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Humidity and Strain Monitoring for Textile Reinforced Concrete

T. Quadflieg[1], S. Tomoscheit[1], T. Gries[1]

[1] Institut fuer Textiltechnik of RWTH Aachen University, Aachen, Germany

ABSTRACT: Textile Reinforced Concrete (TRC) is an excellent building material in terms of sustainability, disaster control and retrofitting of existing structures. Due to its thin-walled structure the TRC elements minimize the need of concrete material. This reduces CO_2 emissions and enhances the ductile failure behaviour. These advantages can be greatly advanced by integrating monitoring functionalities within the existing reinforcement textile. Since TRC elements are precast, the integration of sensors will not cause inefficiency in production. This also mitigates the risk of damage to the sensors during fabrication.

The development of textile-based sensors for structural health monitoring of textile reinforced concrete offers new opportunities. Among the wide range of sensing possibilities, the following two general principles will be presented: humidity sensing and strain/failure sensing within the component.

The humidity sensor detects water penetration through a building envelope or sewage pipes. It aims at the detection of ground water, leakage, broken pipes, or leakage in sewage treatment plants.

The component failure sensor will monitor the strain within the textile reinforcement and break at a specific elongation. Combined with preliminary information on the strain stress diagrams of the reinforcement textiles, this derives information about the inner component condition. This information is critical for the evaluation of damage in buildings after an earthquake or other natural or man-made catastrophic events as well as for the evaluation of the structural deterioration due to corrosion, ageing and other form of damage to the component.

Therefore the two fibre-based sensor principles, the integration of the sensors into the textile reinforcement, the embedment in TRC samples and the sensing properties will be presented.

1 INTRODUCTION

For many years buildings were designed to last long time and regarding the local climate to resist sun, rain and snow. Change in temperature can cause elongation and freezing water can lead to chipping. All these effects are happening rather slow and give the user a chance to report damages personally. In contrast to this approach disasters occure rather quickly und give only short time to respond accordingly. Also extreme weather effects such as floods, wind storms or earthquakes occur statistically more often. Not only the probability of such events is rising, but also the economic damage caused by them. Even more severe is the impact they have on people’s homes and life. Growing density in civil infrastructures opens a huge threat to great losses caused by disasters. The following figure displays the trend in economic losses caused by natural disasters [1].

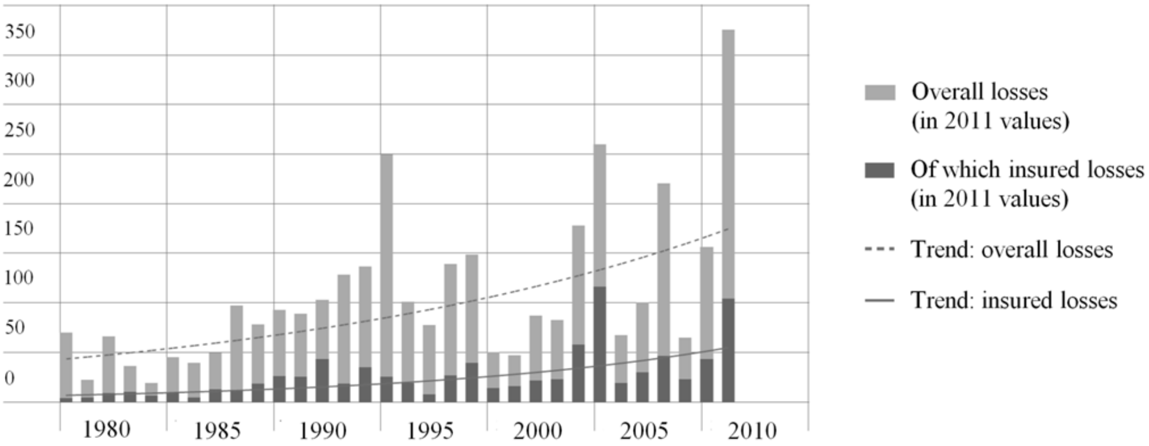


Figure 1 Total Economic Losses due to Extreme Weather Effects

Reasons for this development are the increasing number of world population and the increasing values in the threatened regions [2]. Two of the most harmful event are floods and earthquakes, which both do substantial damage to civil structures [3].

