MECHANICAL PROPERTIES OF ORGANIC AND SYNTHETIC PVA FIBERS

M. Přinosil[1], **J. Němeček**[2]

Abstract: *The utilization of natural fibers in building materials has a long tradition. For their proper application, their properties and material parameters must be correctly identified. This article deals with the evaluation of tensile strength and Young's modulus of elasticity of natural organic and PVA synthetic fibers. These material parameters are experimentally determined using uniaxial tensile test and nanoindentation and the results are compared with each other.*

Keywords: *Organic fibers, tensile strength, Young's modulus of elasticity, nanoindentation.*

1. INTRODUCTION

Current trends of sustainable development require the effective use of natural resources. One of the greatest consumers of these resources is the construction industry. Also in this branch of engineering, people are looking for new technological processes and building materials that would help to fulfill the idea of sustainable development. One of the possibilities is to increase the utilization of organic materials. A typical material is wood, its utilization is one of the basics of engineering. However, there could be more materials with potential application.

In our research, we are developing a mortar suitable for the restoration of historic buildings. It is a composite mortar with lime matrix reinforced with short fibers. This mortar is suitable for application in a masonry that is damaged due to tensile strains. These extensive strains can be brought into masonry by temperature fluctuations, soil deformations in the foundation or seismicity, whether natural or artificial. It leads to damage of mortar (masonry joint), which is a weaker link compared to the bricks and another masonry elements. The cracks then can pave the way for penetration of water with contaminants into the masonry. This leads to speed-up of degradation of masonry itself and the structure, which can result in irreparable damage. Our intention is to develop mortar with lime matrix reinforced with fibers, which shows pseudo-ductile and strain hardening behavior during tensile deformation and fractures in the form of fine distributed cracks – exhibits so-called multiple cracking [1]. Fiber reinforcement ensures the macroscopic integrity and the cracks in mortar have limited width, that prevents water penetration. This approach corresponds to the methodology developed for systematic design of brittle-matrix composites reinforced with short fibers. The methodology was successfully used, for example, for design of Engineered Cementitious Composites – ECC [2].

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Conservationists prefer the use of materials compatible with the original masonry for reconstruction. The presence of fiber-reinforced mortar was proved in a number of historical buildings [3]. Often it was waste material of organic origin (manure, straw, old fabric, sawdust, etc.). Their use was subject to experience rather then systematic research. As part of our intention, we investigate the use of organic fibers. This article deals with determination of material parameters of organic fibers and also synthetic PVA fibers.

2. EXPERIMENTAL RESEARCH

2.1. Selection of materials

At the beginning of the experimental research, it was necessary to select appropriate components of the composite, mainly the fibers. During the selection, the mechanical and economical criteria and availability of the fibers on the market were taken into account.

The fibers can be divided into two basic groups according to their origin - organic and artificial. Both groups have their advantages and disadvantages. Artificial fibers can be further divided according to the material into synthetic and steel. Steel reinforcement was refused with regard to use and appearance of the mortar. Synthetic fibers are easily accessible and individual types cover a wide range of properties. Their geometric and material parameters have due to manufacturing low dispersion, so that final properties of the composite can be easily estimated. From synthetic fibers, polyvinyl-alcohol (PVA – type REC15, made by Kuraray Company) were selected, which has been previously successfully used in ECC material and we have had experience with them.

The main reason for the use of natural fibers is their traditional use in historical mortars [3]. The appreciable disadvantage of organic fibers is inherent scatter of their properties, which may cause difficulties in the mix design. Organic fibers can be further divided according to their origin to vegetable fibers and animal hair. Vegetable fibers rapidly mineralize in alkaline environment of lime mortar [4]. Therefore, their use was refused. From animal hair, we take into account the sheep's, cow's, pig's and horse's, which have the best match with given criteria. Sheep wool contains a high proportion of lanolin, which slows carbonation of lime matrix. Therefore, this type of fibers was excluded.

Finally, four types of fibers were tested – horse (also marked H), goat (G), pig (P) and PVA (PVA).

