

MICROSTRUCTURE MODEL OF A MULTIFILAMENT YARN IMBEDDED IN CONCRETE

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Commission VI, WG VI/4

KEY WORDS: textile reinforced concrete, image tracking, image analysing

ABSTRACT:

Multifilament yarns made of alkali-resistant glass are used as reinforcement element in textile reinforced concrete. To analyse the bond between concrete-matrix and yarn, cross-sections of a specimen are successively taken by a scanning electron microscope (SEM). Positions and diameter of the filaments are detected by image analysing methods in each cross-section. For the reconstruction of the yarn structure (third dimension) the filament-positions are matched between the different cross-sections by using measured distances of the cross-sections. Transforming methods like an iterative closest point set (icp) algorithm and a kalman-filter are used to find the right matches. The bond area, which is represented by the contact area of concrete and filament, is detected after an idealisation of the image in three types: filament, concrete and pores. The section around each filament is tested of bond areas. The locations of the bond areas are interpolated between the cross-sections, so that a kind of canals of bond are generated, which visualizes the spatial bond characteristics.

RÉSUMÉ:

L'armature de fibres de verre à multi-filament est étudiée comme alternative pour le ferrailage du béton traditionnel. Pour étudier l'adhérence entre la matrice de béton et les fibres, des coupes transversales successives d'une éprouve sont examinées avec un microscope électronique à balayage. Les positions et les diamètres des filaments sont détectés à l'aide de traitement d'image dans chaque coupe. Pour la modélisation tridimensionnelle à base de l'analyse de l'image bidimensionnelle, les filaments détectés entre les coupes se sont attribués à l'aide de méthodes de tracking, comme la méthode ICP en combinaison avec un filtrage Kalman. Une adhérence existe si une partie de la matrice de béton touche les filaments de verre. Pour révéler ces surfaces d'adhérence, les coupes transversales sont idéalisées dans les trois matériaux filament, matrice de béton et cavité. Les domaines autour de chaque filament sont analysés à l'aide de l'idéalisation pour détecter les points d'adhérence. Cette localisation est interpolée entre les coupes transversales, de façon à créer des tuyaux d'adhérence ou des parties de tuyaux d'adhérence, ce qui représente un ordre de grandeur de la situation d'adhérence.

KURZFASSUNG:

Multifilament-Glasfaser-Bewehrung wird als Alternative zur herkömmlichen Stahlbewehrung in Beton untersucht. Um den Verbund zwischen Betonmatrix und Garn zu untersuchen, werden sukzessive Querschnitte eines Probekörpers mit einem Rasterelektronenmikroskop (REM) aufgenommen. Die Filamentpositionen und -durchmesser werden mit Hilfe von Bildverarbeitungsverfahren in jedem Querschnitt detektiert. Für die dreidimensionale Modellierung aus der zweidimensionalen Bildanalyse werden die Filamente zwischen den einzelnen Querschnitten mit Hilfe von Trackingverfahren, wie dem ICP-Verfahren und einer Kalmanfilterung, einander zugeordnet. Verbund liegt vor, wenn sich Teile der Betonmatrix und von Glasfilamenten berühren. Um diese Verbundflächen aufzudecken werden die Querschnitte in die drei Typen: Filamente, Betonmatrix und Hohlräume idealisiert. Die Bereiche um jedes Filament werden mit Hilfe der Idealisierung auf Verbundstellen untersucht. Diese Lokalisierung wird zwischen den Querschnitten interpoliert, so dass Verbundröhren oder Teile von Verbundröhren entstehen, die eine Größenordnung der Verbundsituation repräsentieren.

1. INTRODUCTION

Multifilament yarn reinforcement is tested as a steel reinforcement alternative. Concrete components are reinforced because of the weakness to tensile stress. Usually concrete structures are reinforced with steel elements. The advantage of glass in contrary to steel reinforcement is the resistance to corrosion. The concrete components can be designed very thin

because water is allowed to reach the reinforcement. This new technology makes components very light and architecturally interesting (see an example in Figure 1).

The glass reinforcement is a three dimensional textile structure consisting of yarns (rovings) which are bundles out of glass filaments – in this example: about 1600 filaments.

Pullout tests offer a successive breakdown of the filaments beginning from the boundary of the roving to the middle, but

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some in the middle do not break at all (Banholzer, 2004). To proof a correlation between the load bearing behaviour and the bond between concrete and filaments, the penetration of the concrete among the filaments has to be analysed. The filaments are differently bonded, similar to the study of the pullout tests. The bond is analysed to check a correlation between the load bearing behaviour and the bond.