Two major threats resulting from these hazards can be derived: First component failure, which means the civil structure collapses and the building is partially or completely destroyed, and second flooded areas, which means certain protective components such as walls or dikes cannot keep up their function. Floods do harm the building structure in several ways, the following figure outlines the various ways water can penetrate into the building envelope:

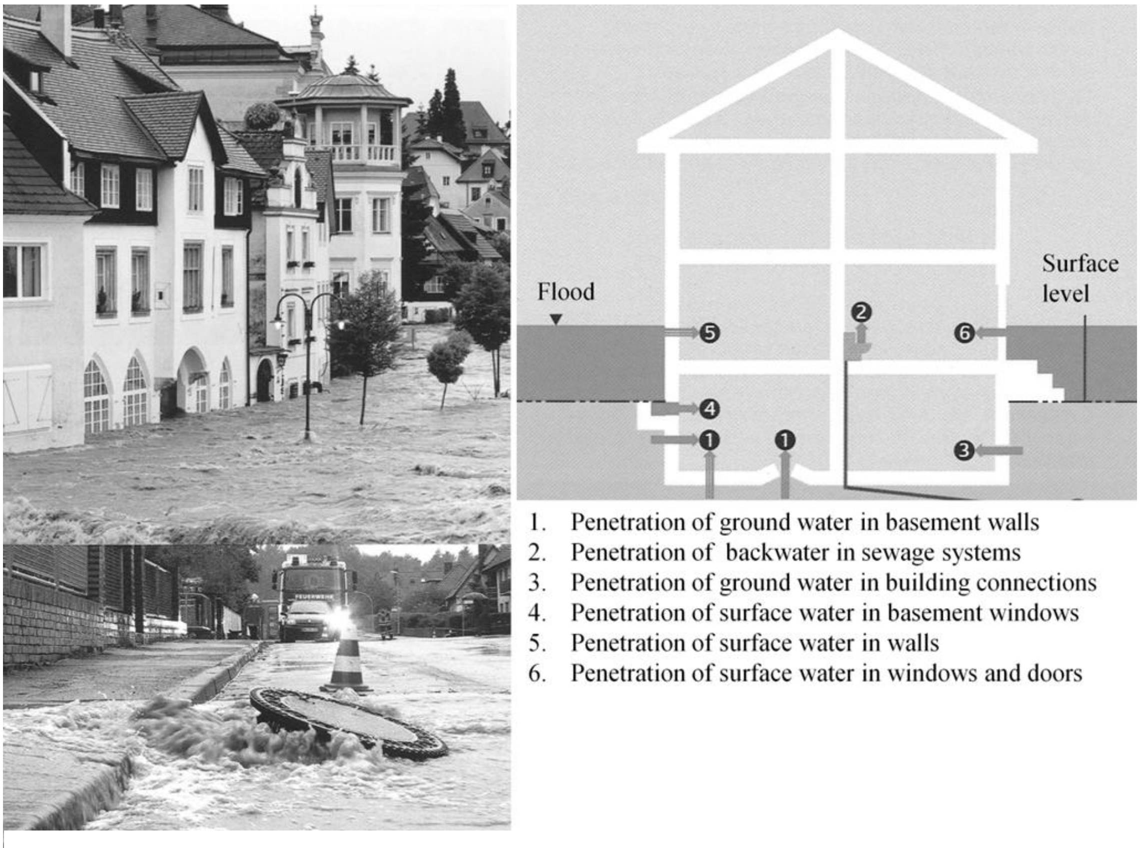
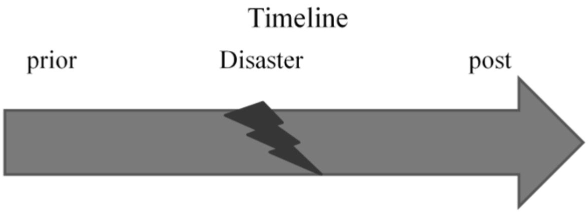


Figure 2 Threats to buildings caused by floods [4]

Regarding these damage mechanisms two sensor principles will be evaluated. First a humidity sensor will be introduced, which can detect leakage within civil structures as well as in pipes or dikes. Second a strain sensor will be introduced, which can detect strain within the component and therefore reports overload and destruction of a component.



With every incident it is important to know the condition of the buildings within three stages: before the incident, to undertake effective prevention measures and reduce the risk best possible. While the incident, to alarm people and activate rescue teams and first responders. And after the incident, to evaluate the amount of damage done and derive information about how to improve security systems. Within occurring incidents time is often the critical factor. Injured people and leaking tanks need quick response. Therefore the information about where the help is needed is crucial to a successful rescue. Sensors and information grids offer great a chance to provide this information. Because of the large areas, that need to be monitored, the sensor system needs to be feasible for large scale monitoring at a low cost level.

