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DESCRIPTION MODEL OF CROSS-SECTION OF FIBRE BUNDLE SHAPE IN PREPREG COMPOSITE

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Abstract. Paper deals with description of fiber bundles in cross-section of woven reinforced composite prepared by prepreg technology from carbon/carbon materials. From hierarchical model it is focused on the meso-scale on the weave structure. Here exists number of basic models describing weave in textile composites. Also exist models describing weave in textile branch. It was observed microphotographs for determination of the real structure and of presence of defects in the structure. Structure, dimensions and shape, is affected by the position of surrounding components including lengthwise, crosswise bundles and defects. Defects position is affected by waviness, prepreg production and curing. For each type of defect was observed also specific shape of surrounding fibre bundles.

1 INTRODUCTION

Description of fibre bundles in cross-section of woven reinforced composite is important for plates prepared by prepreg technology not only for carbon/carbon materials as was used in our case. Fibre bundle have basically oval shape or lenticular shape caused by interlacing into the structure in the first step and by the processing pressure in the next stage. Deformation of shape affects mainly mechanical and structural properties of final product. Lay-out of bundles and their position mutually affect presence of defects.

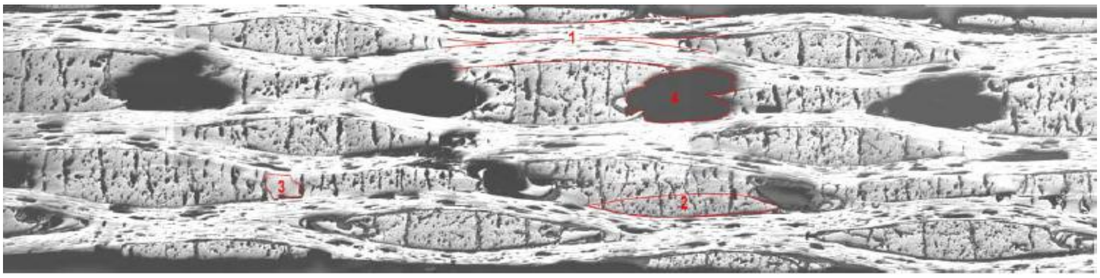

Figure 1. Microphotograph of woven composite [1]

From hierarchical model it is focused on the meso-scale on the weave structure. Here exists number of basic models describing weave in textile composites – Mosaic model, Bridging model, Crimp model etc [2, 3, 4, 5]. Here also exist models describing weave in textile branch – Pierce model, Olofson model, hyperbolic model, Fourier lines model etc [6, 7, 8]. Composite reinforcement can be described by models used for determination of woven textiles geometry after acceptance of composite structure, Figure 2.

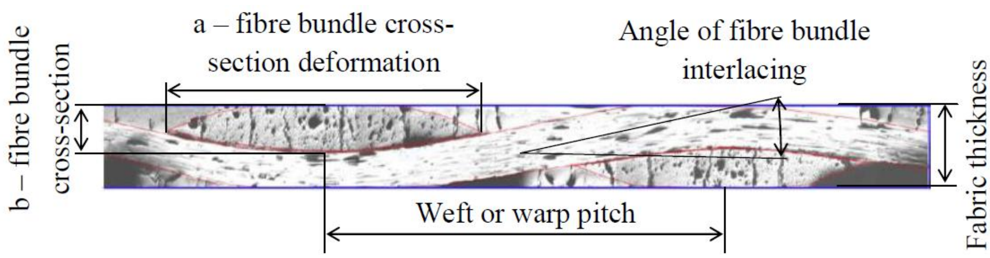

Figure 2. Description of reinforcement components in cross-section of composite

Woven fabrics are referred to as crimped fabrics because yarns of one direction are bent around their crossing neighbour yarns. Warp yarns run parallel to the fabric edges and are virtually unlimited in their length. The weft yarns run across the fabric width. The undulations, which are referred to as crimp, are shown in Pierce's geometric fabric model (figure 3) for a plain weave. Pierce's geometric model relates the fabric parameters as they are coupled among yarn families. The crimp height *h* is related to the crimp angle and yarn length *l* as measured between yarns and the sum of yarn diameters at the crossover regions. Crimp should be described as the amount of waviness produced in a yarn when woven in fabric form; it is a geometric property of the weave because of the woven architecture used [8, 9, 10].

