# DESIGN OPTIMIZATION OF COMPOSITE PARTS USING DOE METHOD

**Petr LEPŠÍK[1], Petr KULHAVÝ[1]**

[1]*Technical University of Liberec, Faculty of Mechanical Engineering, Liberec, Czech Republic*

***Abstract***
*The paper is focused on design optimization of composite parts made of long fibers carbon composite material assembled into plies. Parameters as angles of particular plies and geometry of a part should be optimize according to specific loading of the part. The analytical approach to searching optimal parameters is difficult especially for complex parts. A task becoming more and more difficult with the number of optimized parameters. The way of searching of optimal parameters (angels of particular plies and geometrical parameters of a part) is using method DOE (Design Of Experiment) and SW Ansys which uses this method for optimization tasks. The paper introduces this optimization tasks for case of composite tube. This approach can be used for example for design optimization of composite tubes in innovated car seats etc.*

***Key words:*** *design optimization; composite parts; carbon fibers; prepreg; DOE; Ansys*

## INTRODUCTION

In recent years using of composite materials is still exponentially growing, thanks to the excellent specific strength, possibilities of customize the properties and achievable weight savings. The use of modern advanced composite materials has gained wide acceptance in the last few decades. Compared to metallic structures, composite laminates offer some unique engineering properties while presenting interesting but challenging problems for analysts and designers (*Kherredine L., Gouasmi S., Laissaoui R., Zeghib N. E., 2012*).
In term of the project Innovation of Technical Systems Structures with the use of Composite Materials autors already dealed with the issues of bending properties of thin walled prepreg carbon fibers (*Kulhavý P.; Lepšík P., 2017a*), vibration response of composite structure (*Kulhavý P., Petřík J., Srb P., Lepšík P., 2016*), comparison of modal characteristic of wrapped and winded composite tubes from carbon prepreg (*Kulhavý P.; Lepšík P., 2017b*) etc. After these primary studies it is neccesary to find an effective way of optimization of part design and its parameters according to the specific loading. The method DOE (Design of Experiment) can be used for optimizing of variable input parameters according to the required output parameter. This method has been used with advantage for example for improving the production of composite pipes (*Srebrenkoska S., Kochov A., Minovski R., 2016*) or study of mechanical behaviour of matrix composites (*Deshmanya I., Purohit K., 2011*). The aim of this study is to find the optimal design of a loaded composite part with the use method DOE and SW Ansys.

## MATERIALS AND METHODS

### Materials

This study is focused on long fiber prepreg carbon composite materials assembled into particular plies (**Fig. 1**). Unidirectional prepreg tapes have been the standard material used within the aerospace industry for many years. Pre-saturated fibers are tape consist of fibers in a polymer (often impregnated with thermosetting resins) matrix and protected by a silicone paper. Usually, they are available in widths from 70 to 1300mm (*Srb P., Kulhavy P., Kovar R., Lepsik P., Syrovatkova M., 2016*). Depend on the constitution of the matrix (thermoset or thermoplastic) is the tape stored in a refrigerator. Then, the tape can be automatically or manually laied at various orientation to make the final composite structure. Then, follow the standard process of curing in vacuum, during pressure and temperature, may follow (*Kaw K., 2006*).
All prepreg materials have to be cured according to tightly controlled time, temperature and vacuum requirements. Quality assurance shall continuously record time, temperature and vacuum during the cure process (*Koushyar H, Alavi-Soltani S, Minaie B, Violette M., 2012*). Process of curing the final

product: Apply vacuum, Heat at 72-115°C, Hold on curing time 1-12 hours, then slowly cool at 48°C (*Srb P., Kulhavy P., Kovar R., Lepsik P., Syrovatkova M., 2016*).