2 HUMDITY SENSOR

For integration of threadlike sensors the physical parameter, in this case humidity, needs to be transferred into a electrical signal (voltage). Electrical signals can be processed by the evaluation unit. Therefore the sensor layout was designed with direct correlation of change in measured properties and electrical properties (see figure below).

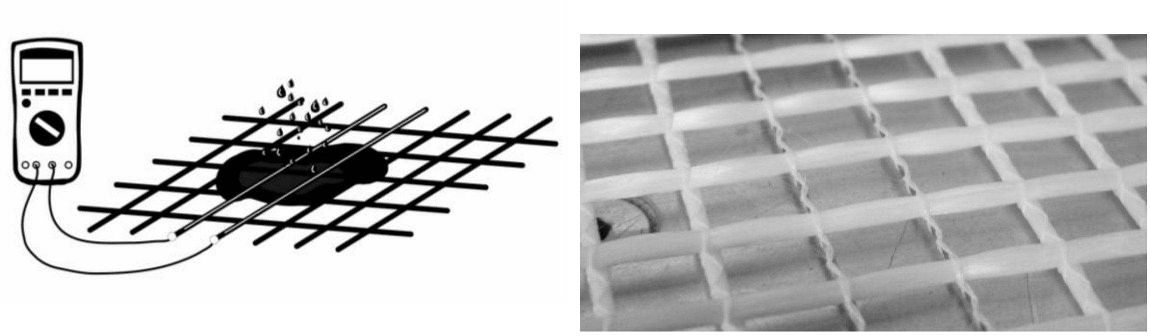


Figure 3 Humidity Sensor principle

The humidity sensor consists of two parallel lines, that are attached to the glass fibre reinforcement. The attachment can be done by stitching, sewing and adhesive bonding. In preliminary tests sewing proved to be the best production method in terms of production speed and accuracy of the sensor placement. This regards varying parameters for laboratory tests. In industrial scale the integration would be done within the textile processing of the reinforcement itself. Therefore no further production step is needed and also the machinery does not need to be changed. The sensor would be inserted as weft or wharp yarn in addition to the glas fibre. The steel fibres used consist of AISI 316L Stainless Steel with two twisted yarns with 275 filaments each. This means 550 filaments total with a diameter of 12 µm each filament. The yarn has 530 tex. Just from its size this exceeds a 67 tex polymer yarn, due to the higher densitiy of steel compared to polymers. The fibre has a full textile character, this means its stiffness and handling allow an processing with standard textile machinery. [8][9]

Without any conductive media in between the electrical resistance between two lines is infinitly large. To set a defined state for the dry sensor, a resistor connecting the two lines is added within the evaluation unit. The resistance follows the equation:

$$\mathrm{R}_{\mathrm{measure}} = \frac{1}{\frac{1}{R_{reference}} + \frac{1}{R_{humidity}}}$$

The reference resistor for measuring water was set to 100 kΩ and therefore the dry state is defined by this value. The water penetration was done within the dry textile reinforcement to characterize the behavior of the textile sensor systems under the influence of water. To cover a typical distance within textile reinforcements distances from four to twelve millimeter were excamined. (see following figure).

