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Application of feature method to the modelling of composite structural elements

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Analysis and modelling

ABSTRACT

Purpose: The paper describes the use of object-oriented methods in modelling and analysis of components made of fibre-based composites. Defined and specified the method for creating fibre primitives. An algorithm for the design of composite structures using object-oriented methods.
Design/methodology/approach: The basic tool is an algorithm to build fibre facilities. Material properties can be found in the previously created databases of material objects. The whole is linked to the relevant formulas and diagrams.
Findings: The basis for the introduction of object-oriented method was to systematize the processes of modelling and analysis of composite materials. Application issue features possible to determine the final form of composite structure.
Research limitations/implications: Research direction is to create tools to support the work of the constructor during the construction of composite components. Material created a database of individual components of laminates, allows to build optimal in terms of established criteria of composite elements.
Practical implications: The practical aspect of using object-oriented method is to use it to define the structure of the laminates. At the modelling stage it is possible to perform the parameterization formula of each phase of the composite. This recipe is especially important during the manufacture of composites.
Originality/value: The paper presents a new approach to modelling of composites by defining a new elementary objects forming the basis for during the composite design process. Algorithms used in the work are particularly important for designers of new technical components made on the basis of fibre composites.
Keywords: Composites; Engineering polymers; Mechanical properties; Computer assistance in the engineering tasks and scientific research; Numerical techniques; CAD/CAM; Materials design; Materials and engineering databases

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1. Introduction

Evolution of the CAx-class software is dictated by market demands to shorten the preparation time to introduce a product to sell. Computer Integration various stages of product life cycle and enables continuous monitoring and adjustment of the product to the current needs and to their generation. The use of modern enterprise software CAx, whose individual modules function as independent applications that can clarify the needs and requirements for the accomplishment of tasks in front of the design and construction. Software vendors have long recognized the potential of using the development of these systems took the issues related to computer modelling and strength analysis of composite components [2, 3, 5, 6].

Feature element is an entity that stores data, establish a network of exchanges of messages, performs some services, thus realizing the general objectives of the system. Taking into account the problem of modelling objects using a graphical-oriented, Feature Based Modelling, we define them as 3D objects or 2D-oriented design characteristics. The division of features due to their use is as follows:

- Design Features - construction feature,
- Machining Features - technological feature,
- Assembly Features - assembly feature,
- Material Features - material feature,
- Tolerance Features -.tolerance feature,
- Functional Features - functional feature.

The study attempts to determine the material of features for the design of structural components based on fibre composites.

2. Defining of features

In order to carry out the process of formalizing the methodology, the use of features in the design of composite components, it was necessary to introduce the relevant definitions.

Material feature, MOE, is called as a collection of information on mechanical, technological and physical properties of engineering materials.

$$MOE =< w_i, i = 1,\ldots,i > \tag{1}$$

where:

w_i – material property.

Material feature, functions as a simple feature, which, together with the structural, geometric feature defined forms filled structural element, creating a complex feature . Inside the master set of MOE, has been specified subset of MOE, which contains a collection of materials for use as separate components of composite materials with varying chemical properties, mechanical and physical.

Elements of a subset of MOE, and a set of engineering materials used as reinforcement in fibrous composite, called material feature - reinforcement and marked with the symbol:

$$MOE_i^Z =< w_p, p = 1,\ldots, p >, p \in N, \tag{2}$$

where:

w_p – material property,

i – iteration of a set $i \in N$.

Reinforcing components, the MOE^Z, can take the form of particles or fibres, entering the matrix material in order to:

- obtain a material with high yield or strength at the operating temperature of the object,
- changes deformability matrix material,
- used as a filler, provided that the matrix material is much more expensive than the reinforcement material.

Elements of a subset of MOE, and a set of engineering materials used as reinforcement in fibrous composite, c called material feature – matrix and marked with the symbol:

$$MOE^M =< w_p, p = 1,\ldots, p >, p \in N, \tag{3}$$

where:

w_p – material property,

i – iteration of a set $i \in N$.

MOE^M fulfils the functions of:

- maintenance of the entire system in a compact form,
- transfer load on reinforcing components,
- protection reinforcing components against direct damage and from other negative influences of surrounding environment.