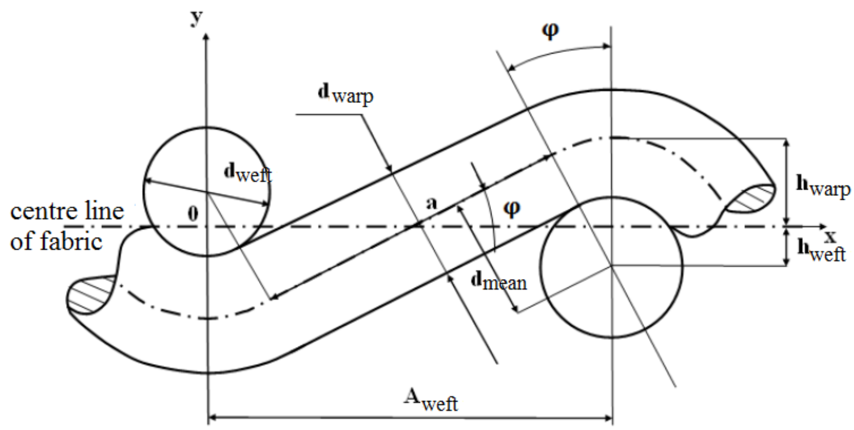

Figure 3. Pierce´s model [6, 8]

Pierce´s model is described by following parameters and others in [9, 11]:

- diameter of warp and weft in cross-section d_{warp}, d_{weft} *[m]*
- mean diameter of yarn $d_{mean} = d_{warp} + d_{weft}/2$
- spacing of warp and weft yarns $A_{warp}[m] = 1/D_{warp}$, $A_{weft}[m] = 1/D_{weft}$
- height of waviness of warp and weft yarns h_{warp}, h_{weft} *[m]*
- sum of the crimp heights both binding waves $h = h_{warp} + h_{weft}$
- crimp angle of warp and weft yarns φ, ψ *[º]*

Bundles are deformed in the structure during weaving, prepreg layering, sliding of laminas during pressing, curing process and interaction between surrounding laminas. Cross-section of fibre bundle can be defined by *a* and *b* proportion values. Some of the determining factors for deformation level are material type, number of fibres in yarn, pressure, yarns set etc. [6, 9, 11]. Lenticular shape was chosen as the most accurate for your purposes of research, Figure 5. Deformation of cross-section at binding point is described by following parameters [6, 9, 11]:

- relative width $\alpha = a/d$
- relative height $\beta = b/d$
- relative compression $\varepsilon_1 = (b-d)/d = \beta - 1$
- relative enlargement $\varepsilon_2 = (a-d)/d = \alpha - 1$

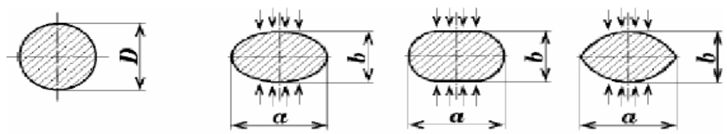

Figure 4. Deformation types of fibre bundle in cross-section [6, 9, 11]