2.2. Uniaxial tensile test

The principle of uniaxial tensile test consists in continuous increasing of deformation of the fiber up to its failure. The experiment was performed by means of the MTS Alliance RT/30 machine. The experiment was controlled by the crosshead displacement applied at constant rate 0,3 mm/min. During the process, the crosshead displacement, force and deformation of extensometer were continuously recorded. Furthermore, optical measurement of displacement was performed using optical camera with macro lens. Before the test, diameter of individual fibers d_f was measured in optical microscope. After that, the fibers were glued to jigs attached to the loading machine. Free length of the fibers between jigs was measured using optical measurement and was approximately 5 mm. Testing set-up is shown in Figure 1. From the obtained stress-strain diagram, the Young's modulus of elasticity E_f and tensile strength f_t of individual fibers were evaluated. Each set of organic fibers consisted of 10 specimens, set of PVA fibers consisted of 5 specimens due to the smaller scatter of properties.

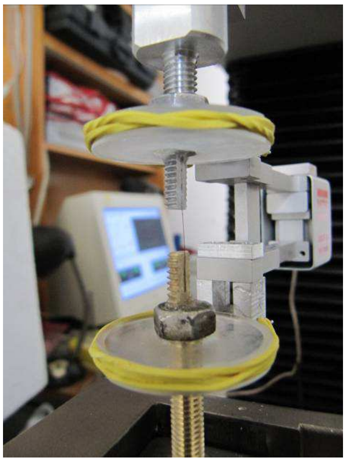


Figure 1: Uniaxial tensile test - testing set-up

2.3. Nanoindentation

The principle of nanoindentation consists in pressing of very small tip into a material. The experiment was performed by means of the CSM Nanohardness tester (Figure 2) with pyramidal (Berkowich) tip. Maximum force was set to 1 mN applied at constant rate 12 mN/min for organic fibers and to 0,5 mN applied at constant rate 6 mN/min for PVA fibers. In both cases, the hold period at maximum force was 15 s. During the process, the penetration depth and loading force were measured. In order to ensure parallelism between the fiber axis and direction of penetration, the fibers were aligned into the supplied frame (Figure 3 left). Then it was casted into highly viscous resin (Figure 3 right). This preparation was cut into 5 mm thick specimens, which were mechanically polished. Using this method, the specimens for nanoindentation were prepared, which were also suitable for measurement of diameter of fibers using optical microscope. From the depth-force diagram, the Young's modulus of elasticity E_f and hardness were evaluated. Each set consisted of 9 fibers, which was cut at least in 3 specimens.