Relation of belonging subsets MOE matrix and reinforcement to a set of MOE are shown in Figure 1 and using relations (4).

$$MOE^Z \wedge MOE^M \subset MOE \text{, wherein} \tag{4}$$

$$MOE^Z \not\subset MOE^M$$

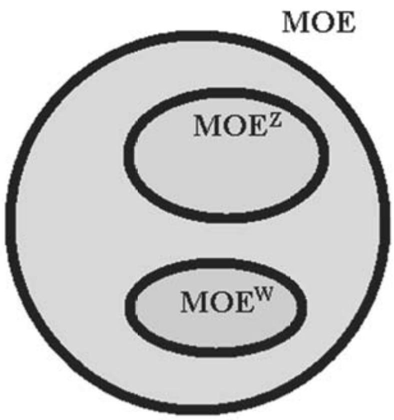

Fig. 1. Sets of MOE

In defining the composite as: material formed from at least two components with different properties in such a way that has improved properties and (or) a new (additional) properties, in relation to the components used separately. The composite material is externally monolithic, with clearly visible boundaries between the components.

The use of such, the definition lets specify a new feature, which is a combination (sum) of simple feature such as MOE and establishment, a new complex feature, named composite feature. Which form represents the relationship (5) COE:

$$COE_{i,j} = MOE_j^Z + MOE_i^M \text{ ,} \tag{5}$$

Feature COE is called as a set of elements, carrying information on the configuration of the composite. Highlighting the following conditions that must be entered as the name and the value of a parameterized object (6).

$$COE_{i,j} =< name, value >, \tag{6}$$

where :
name – the name or symbol parameter,
value – the value assumed by name.
Parameters defining the variables COE:

- Type – the type of composite (unidirectional, particulate, random short fibre, woven),
- Material Matrix – part of a set of MOE^M,
- Matrix volume fraction – the total volume of the matrix in composite,
- Reinforcement material – part of a set of MOE^Z,
- Volume fraction of reinforcement – the total volume of reinforcement in the composite,
- The final thickness – the thickness of a single COE.

The most complicated COE, is a type of woven composite. In addition to the previously mentioned parameters, it has the parameters:

- warp – element of the set of MOE, specifying the warp material,
- weft – element of the set of MOE, specifying the material thread,
- balance factor – determine the volume ratio of the warp and weft,
- angle – the angle determine the arrangement of warp to the weft.

Single COE has anisotropic properties, this phenomenon in structural engineering is undesirable. Therefore, multilayer circuits used in order to reduce this phenomenon. At the design stage configures the appropriate arrangement of the layers and geometric form. The result is a structural material, which to some extent becomes isotropic. The complexity and great diversity in the construction of the composites greatly hampers the identification of strains and stresses at the design stage. Generalized form the layered composite is shown in Fig. 2.