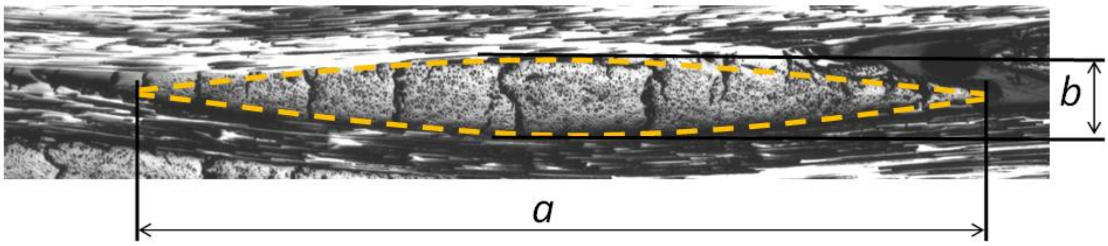

Figure 5. Dimensions of real lentil fibre bundle

2 STRUCTURE SPECIFICATIONS

It was observed number of microphotographs for creation of model based on the real structure and determination of presence of defects in the structure. On the following Figure 6 there are various configurations classified from prepreg made C/C composite. Structure, dimensions and shape, is affected by the position of surrounding components including lengthwise, crosswise bundles and defects. Defects position is affected by waviness, prepreg production and curing. For each type of defect was observed also specific shape of surrounding fibre bundles.

Tested material was eight layer laminate in plane weave. Both components were carbon in a different states, fibres was defined for computation as a transversally isotropic and matrix as an isotropic material with random ordering of internal structure. It was previously defined that porosity of this material is 20 – 25 %, from that it is counted 10 – 15 % to the porosity in the bundles themselves from previous research [1, 12].

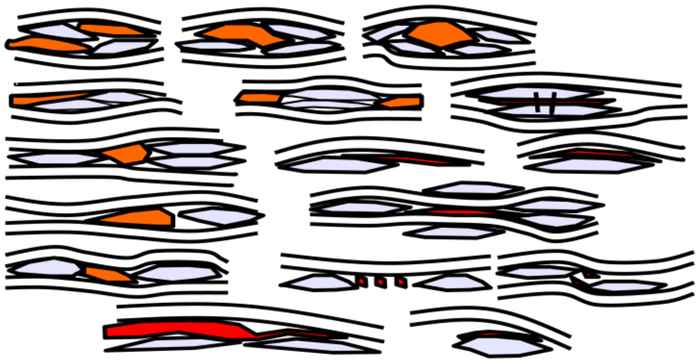

Figure 6. Components and their position [12]

3 MODEL DESCRIPTION

It was designed 2D model from real components description and on the confirmed data was build 3D model on the same base. The whole structure of a composite was defined at first for the 2D multi-scale modelling in the levels [1, 13]: matrix-fibres in lengthwise and crosswise direction → matrix-fibres part with pores in both directions → three types of unit cell raised from observing the real composite microphotographs → laminas for all types of unit cells → whole composite. All levels are possible to construct in 3D too. Meso-scale model consists of two types of basic unit cell in our 3D case. Today state is constructed as an ideal shape of bundles interlaced together as a brick possible to be set together in a phase or asymmetry phase. Packing density of fibres in cross-section is assumed to be constant in whole bundle body and defined only as a random with specified volume.

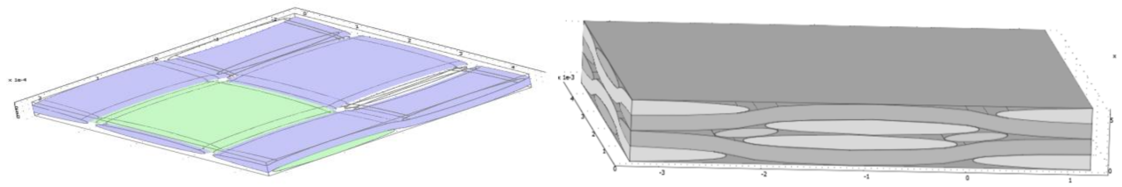

Figure 7. Models of meso-scale level [13]

11 FOCUS ON STRUCTURAL ELEMENTS

It was observed number of real cross-sections of fibre bundles for determination of statistically significant amount of values with the respect of position and surrounding types of components including defects. Sliding of laminas during processing affects incorrect contact of their surfaces. Presence of defects influences position and dimensions of bundles in cross-section afterwards. Processing pressure is also important influencing factor. Pressure of bundles onto each other not only in weave fabric but also between laminas in return affects size of defects as well as shape of bundle and lay-out of fibres in the bundle.