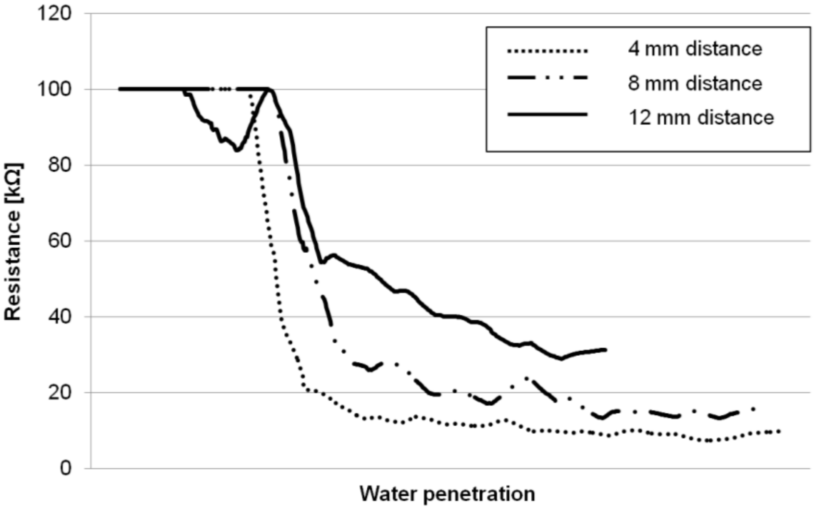


Figure 4 Resistance-Water penetration diagram of humidity sensors

The water was contributed on an area of 100 mm of the speciments. Within very few seconds response time the resistance between the two conductive paths changes. Compared to the dry state of 100 kΩ a clear distinction to the wet state can be made for all samples. For 12 mm distance between the two lines the resistance asymptotically reaches a level of 30 kΩ. For 8 mm distance between the two lines the resistance asymptotically reaches a level of 18 kΩ and for 4 mm a level of 15 kΩ. All distances show good behavior in terms of utilization as sensor fibres.

3 STRAIN SENSOR

The component failure sensor will monitor the strain within the textile reinforcement and break at a specific elongation. Combined with preliminary information on the strain stress diagrams of the reinforcement textiles, this derives information about the inner component condition. This information is critical for the evaluation of damage in buildings after an earthquake or other natural or man-made catastrophic events as well as for the evaluation of the structural deterioration due to corrosion, ageing and other form of damage to the component [5][6][7].

The strain sensor itself is attached to the textile reinforcements similar to the humidity sensor. The difference is, that for strain monitoring only one sensor line is needed. The change in resistance is characterized by the following equation:

$$\Delta R = \frac{\partial R}{\partial \rho} \cdot \Delta \rho + \frac{\partial R}{\partial l} \cdot \Delta l + \frac{\partial R}{\partial d} \cdot \Delta d$$

ρ: specific resistance, l: length, d: diameter

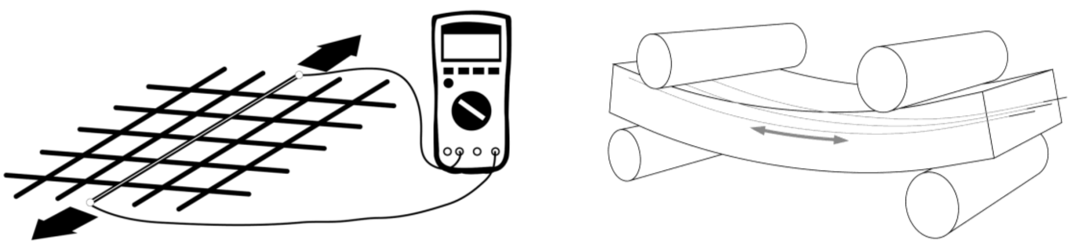


Figure 5 Strain sensor principle

Due to stress to the component the textile reinforcement gets stretched. The sensor attached to one of the rowing gets stretched as well and changes its electrical properties. The sensing principle is analog to the principle of strain gages. In comparison to strain gages the textile sensor works in a different scale. Strain gages cover local detection of stress and therefore need to be placed with high responsibility at the exact spot where the stress will appear. The textile sensor works with the full length of the component and in case of dikes up to several kilometers. The as strain sensor fibres copper, silver and stainless steel were tested and stainless steel proved best in terms of sensor signal and component behavior. The following diagram shows the correlation of the sensor signal and a glass fibre.