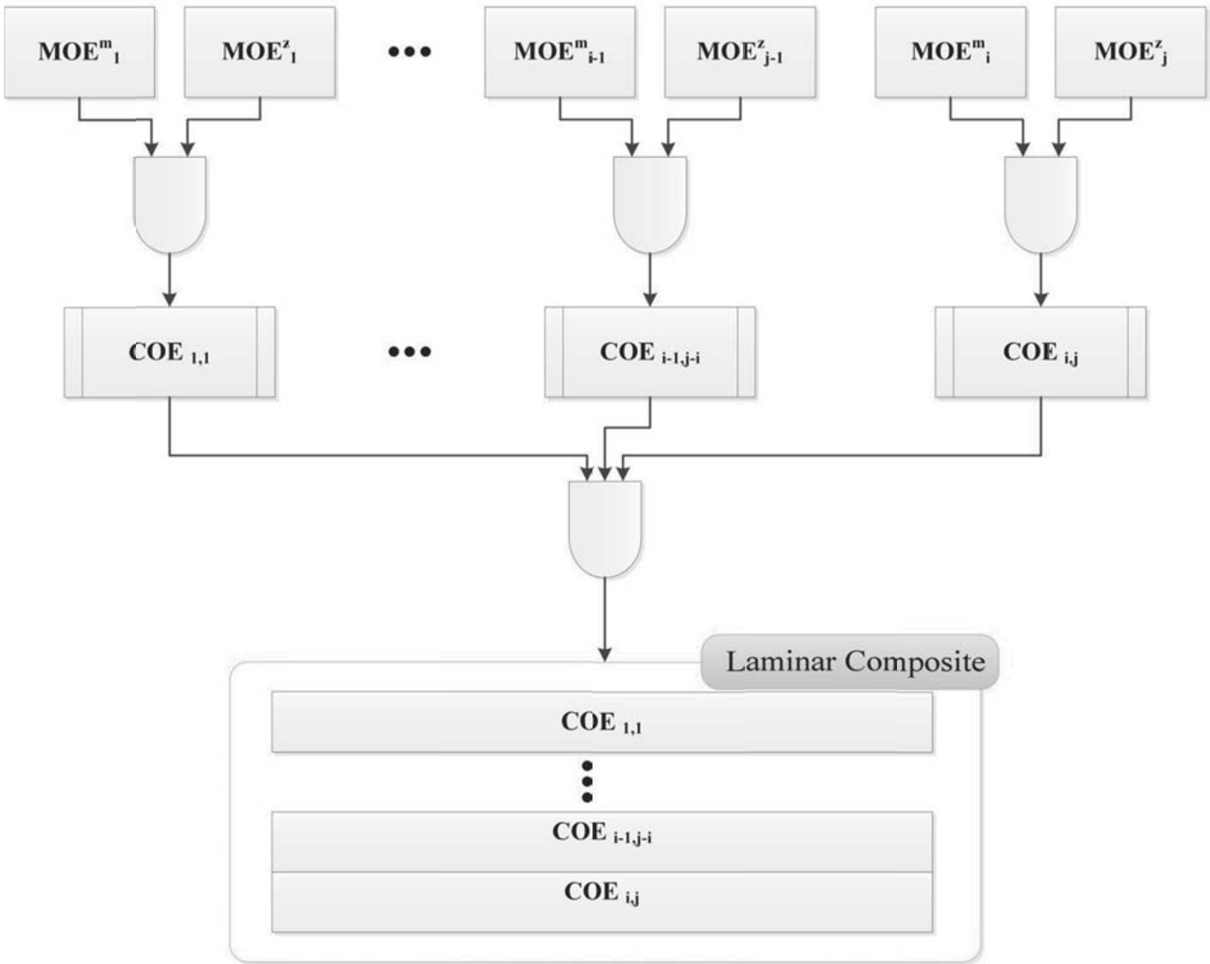

Fig. 2. Composite model

Another level of complexity of composite materials is the building of the individual layers, COE-type items, composite laminate. Creates a new object that is submitting several elementary COE and the master made the element of an elementary COE.

Laminar feature, WOE – called the structure of the interaction between the individual COE.

$$LOE = \sum_{k=1}^{l \in N} COE^k, \tag{7}$$

where:
LOE – laminar feature,
COE – composite feature,
k – iteration of the further layers,
l – finite number of COE layers.

The contention particular feature elements had no links with the geometric form of the surface on which a composite was built. In defining the boundary conditions and the relationship between a composite element, and interacting objects, creating structural feature . It is a complex object, built with composite feature elements and composite structural feature (8).

$$SOE = (LOE + GOE + KOE + \ldots + FOE), \tag{8}$$

where:
SOE – composite structural feature,
GOE – geometrical feature,
KOE – construction feature,
FOE – functional feature.

The algorithm of the layer composite construction was started by defining a database of materials features used to build a COE. From a database of engineering materials drawn materials used in the manufacture of fibrous composites, thus created sub-bases of matrix and reinforcement materials. The basis for carrying out the process of designing the composite structures is to create a record, in the form of drawings depicting the geometrical form. Clearly defined area of a 3D model of the component which has been created from the functional features, is the basis for the construction of a layered composite. The thickness of single layer spacing ranges from 0.03 to several mm, the diversity of values results from the used materials and manufacturing technology. Obtain a final thickness of the model derives from the sum of the thickness of each layer, the dependence (8) shows the resulting thickness dimension of the stack.

$$G = \sum_{k=1}^{n \in N} g(COE_{i,j}^k), \tag{9}$$

where:
G – total thickness of LOE,
$COE_{i,j}^k$ – composite feature,
$g(COE_{i,j}^k)$ – the value of a single layer thickness.