Following models are described in a diploma work of the author [12] and specified closely in this presented paper with description on microphotographs. It is not always possible that bundles bend and completely cover area of composite, as on Figure 8, while matrix and defects are presence in composite too.

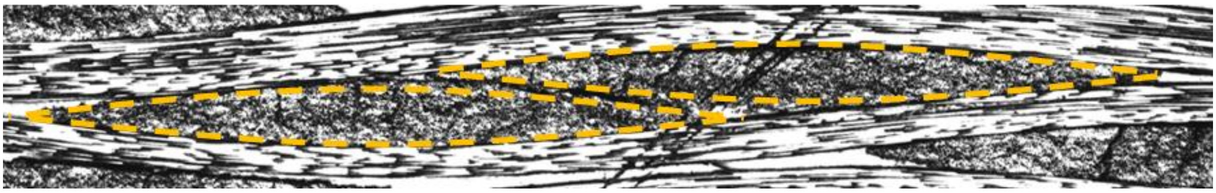

Figure 8. Two crosswise bundles after sliding of laminas (mean pressured sample - 25x zoom)

Defects arise after burns out of matrix where crosswise and lengthwise bundles are not in complete contact together in binding points. Models with two crosswise bundles are shown on figures 9, 10 and 11.

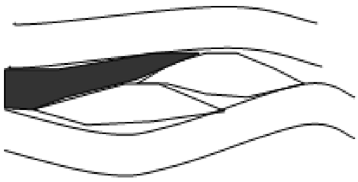

Figure 9. Two bundles aside defect

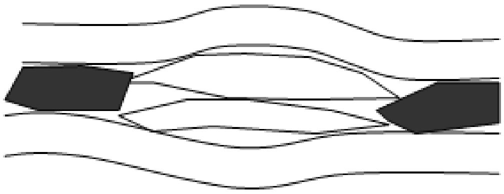

Figure 10. Two bundles aside defects from both sides

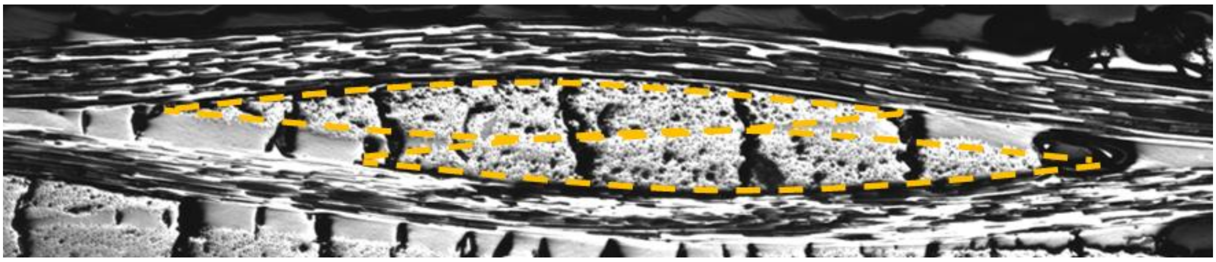

Figure 11. Two bundles surrounded by matrix and defect on one side (mean pressured sample - 25x zoom)

Crossing of three crosswise bundles, model on figure 12, show similar geometry as crosswise bundle surrounded by lengthwise bundles, model on figure 13. Also defects are in comparable geometry. Size of defects is then affected by the pressure of lengthwise bundles. Crosswise bundles are from two laminas. Defects, if they are in presence, arise after burning out matrix which does not flow out.

