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An experimental preparation of fibre concrete to software's detection of fibres

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Abstract. Fibre concrete requirements are only met if the fibres in its volume are evenly distributed. Their direction and orientation should be equal around each axis in a three-dimensional space. The requirement is that the fibres to be evaluated in the final hardened fibre concrete are cut from fibre concrete sections. Homogeneity can also be verified on fibre-concrete cross-sections. Fibre Position Evaluation is a mathematical task that is not presented here but is currently made up of the results of this experiment. In the first step, it was necessary to prepare samples to obtain the necessary cross-sections. In the next step, it was necessary to create conditions by creating a contrast between the fibres and the concrete to create software capable of detecting fibres. In this paper, the principle of detection of fibres based on the detection of cut section images is described. There are several methods used to highlight the concrete matrix over the fibres. Also presented are the results of adding and detecting fibres.

1. Introduction

The basic requirement for full-fledged effect of fibres in steel fibre reinforced concrete "SFRC" is even distribution of fibres called homogeneity. SFRC refers to composite material exhibiting higher strength characteristics, consisting of concrete, and fibres. SFRC is a cement composite, which is characterized by high tensile and flexural strength. These are the qualities of demanded and utilized in modern architectural elements of structures.

The deployment of fibres in fresh or hardened concrete has been the subject of several studies, for example [3, 5, 7]. SFRC has been investigated by different devices through metal detectors to X-ray machines [8, 9, 11, 16, 19, 20] or by electromagnetically methods [9]. To ensure homogeneity of fibres in concrete is not a straightforward process. The purpose of measuring and experiments was to determine how the fibres in concrete are actually arranged and define the uniformity of fibre arrangement, i.e. homogeneity. A number of factors come into play during the process of manufacturing fibre reinforced concrete structures that influence the final layout and orientation of the fibres. The ideal approach would be to orient the fibres according to the load direction of the structure. As part of the research it is also necessary to follow the direction of fibre rotation according to the direction of filling of the sample [12, 17]. The choice of fibres in the production of SFRC structures plays an important role. As a matter of fact, the shape of these structures during the production affects the final position and arrangement of the fibres. The orientation factor of the fibres affects the



direction of the fibres and therefore the dimensional characteristics of the beams are crucial to choosing the length of the fibres [6, 10]. All experimental research was conducted in laboratory conditions. In practice, however, inspection directly on the site with the results of the right steps in the implementation of SFRC structures is required.

2. Materials and methodology

2.1. Materials

Material used. Mixed Portland cement CEM II / B-M (S-V-LL) 32.5 R, mined aggregate and steel fibres 60 mm long and 1 mm in diameter were used to produce the six fibre-concrete samples (beams). As for the concrete production, a fresh reference concrete formula was used, according to EN 14845: 2007 [21- 24] with water to cement ratio of 0.55. The cement dose amounted to 320 kg/m³, water dose 176 kg/m³, aggregate fractions 0/4 mm and 8/16 mm aggregate fractions [21] were loaded both with 952 kg/m³. The dosage of the fibres [1, 13] was determined according to the draft for floor structures - 30 kg/m³.

Experimental beams. For research purposes and to verify dispersion ratings of the reinforcement, beam samples with dimensions of 150x150x550 mm have been produced (Figure 1). The beams were cut into smaller parts with dimensions of 100 mm. The cut surfaces of the fibre-reinforced concrete beams (150x150 mm) were photographed and analysed with the help of a software program. The developed software was supposed to identify the number of fibres, their direction and spatial orientation taken from the images of fibre-reinforced sample cuts.

Cutting samples and photography. The cutting of experimental beam samples was conducted on a bench saw with a high-speed cutting disc. The beam has been slid on a sliding table (runner) at an appropriate speed so that the fibres on the surface of the cut would not have been deformed. Diamonds on the cutting disc could damage the surface of the transacted fibre, which may result in lower light reflection during photography. This may cause an incomplete loading of fibres by the developed software. In the case of damaged fibres, the surface of the cut may additionally be sanded, achieving a straight cut surface of the fibres.