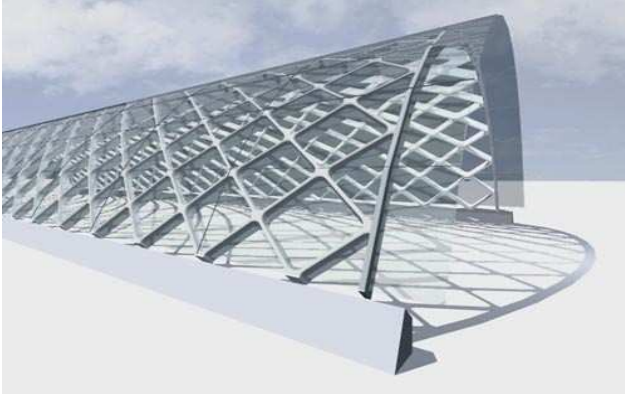


Figure 1. Textile reinforced concrete bend

A first idea to proof the bond is a CT scanning analyse. First tests show that the resolution is not high enough to separate the filaments or the pores. With this method only a localisation of a yarn is possible.

An alternative method is to analyse the cross-sections, taken by scanning electron microscopes (SEM), and extracting the data into the third dimension.

The bond dimension can be seen in these cross-sections by analysing the areas of contact between concrete and filaments. No transmission is possible between filaments and pores or filaments and neighbour filaments. This case is no stabilisation for tensile stress because the filaments are flexible in the concrete component.

To understand the penetration of the concrete successive cross-sections are measured. If there are many or large areas of contact, the load bearing behaviour is solid.

The two-dimensional analysis does not explain the load bearing behaviour of the tests, so the third dimension needs to be modelled.

The beginning of this article deals with the preparation of the specimen to take the SEM-images. After that the two-dimensional image analysing to local the filament positions is described. The next subsection is about the tracking method to model the three dimensional filament courses. Finally the algorithm to detect the bond between filaments and concrete in the images and the extrapolation in the third dimension is presented.

2. TYPE EXAMPLE PREPARATION

A yarn reinforced concrete body is cut to a small piece which contains just one roving. This piece is soaked with epoxy resin to fix the filaments. At two sides, cuts are made very close to the roving to see them in every cross-section. The edges of the cuts are used for the orientation of the cross-sections among themselves.

The cross-sections are made by rubbing away small layers of the type example. Without the epoxy resin the filament locations would change in every cross-section because they would move by abrading the small layers and a tracking of the course would not be possible.

In figure 2 is an example with a scale for the dimension.

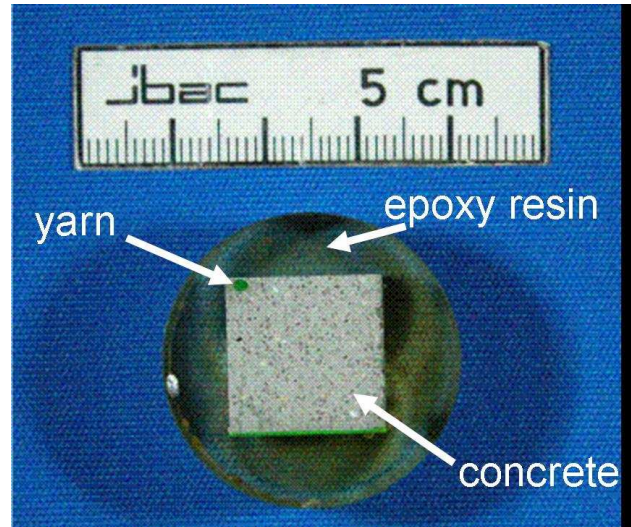


Figure 2. Type example of a roving in concrete

3. 3D YARN STRUCTURE

The model is formed in two main steps: the filament course-modelling and the bond between filaments and concrete-modelling. The data of both parts are first detected out of the SEM-images and then interpolated in the third dimension.

3.1 Two-dimensional filament detection

Figure 3 shows a SEM-image with the three types: glass-filaments (light-coloured areas), concrete (all kinds of grey areas) and pores (black areas). Around the roving is a knitting yarn to form a textile. That means for the bond a behaviour like a pore because there is no contact of the filaments to concrete at this position. The program detects the knitting yarn as a pore, because it is also black. This is alright and there is no need to make differences between black areas of pores and black areas of knitting yarn in the image because in areas of contact between the knitting yarn and filaments there is also no bond like in the areas of contact between pores and filaments.

In a pre-processing step, the region of interest (yarn area) is chosen by a mask to decrease the calculation time.

