be carefully integrated and woven into the fabric, while at their ends an interface device needs to be attached for data transfering. Other type of smart textile is by using electrical conductive fibers which possess certain electrical conductive properties and used for the transmission of electrical signal, heating or electromagnetic protection. Such STs have applications in wearables, clothing, medics etc. They can also be used in the construction industry form monitoring electrical charge in buildings such as: production facilities, certain sensitive parts of hospitals etc.
The application of carbon fibers has been examined by several researchers regarding their changes in electrical resistance during tensile elongation. Other studies showed that the carbon fiber sensors can find application in strain measurements and micro-crack detection on composite materials. With the optical sensing technology, information on water leakage can be derived indirectly by monitoring temperature changes.
The ICT technologies used in EarlyDike System consists of a Sensor and Spatial Data Infrastructure (SSDI), for data collection and storage, dataflow management, as well as measurement, simulation units and enables the browser-based data presentation. The monitoring system integrates web services such as the Sensor Observation Service (SOS), GeoMQTT which is an extension to the Internet-of-Things (IoT) protocol Message Queue Telemetry Transport (MQTT), while for the data presentation Web GIS application is used, this enabling early warning syste, monitoring and the conditions of the dike construction.
Smart geotextiles can be used for predicting soil movements in slopes and embankments. Different materials are applied in the smart geotextiles, such as optical fibers to indicate soil movement, several fibers to correct for temperature variations (Geodetec, TenCate) or use localized gratings inside the optical fiber (MuST SMARTGeoTex Fabric, Roctest-Smartec). One of the issues noted in the production of smart geotextiles for soil movement monitoring is the resolution of the sensing yarn which affects the price affordability of the product. For solving this problem, the MULTITEXCO project proposes one optical fiber in a geogrid for soil stabilization, while the sensing technology is distributed within a distance of few mm. One readout unit is used for covering 100m of geogrid, while switching between fiber sections will reduce the costs.
Existing wall structure, especially older ones are prone to horizontal forces, such as earthquakes. Their reinforcement and retrofit can be done wy using smart geotextiles embedded in mortar composites, which can be further plastered or painted. The MULTITEXCO project proposes sensors in the smart geotextiles which can monitor the structural deformations of the wall or possilbe crack openings in case of earthquak, by integrating a printable sensor embedded in Eq-Top® fabric, which can be placed on vulnerable wall positions.
Additionally, in architectural large span structures prone to fluttering and ponding, or exposed by high working temperatures etc., there is the need of a continuous monitoring in order to to prevent damage. Therefore, miniature temperature sensors are integrated in hybrid fabrics with integrated electric leads enabling temperature monitoring, pressure monitoring and chemical sensing of gasses.
Polymer optical fiber OTDR technology and smart geotextiles are applied in railway embankments for its reinforcement and monitoring. In other application a standard PMMA POF is integrated in the geotextile for measurement of distributed strain behavior strain up to 40% on a length of 100 m. Further, in a real application for monitoring mechanical straining in mine, a thin rope-like geotextile placed between two layers of non-woven filter is used.
The production of smart geotextile may result in materials` instabilities in case of dynamic loads such as wind loads, water ponding and snow pile-up on the fabrics. Hence, enabling signaling of increased loads applied on the smart geotextile can give a early warning signs for action and protect the whole structure, achieavable by integrating flexible pressure sensors in a PVC coated fabric.
Smart textile illumination was investigated, mostly developed for sports and work wear. Osram for example integrates LED to clothing by sthitching. However, their inherent characteristics such as: integration of GPS monitoring, increased visibility, visual and audio signals for monitoring, prediction and alarming etc., make them suitable for application in the construction industry in structures, and in clothing for construction workers as well.

FUTURE COLLABORATIONS (if applicable)

The research stay enabled to establish new partnerships on the subject of smart geotextiles. The Hosts` experience in these topics is of significant support for a succeful research outcome of this STSM. The Host expressed great interest in continuing the work that we’ve started during the STSM. Together we have set activities in order to continue with the examination of smart geotextiles for civil structures, after the

completion of the STSM.
The STSM is of benefit for the STSM researcher and the Host as it enabled establishing network for future collaboration in terms of joint application for future research projects in order to advance the research in this domain. The knowledge exchange between the Host and the Guest provided means further a mutual collaboration in order to apply for joint research and EU funded project on similar subjects regarding smart geotextiles and smart textiles overall. Also, the STSM provided basis for establishing future collaboration and networking with possibilities for staff exchange, guest lecture and a joint work in educating students, conducting seminars and workshops for professionals and the industry. With conducting of the STSM, the applicant will bring the gained knowledge and skills to his home country and disseminate it with peers.
It has been agreed to continue with the analysis of the obtained results and to integrate them in research papers for a conference and journal such as Journal of Architecture, Journal of Architectural Design etc.