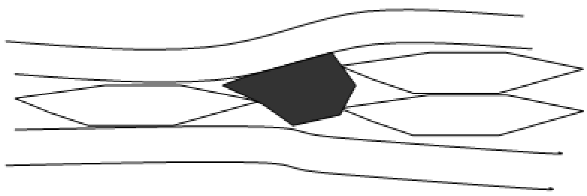

Figure 12. Three bundles aside defect

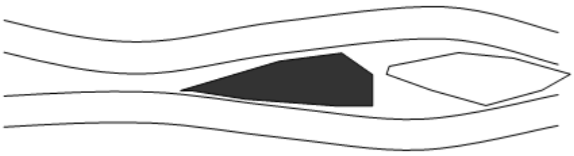

Figure 13. Bundle aside defect

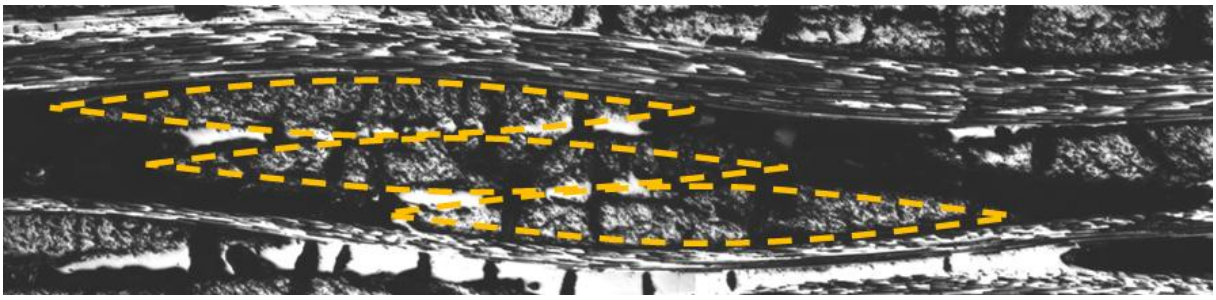

Figure 10. Bundles in cross-section from two laminas (mean pressured sample - 25x zoom)

Distance between crosswise bundles is affected by forces from lengthwise bundles. Figure 14 show model of settlement in one layer from crosswise bundles and two lengthwise bundles from two laminas. If bundles come near, defect could not rise. Complete connection is however avoided by interlacing.

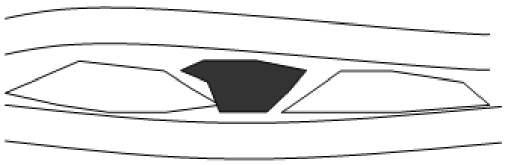

Figure 14. Crosswise bundles and defect surrounded by lengthwise bundles – two laminas

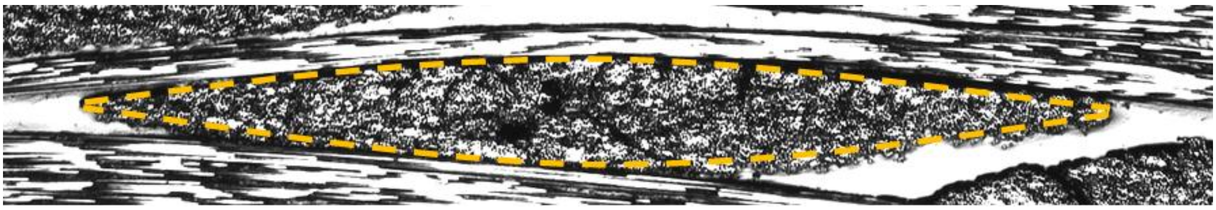

Figure 15. Passing of bundles – one crosswise bundle between two lengthwise bundles (mean pressured sample - 25x zoom)

Lower pressured composites have defects after burning out the matrix. If defect is just one or two defects arise is dependent on placement of bundles or sliding of laminas during processing. Higher pressured materials were pressed and flown off more thoroughly so that size of defects is smaller and bundles are have got tendency close together how interlacing allows.

12 CONCLUSIONS

- Image analysis method is useful to qualitative classify parameters describing woven reinforced composites from the point of view of structure. Reliability of measurement by image analysis is dependent on number of measurements, selection ratio, number of samples and time which was defined for research.
- Bundles in structure are optimally studied through the cross-section so crosswise bundles are selected for classification. Bundles are surrounded by lengthwise bundles, matrix and defects and it is possible so summaries with models. We selected 5 basic models described with position in composite in interaction with other components.
- After obtaining the dimensions of each type of fibre bundle and this result can be added into existing computation 3D models of meso-scale of composites with idealised structure so match with real composite will be higher.

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