At first the light-coloured filaments get separated by a threshold value method. Around every separated area a smallest enclosing circle is adjusted. Because some filaments are very close to their neighbour, a filter splits separated areas which contain more than one filament. After this the location of the centres and the diameters of the filaments in every cross-section are known.

To simulate the boundary of the roving a polygon around the whole roving is estimated through the exterior filaments. This is necessary to calculate the distance between every filament position and the boundary. With this information it is possible to check the speculation of a better penetration of the concrete near the boundary of the roving than in the middle (Kang et al, 2008).

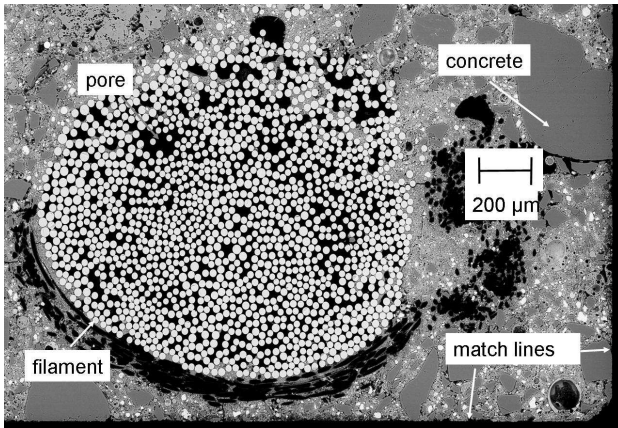


Figure 3. Cross-section of an imbedded yarn

To find the course of every filament by tracking the filament positions in the successive cross-sections, an orientation of the SEM-images is important. To orient these images among themselves two matching lines, which are in every image, help to determine the global orientation. These matching lines are the edges of the cuts near the roving (see chapter 2.).

3.2 Three-dimensional filament course

The courses of the filaments through the specimen are modelled by the known filament locations and the distances of the cross-sections.

The filaments take course through the whole specimen, so they are sliced in every cross-section. With the positions of a filament, taken from every image, their course can be modelled. But to estimate the course of a filament, a matching of the filaments between the cross-sections is essential because of the close distance of the filaments. It is not possible to allocate the same filaments between the cross-sections without a matching algorithm (See the differences between the cross-sections in figure 4).

To get a start matching of the filaments between the first two images, the cross-section distance between the first two is chosen very close. After some manual matching by provision for the diameter, the filament positions of the first cross-section get transformed affine and a matching to nearly every filament becomes determined by the ICP-Algorithm (Besel et al 1992). After this first matching the distances between the cross-sections are bigger because the next matching is not estimated by the ICP-Algorithm. The course of every matched filament is known by calculating it with the positions of this filament in the two cross-sections. By using the course a forecast of the position in the next cross-section is possible.

There is a big advantage by tracking every filament independently because there is no information about a global transforming behaviour of all filaments.

See an overview of the hole tracking strategy in figure 4.