The fibres used in the experimental beam sample production were selected with respect to its dimensions and were identical with the fibres used to produce the SFRC structure. The direction of detected fibres is dependent upon the indicative factor of the structure and therefore the dimensional characteristics of the beams crucial to the choice of the fibre's length. The orientation factor has been the subject of the research [6, 10, 15] and indicates the direction and position of the fibres at the edges of the sample. The casting walls have a big impact on the direction of the fibres and therefore the indicative factor is in the element's middle $\alpha_1 = 0.5$; $\alpha_2 = 0.6$ and at the edges $\alpha_3 = 0.84$. Depending on the shape of the casting the " α " is calculated as a total. The fibres were thus selected with a length of 60 mm and a diameter of 1.06 mm. Their slenderness ratio equals to 55. Slenderness ratio characterizes the shape of the fibre and determines the ratio of fibre length to its thickness. The same formula was used in the concrete implementation of SFRC floors [18, 4] in industrial buildings.

2.2. Design of the contrast

Chemistry contrast. According to the available chemicals to enhance the contrast of colours between concrete and fibres, we chose primarily the use of concrete surface properties. Specifically, it is the use of cementitious alkalinity in concrete, which can be used to stain the surface of a fractured concrete surface with acid-base indicators. Indicators are substances that change its characteristic features indicate the change or the current status of the chemical composition of the system. Colour acid-base indicators change colour depending on the pH value of the material [2, 14].

The cement stone in the concrete is alkaline (the pore liquid has a pH value about of 12 to 13.5 depending on the type of cement used). Acid-base indicator solutions change a pH value dependent staining. The bromothymol blue used has a yellow colour at a pH value less than 6.0 and turns blue at a pH value greater than 7.6. Colour of "A" represented the wet surface of concrete with a pH value

about 12 to 13 using the obtained blue colour indicator (Figure 1 on the left). A similar change occurs even with the use of an experimental substance - phenolphthalein. For this experiment, the acid-base indicator phenolphthalein was chosen as its alcoholic solution. It stained the concrete surface to red, that can be seen in figure 1 on the left side labelled as colour "B". In the latter case, substances were used to colour the surface of the concrete using other added chemicals. By rubbing the surface of the concrete with potassium ferrocyanide and adding a solution of ferric salts (in my case ferric nitrate) gives us a blue precipitate, called as *the Berlin Blue*, labelled as colour "C" in figure 1 on the left side. The concrete surface is coloured only if it is still not carbonated.

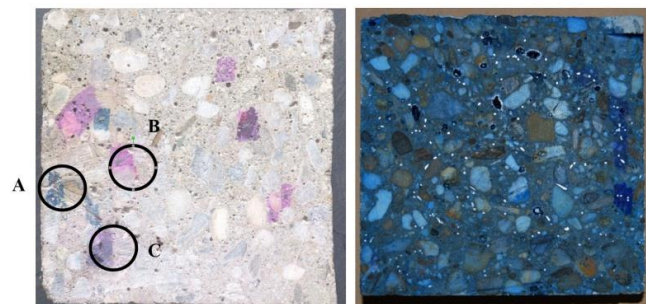


Figure 1. Left sample with chemical tests, right sample with pen ink. A: bromothymol blue; B: phenolphthalein; C: potassium ferrocyanide and ferric nitrate.

Mechanics contrast. The sawing speed is signed in the grooves formed on the exposed fibre surfaces. This is an undesirable effect for surface shooting because the fibre surfaces do not form a single-coloured surface, but several shades. Elimination of this deficiency would consist in additional grinding. For grinding, we chose a water-cooled electric grinder and grinding wheels used for grinding and polishing ornamental stones and marble. It is a powerful grinder with a smooth blade that reaches a smooth and flat concrete and fibre surface at high speeds (Figure 4 and 5). In this way, the formation of a better surface was achieved and the fibres had a flat surface capable of reflecting enough of the same light in the image.