3. Multilevel and multiscale modelling

In literature multiscale modelling in physics is used to calculation of material properties or system behaviour on one level using information or models and properties from different levels. Following levels are usually distinguished: level of quantum mechanical models (information about phenomena occurring between the electrons), level of micro models (information about phenomena occurring between the atoms), mesoscale or nano level (information about phenomena occurring between molecules and group of atoms), micro level models (information about the phenomena occurring in the structural objects). Multiscale modelling is particularly important in integrated computational materials engineering since it allows to predict material properties or system behaviour based on knowledge of the atomistic structure and properties of elementary processes [1].

In regard to the design of composite materials attempt to define multilevel and multiscale components of structural element. When quantum level is defined as the basic unit of the composite material which components exist as two separate phases, then the analysis of matrix and reinforcement are made independently. In the process of combining independent phase of the quantum level (MOE^m and MOE^z), created a layer called the micro level. At this level has been previously created object called composite feature (COE). In the process of combining individual layers of COE, which is in the level of meso (nano) obtains ownership of WOE. The combination of layers creates a Laminar Composite. If we superimpose a WOE ties and boundary conditions and define a geometric figure, the object will receive the structure, this layer is known as macro level (Fig. 3).

Multiscale analysis is defined as a feedback loop in the design of composite structures. It is possible to analyse particular components in terms of set conditions. Defines the primary loop, which is a fundamental feature of the proposed composite. In this loop you can use these conditions for endurance:

- stress,
- deformation,
- displacement,
- rotation.

Simultaneously, an additional condition may be a primary condition related to the property of the layer:

- angle arrangement of fibres,
- weight,
- layer thickness,
- type of matrix material,
- type of material reinforcement;

or all of the composite:

- weight,
- total thickness.

Specific conditions may be applied from the basic material of a particular phase, through the layer to the total composition. In the process of optimization of the composite can be applied to the same conditions, further clarification of their weight values. The feedback was presented as a secondary loop design.