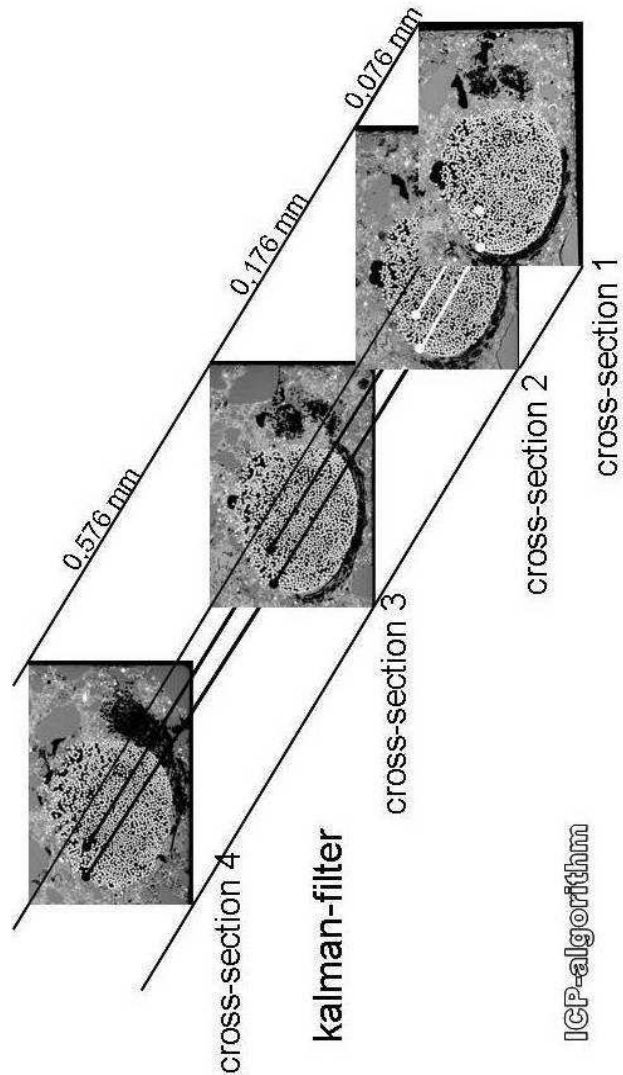


Figure 4. Schematic procedure of allocation

The start matching for the kalman filter is given by a first location and trend of the filament course. This input is estimated by the known trend from the first matching. With this trend and the known distances between the cross-sections, a forecast of the filament position in the next cross section can be calculated (Steffen et al, 2007). Considering the forecast by tracking the hitherto trend and using the found position, the kalman filter is a good tool to work with. The function to calculate the position in the following cross-section is linear because the filaments are massive glass tubes which cannot flex very much because of its stiffness (see a scaled model in Figure 5).

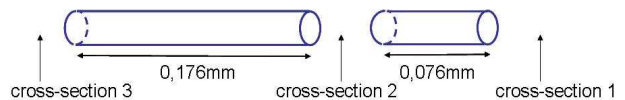


Figure 5. Average proportion cross-section distances to radii

In many cases there is more than one possibility to match a filament although the estimated position. This may be because the filament course is not exactly known and the real position differs from the estimated position and there are some filaments near the estimated position and the right filament has to be picked out. Another possibility may be a double matching of a

filament. In these and other cases the diameters of the filaments are considered for allocation.

The linear model is realistic which is shown by the visualisation in figure 6. Here are the three dimensional coordinates by using the distances of the cross-sections as the third coordinate (z) shown.

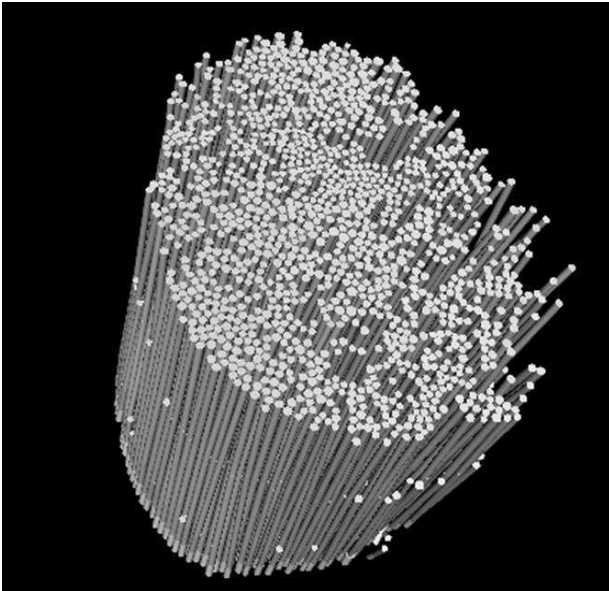


Figure 6. Visualisation of the yarn structure

4. BOND ANALYSIS

To analyse the structure of bond areas between filaments and concrete, the SEM-images get assayed with image analysing methods. The results get extrapolated in the third dimension.

4.1 Two-dimensional neighbour analysis

At first every cross-section gets idealised into the three types glass (-filaments), pores and concrete by using threshold methods. In figure 7 is an idealised example with light filaments, dark concrete matrix and light grey pores.

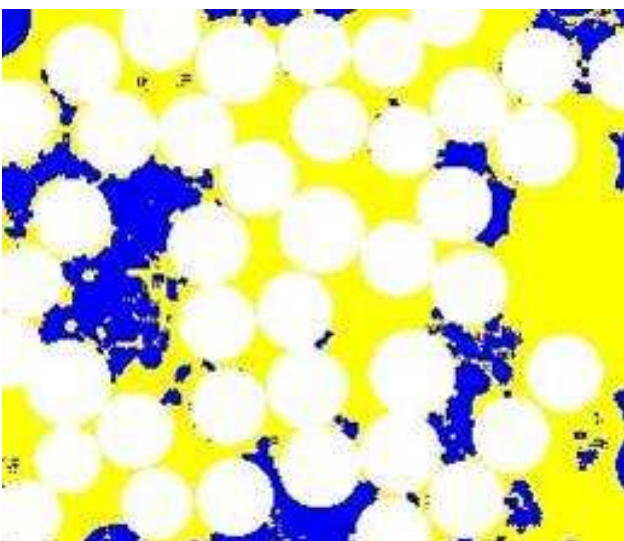


Figure 7. Three type idealisation

The transition zone between white filaments and black pores appears as a grey area although there is no concrete matrix. In

order to solve this problem a larger neighbourhood of every filament is investigated. Therefore, the proximity of a filament is divided into ring sections with a given width (see figure 8).