2.3. Photography

The camera was placed on a tripod to achieve higher image quality during imaging (Figure 2). Additional flash has not been used during imaging, so the software is also able to process the reflection of natural light from the fibres. Shiny surfaces of the cut fibres with higher reflectivity than concrete reflected more light. Thus, they appear on images as bright areas (areas with high brightness). Imaging is conducted on all surface cuts. The cut surfaces have not been additionally treated.

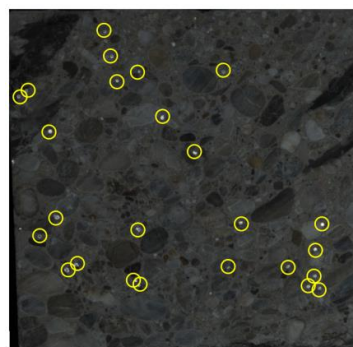


Figure 2. Manual fibre counting.

2.4. Analysis software

To search for fibres a specific application has been suggested (Figure 3). The basic application is designed in C ++. The application architecture is built to make use of external libraries OpenCV. OpenCV is an open-platform library designed for image processing. It is focused on the computer vision and image processing in real-time [25]. Graphical application environment is created in the library of the Microsoft Foundation Class Library (MFC), which encapsulates the Windows API in C ++ classes, ensuring full compatibility with most Windows platforms. Used technologies ensure scalability of the application and expandability of the new features in the future.

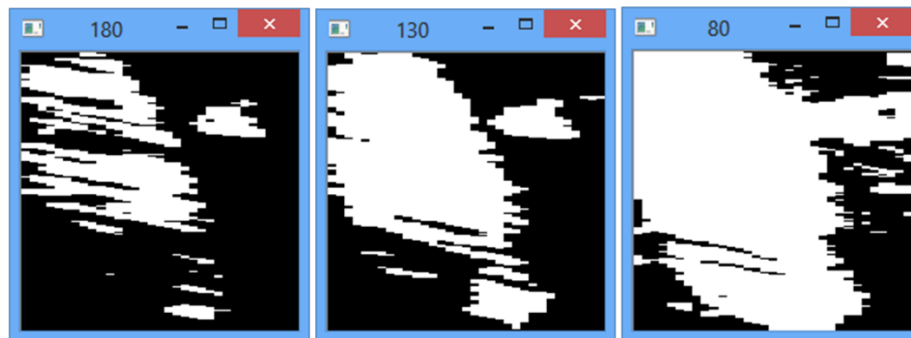


Figure 3. An exemplary software thresholding and search for contours of the fibre.

On to the loaded input image different filters of the OpenCV library are applied. If the input image is large and it contains dead spots on the edges, the software uses thresholding (image processing). Subsequently contours are searched for, while convexity defects are combined to form one solid object. The result of this step is the cut-out image of the concrete sample. The image of the concrete sample is then processed using morphological reconstruction to eliminate local maximums. Subsequently, methods of erosion and dilation were applied to improve the quality of bright parts. Along with the binary thresholding bright parts were obtained, which in our case represents the found fibres.



Figure 4. The trimmed image with fibres detected.

3. Results

To confirm the reliability of the software, it was necessary to detect multiple images. Each image analysed by the software was also analysed manually. The software was able to identify all the threads from the sample sharpened image. The success rate was 99.97% of the found fibres compared to the actual state. This was 2.32% more for inkjet images. The reason could be the creation of high contrast between grey and concrete fibres in weak to strong blue (Figure 1, right). In the picture, we can see a strongly blue "puddle" with a grey border, causing extra fibres to load. For further imaging, samples were prepared by cutting with additional surface grinding for higher accuracy of detected fibres. Table 1 shows the results from sample number 1 in sections B to K.

Table 1. Number of fibres with chemical and mechanical contrasting, and deficiency on sample 1.