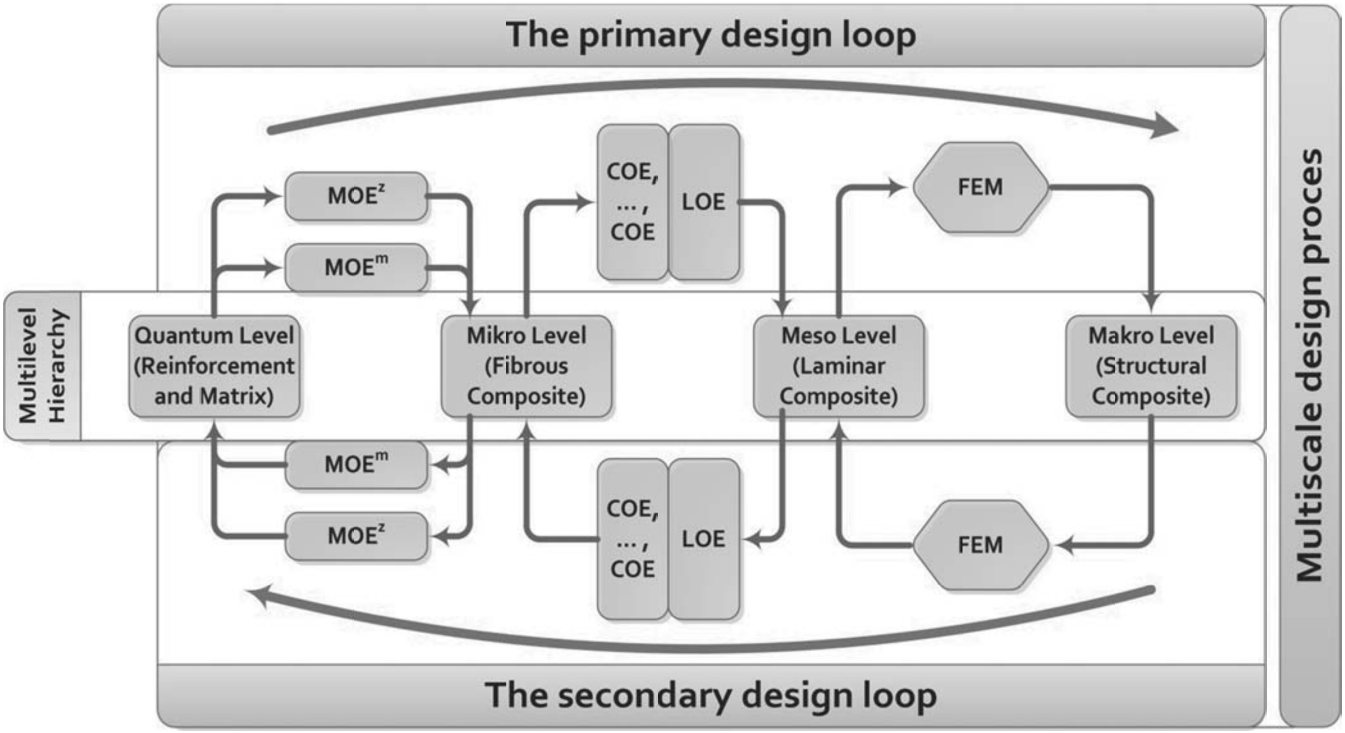

Fig. 3. Multiscale and multilevel modelling

4. Algorithm design of composite

Direct use of the composition of the composite fulfils features by shape and material. In the process of designing a product made of fibrous composites distinguished several stages:

- strictly defined function and destiny,
- determine the shape of the product,
- material selection,
- manufacturing technology.

Scope design provides a greater part of the required form of the product. Design covers the design and construction as the technological process of production. Fig. 4 presents the algorithm proceedings in the design process of the optimization process based on accepted criteria. For the design of composite structural elements particularly the roles of the types of projects:

- Original,
- Adaptive – mostly implemented,
- Alternative.

The design algorithm uses object-oriented approach, covering the following topics and types of objects:

- Geometric – geometrical feature (GOE),
- Endurance – endurance feature (WOE),
- Technological – technological feature (TOE),
- Material – material feature (MOE), singling out a particular type of material.

In the algorithm (Fig. 4) has been taken into account the direction and the return flow of information from particular facilities with detailed design subprocesses. The results of the algorithm is a collection of information contained in the complex feature (SOE). Use the recipe will allow you to produce a composite in accordance with the expectations of the constructor. Simultaneously, the algorithm allows reducing the number of required experimental studies on real object. The number of iterations in the design process depends on from the set requirements and the function is to fulfil target of SOE.

5. Practical application of object-oriented methods

Process of modelling composite structural components was shown in the example of modelling a sample made from four layers of fiberglass fabric with a weight of 450 g/m^2, in the matrix epoxy resin. The laminate was combined with a steel plate with sixteen of the blind rivets [8], diameter of 4.8 mm. The modelling process began by creating a plane with dimensions corresponding to the actual dimensions of the sample. Plane was created by drawing a line (Sketch-Line) with a length corresponding to the transverse dimension of the sample, and then dragged it (Extrude) on the dimension of the longitudinal sample (Fig. 5) [9, 10, 11, 12, 13, 14, 15, 16].

In the next stage, set up additional sketches and inserted into the plane for dividing the sample with a tool to divide face. The corresponding splitting plane must take into account the holes and bare areas, and load the actual sample (Fig. 6)