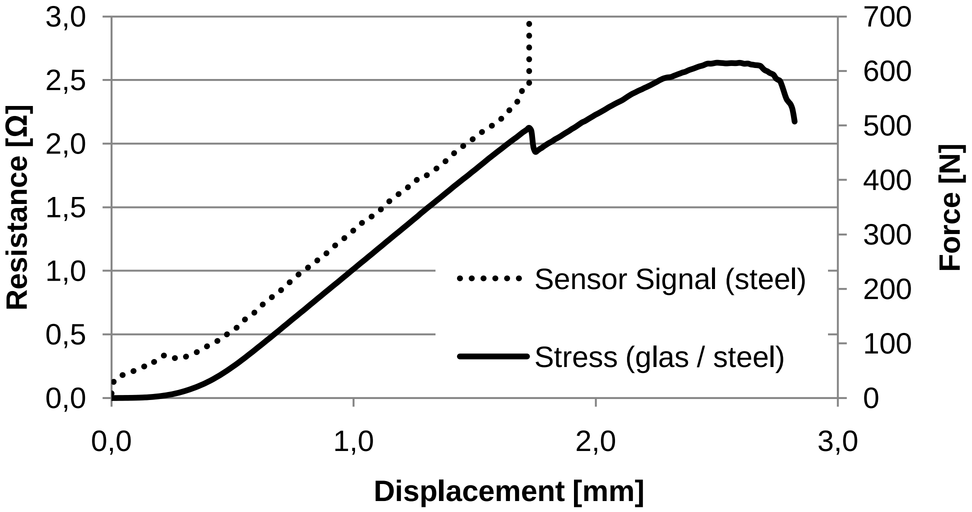


Figure 6 Strain-stress diagram of glass and steel fibres

The glass fibre bears load up to 600 N, the steel fibre attached to it breaks at 500 N, which is shown by the step within the stress curve. At the same time the sensor signal stops (infinite large value).

The two main results are:

1. linear proportional correlation of sensor signal and stress curve up to 80 % of maximum load
2. sensor breakage in critical stress area above 80 % of maximum load stress level

The almost linear signal behavior in low stress levels allows online monitoring of components and determination of actual load bearing status. The typical elongation for concrete applications is below 1.5 % elongation [10][11]. In this case the samples had a length of 125 mm, this means the usual working area for textile reinforcement applications is up to 1.8 mm within the diagram, which is almost exactly the point, where the sensor fibre broke. So for this load bearing status the sensor fibre shows very good suitability for online monitoring applications, such as dikes, bridges and load bearing structures.

Within the concrete matrix the suitability was tests with four point bending tests.

Figure 7: pictures of four point bending test

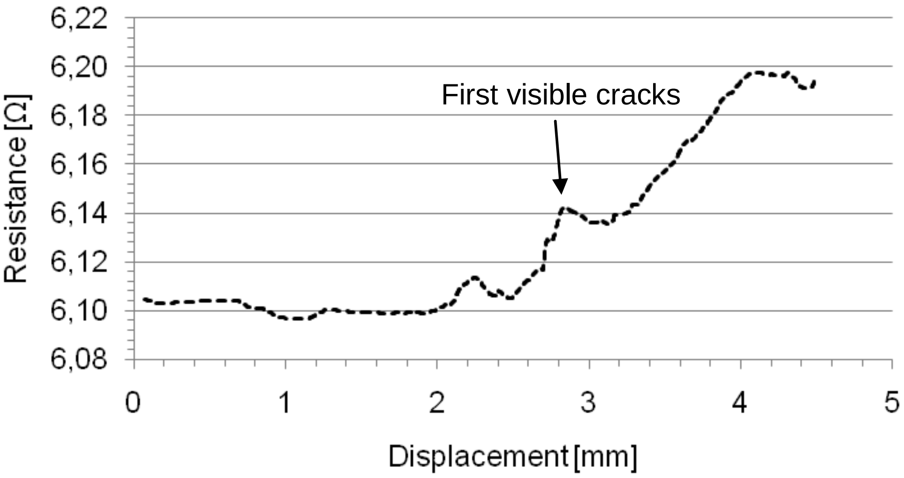


Figure 8: displacement / fibre resistance diagram four point bending test

The measurement of the resistance of the integrated steel fibres shows a correlation of the change in deformation and a change in the resistance in the range of 100 mΩ. Ongoing research is focusing on correlating inner component behaviour and the detection via the sensor yarn.

4 CONCLUSIONS

The humidity sensor detects water penetration through a building envelope or sewage pipes. It aims at the detection of ground water, leakage, broken pipes, or leakage in sewage treatment plants. Due to its flexibility in shape and thickness textile reinforced concrete offers a promising alternative to existing solutions. The humidity tests have proven a clear distinction between dry and wet condition. Further research will focus on 3D grids to provide also information about progress and distribution of liquids within the component.

The strain sensor offers good results within the typical working area of concrete below 1.5 % strain with a highly proportional sensor signal to the load bearing status. This enables the integration of online monitoring systems within load bearing structures. The breakage of the sensor at 80 % of the maximum reinforcement load offers opportunities in adding offline monitoring systems to large scale applications. In this case information if the component has faced high stress levels on the reinforcement is provided as non destructive testing method.

For both sensors stainless steel fibres were used, which offer great properties in terms of corrosive resistance, availability and price. The filament diameters used provide yarn like character and enable full compatibility to existing production methods for textile reinforcements.

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