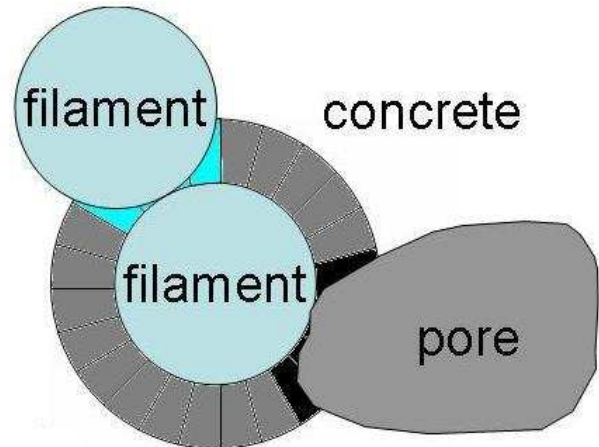


Figure 8. Ring operator

The pixels in the ring section are assigned to the types filaments, concrete matrix and pores. The whole ring section is assigned to one of the three types. This leads to a kind of digitalization (see figure 9).

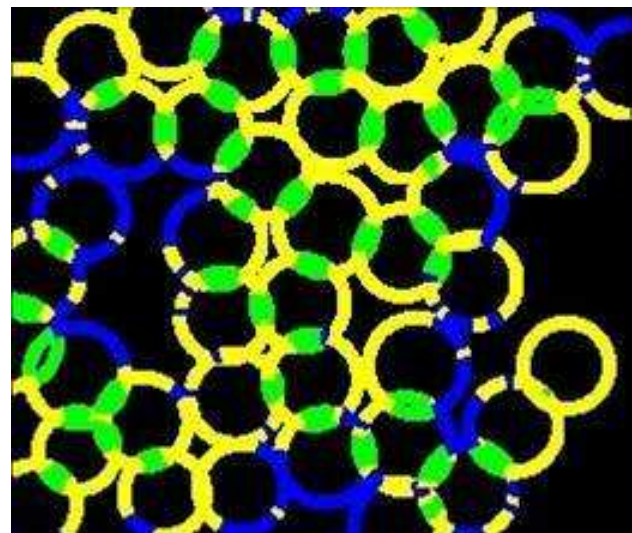


Figure 9. Results of the ring operator

The results of the ring-operator give a dimension of the bond in the cross-section. Analysing the filaments informs about the disposition of bad and good bond filaments. The results show an inferior bond in the middle of the roving. The bond near the boundary is much better (Kang et al, 2008; Lange, 2009).

4.2 Tree-dimensional bond

To extrapolate the bond in the third dimension the localised bond ring segments get organised into bond and no bond regions. These regions are allocated between the cross-sections along the filaments.

Segments of bond get combined into areas of bond. Along the filament the areas of bond are tracked. These areas may move and grow or contract between the cross sections. They can also start or stop. By tolerating these possibilities canals of bond or parts of canals of bond are formed (see figure 9a). If there is

bond along a filament in a cross-section but not in the following cross-section or the other way around, this model starts to simulate the bond on the half way between the cross-sections (see figure 9b).

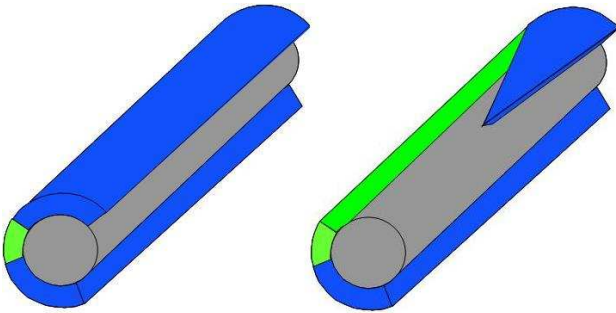


Figure 9. (a) Canal of bond along filaments (b) Canal of bond with different bond in the cross-sections

5. ACKNOWLEDGEMENT

This research project is part of the Collaborative Research Center 532 “Textile Reinforced Concrete-technical basis for the development of a new technology” and is sponsored by the Deutsche Forschungsgemeinschaft (DFG) (German Research Foundation). The support is gratefully acknowledged.

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