Structural analysis of parts made by 3D printing reinforced by long fibers

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1. Introduction to composites and modelling of CFRTP composites

The composites are attractive materials for many sectors of industry, but their working principle limits faster extension in the manufacturing process. In recent time, additive manufacturing becomes an alternative to the traditional production methods and 3D printing is one of the methods, which are involved in additive manufacturing. Although there are many production limitations, the production variability of printed composites is better than offer conventional methods. The production limitations significantly relate to fibre addition into a printed structure. This is the case for solely two 3D printing methods allow printing of continuous fibre reinforced thermoplastic (CFRTP) composite. The parts produced by additive manufacturing achieve a tensile strength of approximately 700 MPa. The development of 3D printing and composite production is still ongoing, thus there is an expectation of a continued increase in the production [4].

The most of applications require reliable prediction of composite behaviour under loading. Stress and deformation analysis of reinforced composites can be done at three different levels. The microscopic level examines deformations and stresses at the level of composite constituents. Attributes, which affect results, are fibre shape, geometric distribution and properties of composite components. At the macroscopic level, a composite is considered as homogeneous equivalent material, but solely deformation, buckling and vibration frequencies could be predicted. Simulation at the microscopic level is limited by a computational capacity and the macroscopic level cannot calculate stress distribution in a laminate. The mesoscale approach gets over these limitations and allows prediction of stresses and strains in every lamina, but elastic properties, fibre orientation and layer thickness of each lamina must be given into the program [3].
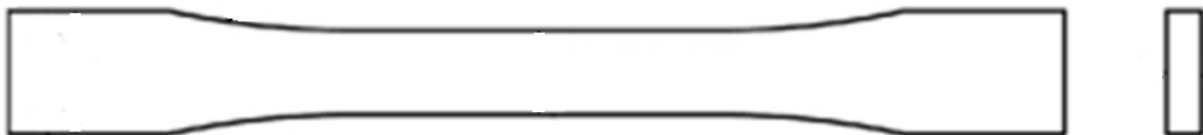

Fig. 1. Specimen shape

The simulation of CFRTP composite specimen loaded to the tension was performed using two methods - rebar and geometry distribution approaches. Assessed dogbone shaped specimen (Fig. 1) was designed in the CAD program and imported to the slicing software developed by the printer manufacturer.

The models of the specimen were created using scripts in MATLAB, which help with model generation in program ADINA. Both modelling approaches are described, analysed and compared in the next chapter.

2. Modelling of CFRTP composites – description and analysis

2.1 Embedded reinforcement method

The method initially proposed for modelling of reinforced concrete; currently exploited for composite modelling. The model is based on the virtual work principle. The reinforcement could be modelled as smearded or discrete rebar.

The discrete rebar models each fibre separately. This method is appropriate to modelling of structures, which consist of sparsely deposited fibres with inconsistent attitudes, for instance, fibre orientation, material, cross-section etc. The reinforcement start point and curved trajectory of the fibre in the structure do not represent complications, because each fibre in this method is modelled separately as a beam with uniaxial stiffness. The widespread problem is the bonding between fibre and matrix. Therefore representing elements, such as REINF 264 (Fig. 2), do not allow relative movement between composite components [2].
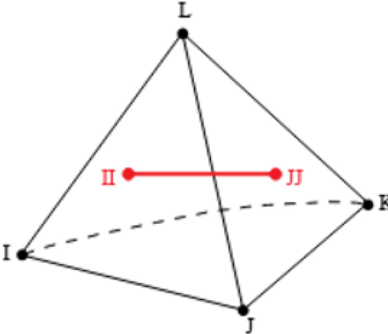

Fig. 2. Element REINF 264, [2]