Figure 2: Nanoindentation - testing set-up

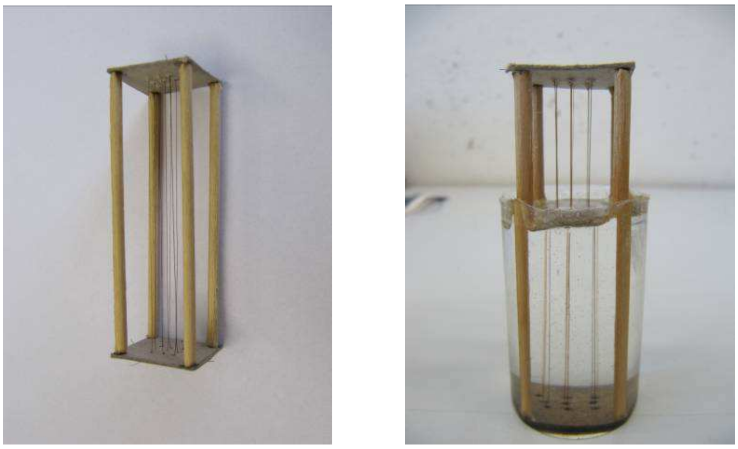


Figure 3: Nanoindentation - specimen

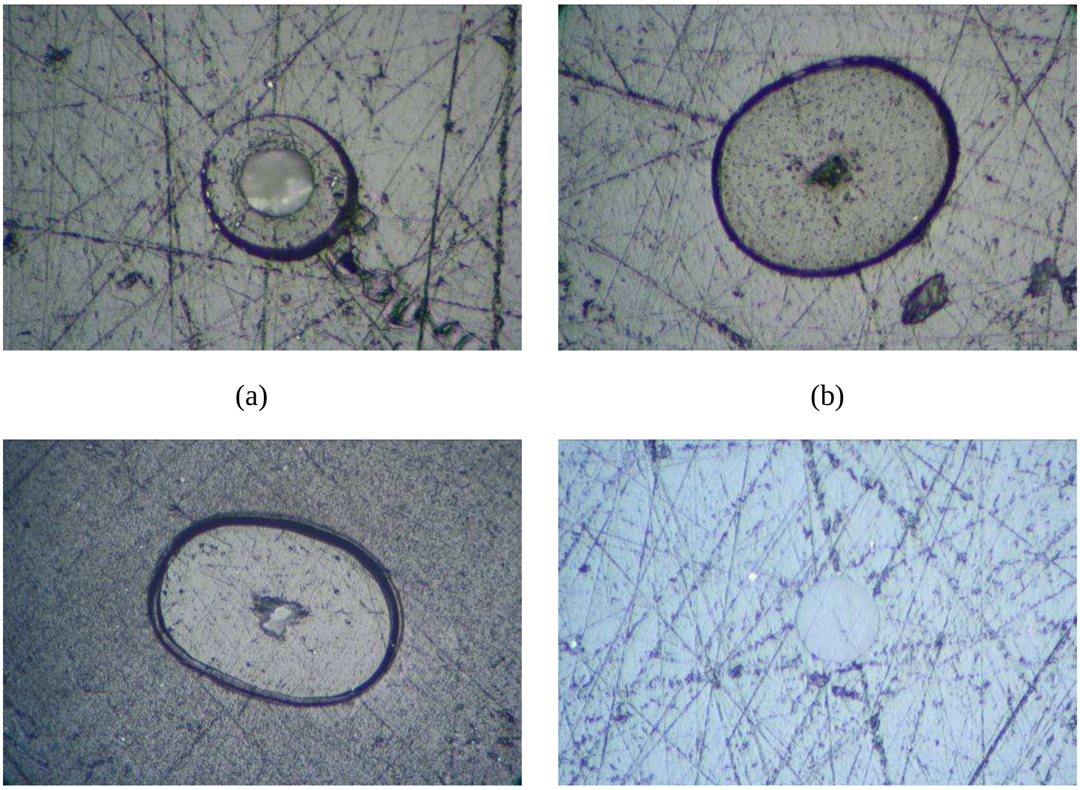
3. MICROSTRUCTURE AND FIBER COMPOSITION

Microstructure of natural wool has a similar composition as human hair [5]. We expect that all organic fibers in our research have similar composition. The basic element is α-keratin. The keratin is composed of high content of cystine. This amino acid forms intermolecular disulfide linkages of proteins and significantly affects the mechanical properties. In addition, hair is rich in peptide bonds and hydrogen bonds between groups of chain molecules. The fiber consists of three basic layers (components) – Cuticle, Cortex and Medulla. Cuticle is the outer protective membrane. It is composed of flat cells that overlap each other from root of the fiber to the tip. The cuticle in human hair is 5-10 scales thick. Each cuticle cell is composed of the cell membrane on both surfaces and three major layers - epicuticle or A-layer (>30% cystine), exocuticle (>15% cystine) and endocuticle (~30% cystine). The high content of cystine determines noticeable mechanical parameters. Cortex takes up a major portion of cross-sectional area of the fiber. It is composed by the cell membrane, cortical cells and intercellular binding material. The intercellular cement has a low content of cystine (~2%). Elongated cortical cells are aligned in the fiber direction. These cells are mainly composed of macrofibrils. Each macrofibril consists of microfibrils (~6% cystine) and the matrix (~21% cystine). The medulla is the central part of a human hair that contributes negligibly to the mechanical properties of the fiber.