	Chemical contrast			Mechanical contrast		
	Manual counting	Analysis software	Variation (%)	Manual counting	Analysis software	Variation (%)
1B	31	30	103.23	31	31	100.00
1C; 1D	44	42	95.45	44	44	100.00
1E; 1F	38	38	107.89	38	37	97.37
1G; 1H	54	52	100.00	54	54	100.00
1I; 1J	63	63	100.00	63	63	100.00
1K	41	38	107.32	41	42	102.44
Average			102.32			99.97

Multiple samples had to be processed to obtain the relevant output. All resulting measurements showed the need to scan mechanically modified fibre concrete surfaces. The software showed the most accurate results after mechanical surface treatment. Its success rate was 99.97%. At the same time, the number of fibres in single sections represents fibre density and homogeneity along the sample.

4. Conclusion

The research presented in this article deals with the evaluation of uniformity of dispersed fibres in fibre reinforced concrete structures. Its focus lies on the basic characteristics of fibre concrete. It is a composite material with ideally dispersed reinforcing elements in the form of fibres.

The process of automatic image processing is already used in practise. However, it is at the beginning in the field of fibre concrete. Its benefits are needed for homogeneity research and the speed of evaluation of results. It saves time and its accuracy is sometimes higher than manual counting and identification of fibres. The correct algorithm will be able to determine the homogeneity in the final fibre concrete.

The chemical process was best demonstrated in increasing contrast. However, the software detected a higher number of threads in the section. This could be due to wet stones in the concrete matrix. At that time, the software also included these small stones. The result is an average of 2.32% more fibre-identified software than the actual amount of fibre detected. The lower contrast was reflected in the sample ground. The fibres get a higher gloss, which is more accurate for the developed software in its identification spectrum. The results showed an accuracy of 99.97% on 6 samples. This process is useful for further processing images on samples. Thanks to automated image processing, fibre counting is possible efficiently.

The tool creates a basis for further processing of fibre homogeneity issues and serves as a control tool for the evaluation of manufacturing fibre reinforced concrete structures. It can also be applied to production of fibre reinforced concrete structures with controlled orientation, where the assumption of acting internal forces is known. It also creates a basis for the development of evaluation software and more detailed expression of decomposition of forces into individual axes. Currently the conducted

research is aimed at verifying the possibility of evaluating the images obtained from the CT-Scan device - see picture below.

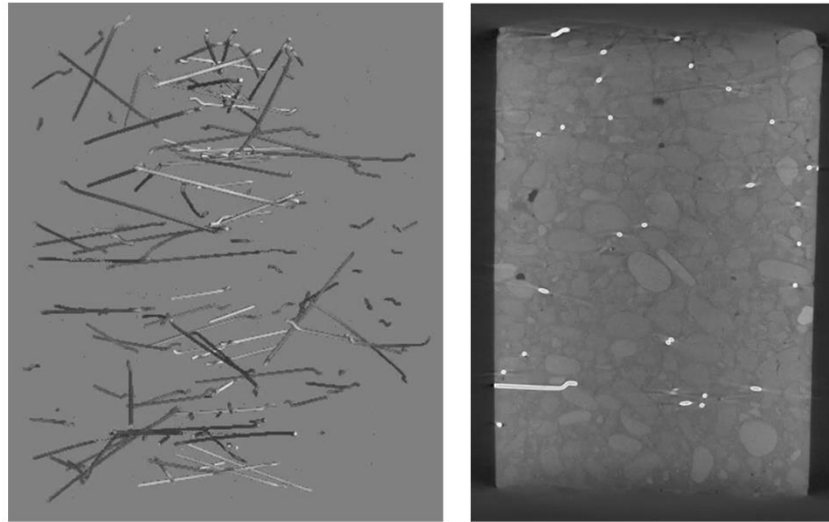


Figure 5. Output images from the CT-SCAN left image sample and right radiographs.

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