The discrete rebar element was the first assessed modelling method of CFRTP composite. The modelling process of the composites in program ADINA is realised in the following steps. Rebar line representing designed reinforcements in the composite structure intersects faces of generated 3D solid elements (Fig. 3, left). In this intersections are created nodes, which are subsequently connected utilizing truss elements. The constraint equations define connections between the rebar truss elements and generated mesh of the matrix. The connection is prepared between the nodes and the three closest nodes of the mesh (Fig. 3, right) [1].
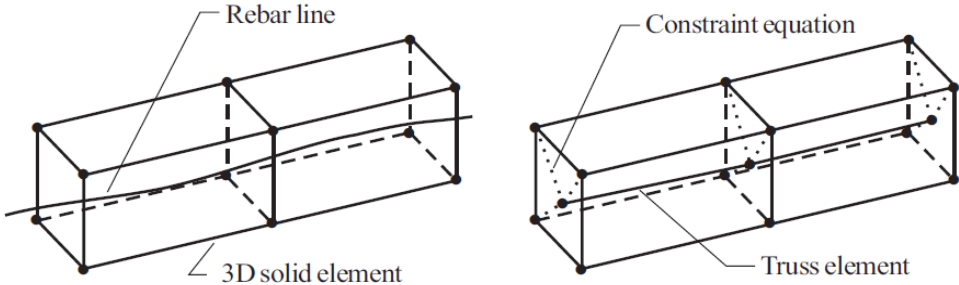

Fig. 3. Generation process of rebar elements, [1]

The constraint equations are added to the system of equations, that models simulated tension test. The addition effects to raising matrix density, therefore computation becomes more difficult at time consumption and computational resources.

In terms of mesh convergence criterion, usage of the rebar elements affects solution accuracy because finite element program divides the rebar lines into the truss elements of various lengths (Fig. 4).
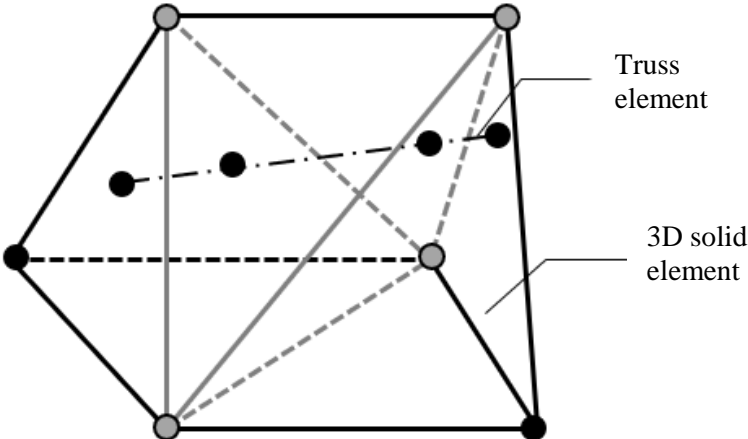

Fig. 4. Different length of truss elements

Sizing variability of the truss rebar elements requires the application of direct solvers. Various lengths of the truss elements affect the computational precision. In comparison to longer truss elements, relatively negligible computational error in deformations of small truss element can cause a large error in strains and stresses. This feature of the rebar modelling influences the occurrence of significant variations of stresses on fibres (Fig. 5).
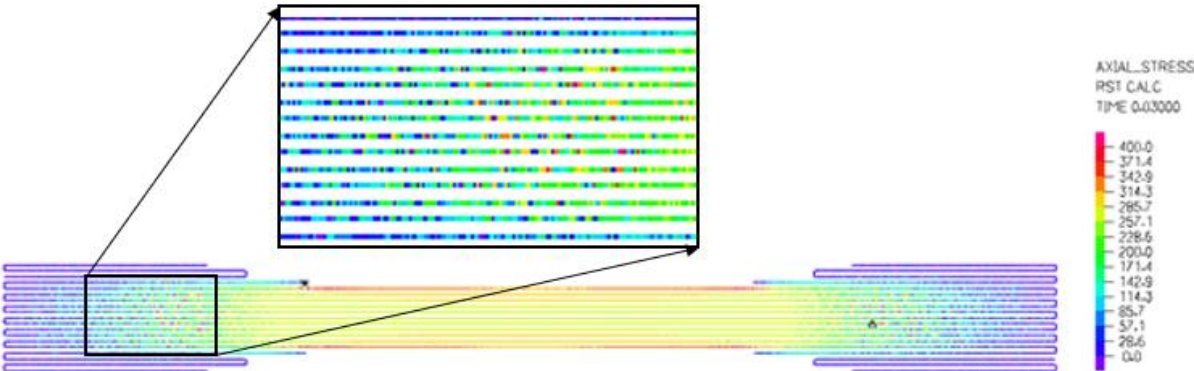