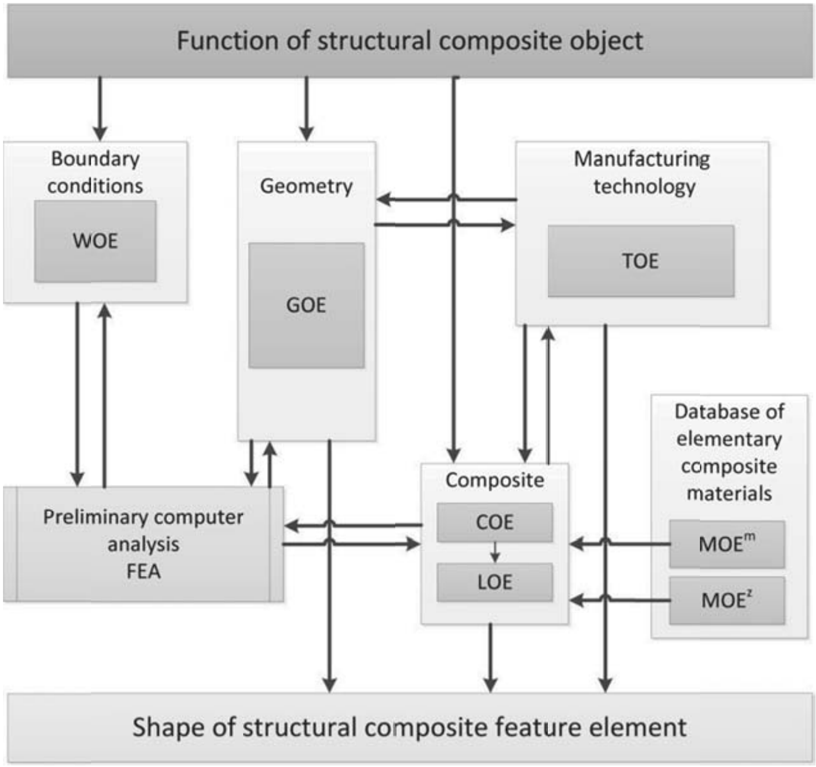

Fig. 4. Multiscale and multilevel modelling [4]

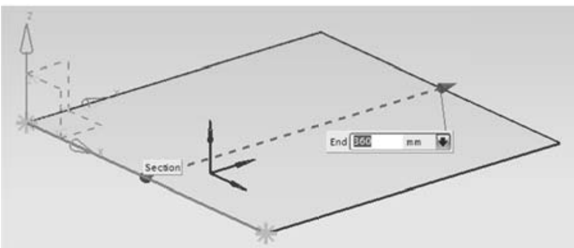

Fig. 5. One of the stages of creating a numerical model

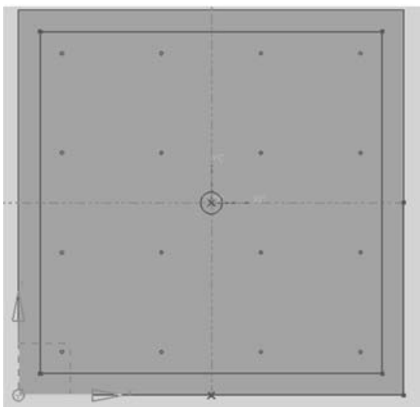

Fig. 6. Plate with all the reference objects

All the functions belong to the structural features. They are primitive objects, which creates a set of complex object, which becomes the base for further modelling and analysis processes.

The library NX 7.5 has no predefined materials used for the implementation of the sample. It was necessary to create a base of MOE, related to the material used as reinforcement and matrix (Fig. 7). In the process of modelling construction composite elements can distinguish between two types of composite structures. Composite materials formed from homogeneous or heterogeneous.

For homogeneous materials, composite materials have been classified, reinforced fibres. Distinguishes the following types of reinforcement:

- woven,
- unidirectional,
- random short fibre,
- particulate.

Depending on the type of reinforcement is required to define two or three. MOE objects. In the event of the type of reinforcement: unidirectional, random short fibre, particulate are requiring to define MOE^m and MOE^z objects. However, the use of reinforcement of type woven, it is necessary to define the MOE^m object and two objects MOE^z for warp and weft (Fig. 8) [10, 11, 12, 13, 14, 15, 16].

The materials used as reinforcement were put to the database as MOE objects defining the information on material properties. Basic information describing the new object MOE are: Young's modulus, Poisson's ratio and modulus of Kirchoff.