4. RESULTS OF THE TESTS

4.1. Optical measurement

Using a digital camera connected to optical microscope, the high resolution image of each fiber was taken at magnification 250 or 500. These images were further analyzed. In each photo, the fiber surface area was measured and for organic fibers also the area of the cavity. Furthermore, the ratio of these values was calculated. Examples of images are shown in Figure 4 and the results are summarized in XXX.



(a) (b)

(c) (d)

Figure 4: An example of (a) goat (b) horse (c) pig (d) PVA fiber

4.2. Uniaxial tensile test

Obtained stress-strain diagrams are shown in Figure 5. Young’s modulus of elasticity E_f was evaluated from the slope of initial linear-elastic part. The results of organic fibers have almost bilinear character with high ductility in the tens of percent. Tensile strength of organic fibers was evaluated as the load level at which the fiber began significantly plastically deform.

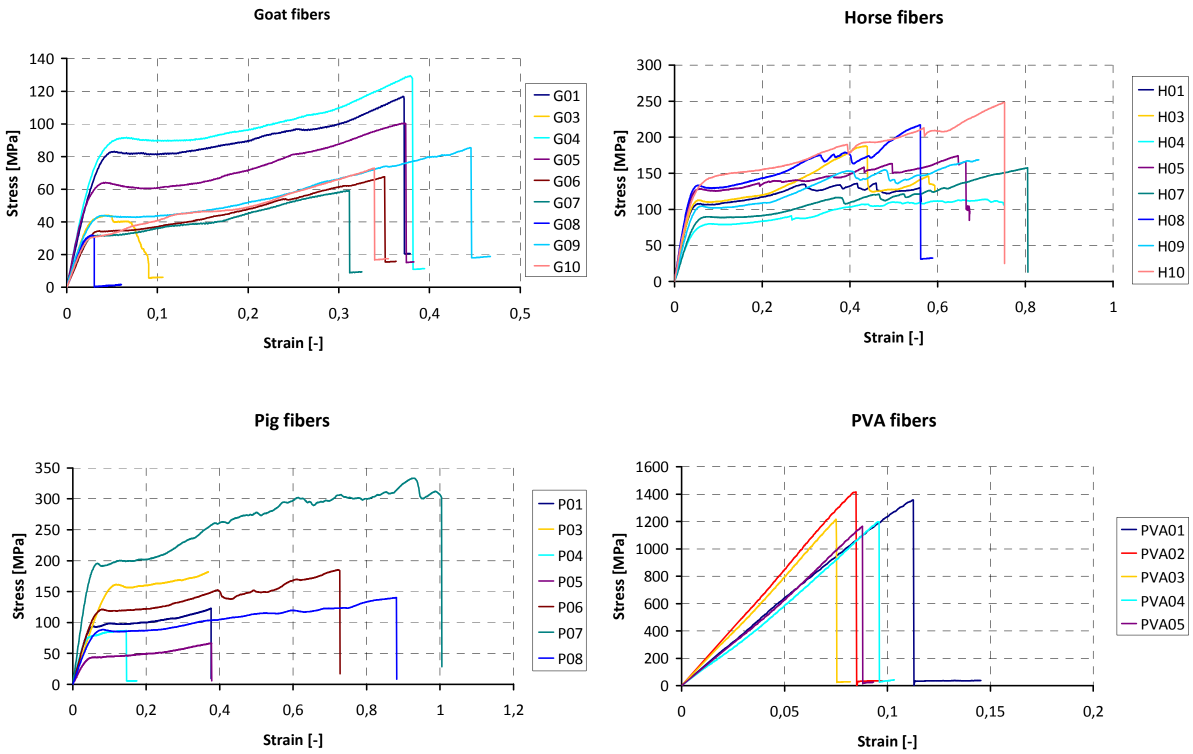


Figure 5: Stress – strain diagrams from the uniaxial tensile tests for individual groups of fibers

4.3. Nanoindentation

5. CONCLUSIONS

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