Fig. 5. Stress distribution in fibers of CFRTP composite specimen modelled using rebar elements

2.2 Geometry distribution approach

The second assessed modelling method was geometry distribution of the composite model. As a result, the location of the truss element representing fibre reinforcement in the structure is on the edge of the matrix element (Fig. 6). The connections between the truss elements and the solid elements are generated without constraint equations. Thus stiffnesses of fibres are added to some elements in matrix stiffness. This type of modelling reduces computational time consumption.
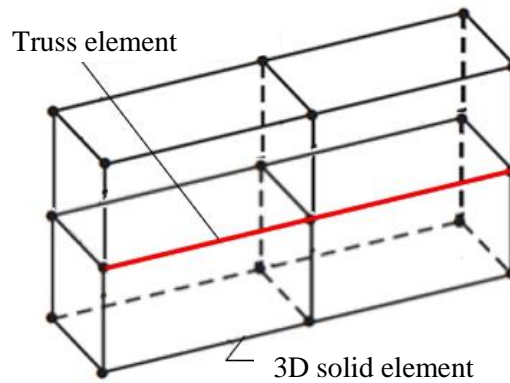
Fig. 6. Truss element located on edge of matrix element

The main advantage of the method is equal sizing of the truss elements because there is a relatively small difference between the largest and the smallest elements on diagonal. Therefore iterative solvers are efficient. Compared to the rebar elements, solution accuracy is higher and computed stress distributions fluently change without significant gaps (Fig. 7).
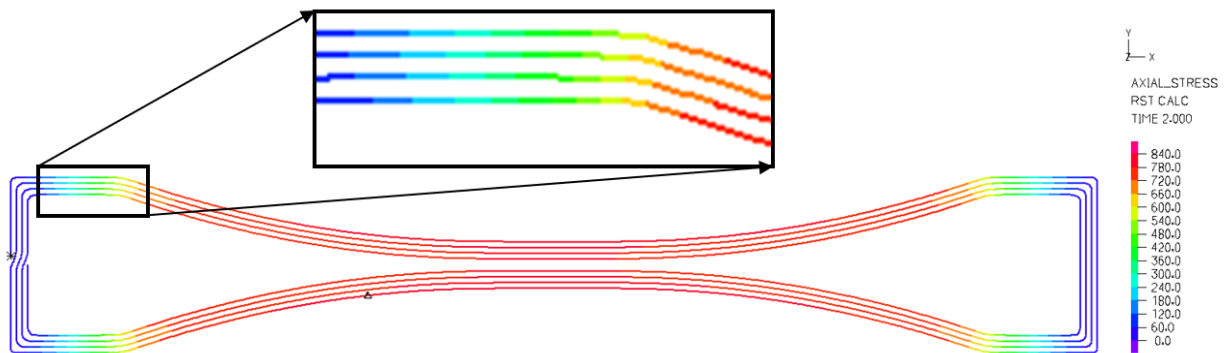

Fig. 7. Stress distribution in fibers of CFRTP composite specimen modelled using geometry distribution

3. Conclusion

Both presented methods are appropriate to modelling of CFRTP composites in program ADINA, but geometry distribution modelling approach offers more benefits than rebar elements method. These benefits are: stress computation in fibres is more precise, a matrix of the system has smaller bandwidth and display of stresses on fibre layers is better.

Acknowledgements

References

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