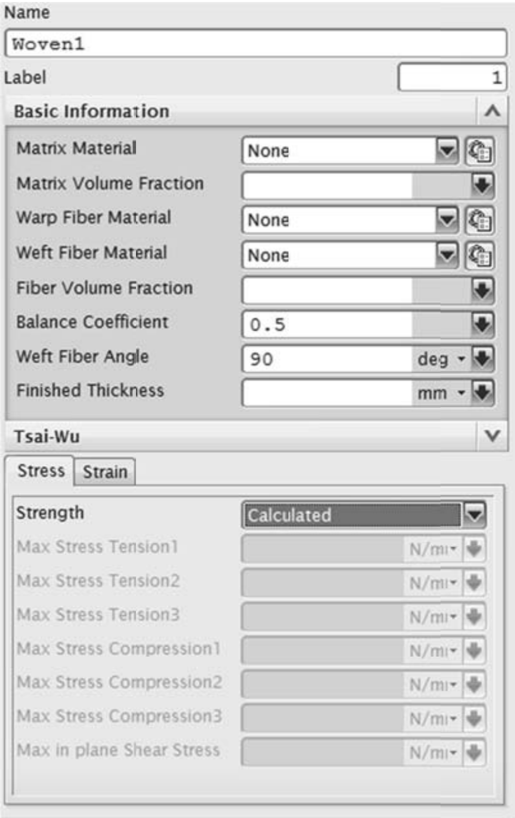

Fig. 7. COE configuration window

Function Laminate Modeller (Fig. 9), enables processing of individual objects previously created COE – which are single plys, to the type of the object LOE, which is the overarching, complex feature. Strength properties are at each stage of modelling are reviewed. Basic material properties are changing from the basic unit of which is the MOE, through the COE, to LOE. Depending on the recipe used, the values associated with the additional variables in the object type COE, mechanical properties may increase or decrease.

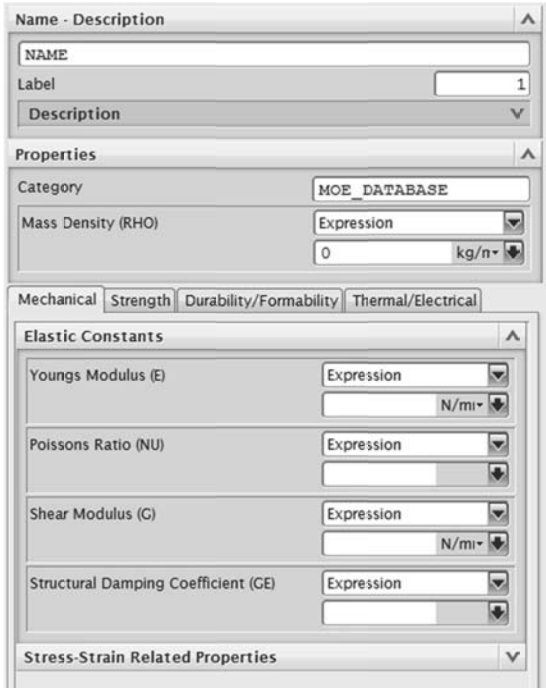

Fig. 8. Basic configuration of MOE

Fig. 9. Laminate Modeller

At the same time it is possible to obtain a composite with optimal properties for the given problem of the use of the object (Fig. 9) [9, 10, 11, 12, 13, 14, 15, 16].

Before starting the simulation, it is necessary to define the boundary conditions. For this purpose, uses objects endurance WOE:

- constraints,
- contact pressure from the rivet,
- exciting force.

Thus prepared Model has been undergone to the process of mesh, a division of analysed object of finite elements (Fig. 10) [7].

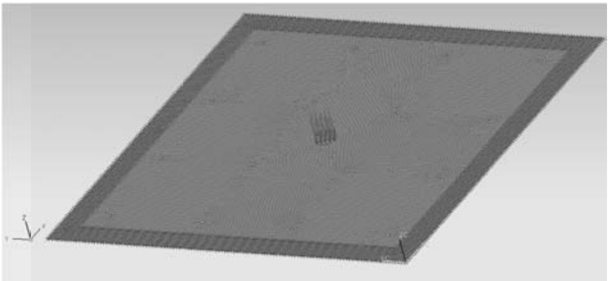

Fig. 10. Prepared model to perform the analysis

Thus prepared, the model can be used to carry out a preliminary stress analysis (Fig. 10), verification of application materials in individual layers and the materials from which the individual layers were prepared. The imposition of boundary conditions on the objects COE, at this stage creates a new object, which was defined as structural feature of SOE.

6. Conclusions

This paper attempts to develop a method that would allow for the acceleration of work related to the process of designing structural elements in modelling and stress analysis. Direction of research was to integrate the modelling and analysis with the selection of the optimization composition of composite. In order to integrate the processes described above using the method of feature. This method allowed the perform systematization of the process of building a composite using computer methods.

Application of multiscale analysis of composite materials, helps build composites in the process of analysing iterative his property from different angles.

The process underlying the initial choice of materials is carried out using a previously defined function. Verification, analysis and modification of the underlying components of the composite takes place in the feedback loop. In order to facilitate the analysis of the various stages of construction of the composite were divided into levels. Compared them up to the quantum objects – corresponds to material features MOE. Subsequently the micro scale, corresponds to composite features COE, meso-scale – the basic version of the laminate LOE, the micro scale – corresponding to structural feature SOE.

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