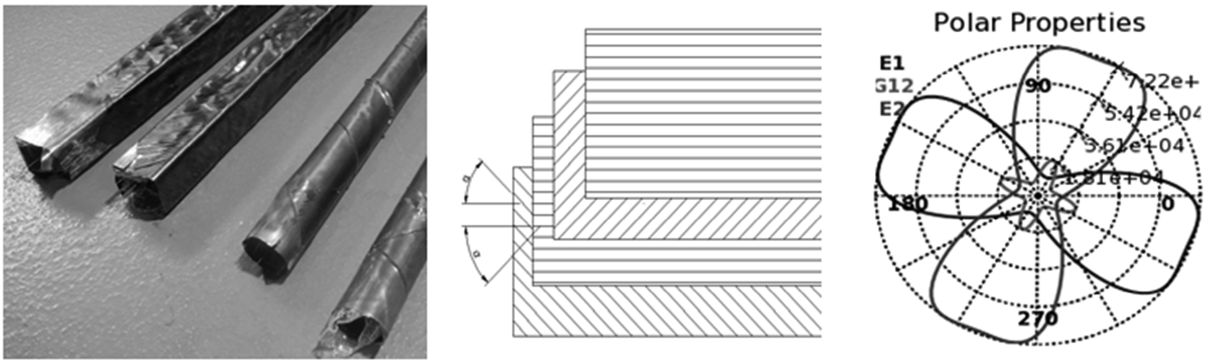


**Fig. 1** Composite part a) Real tubes, b) A plies layout, c) The basic material properties

The design of curved tube of elliptical cross section made of 4 plies fixed at one end and loaded by force at opposite end was optimized in term of this study. Constant input parameters were lenghts and radius of the tube, angle of 1st and 2cd ply (45/-45), loading force (340N) and material properties. Optimized parameters were angles of 3rd and 4th ply and lenght of axes of elliptical cross section. The desired result was minimal deformation of the tube.

**Methods**

Method Design of Experiments (DOE) which is included in SW Ansys has been used for this task. First the computer model of the composite tube was created in SW Ansys then the algorithm of DOE was used.

The model of the curved tube of elliptical cross section is created of 4 plies with 2 constant angles (45/-45) and 2 parametrical angles with initial vaues (45/-45) Model (Fig. 2) is created as shell layered with the use of composite preprocessor ACP. The model contain mapped face mesh with quadrilaterals elements, 1124 nodes and 1107 elements. According to the geometry of draft profile with parametrical radius of the tube, edgewise defined rosettes were neccessary to use for accurate definition of directional vectors of particupar plies depending on the real curvature of the geometry. The numerical model was solved as a statical where one end of a tube was fixed and at the second one was the force.

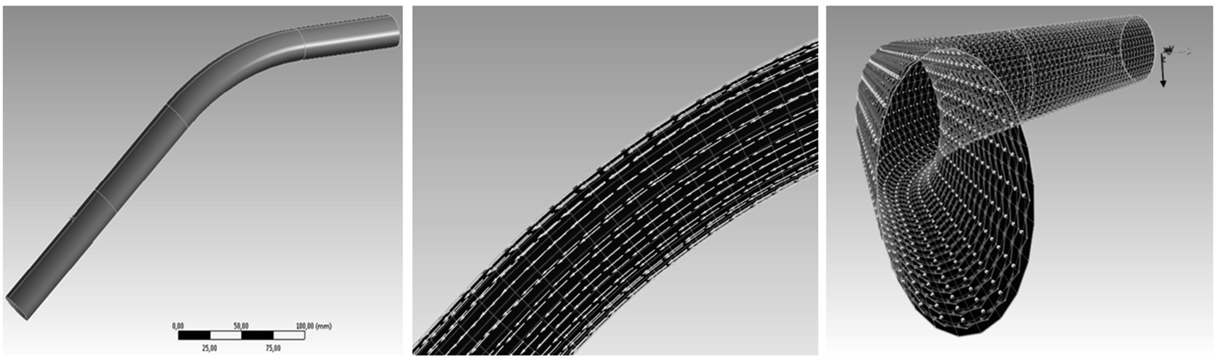

**Fig. 2** Model of composite curved tube of elliptical cross section

Design of Experiments (DOE is a technique used to scientifically determine the location of sampling points and is included as part of the Response Surface, Goal Driven Optimization, and Analysis systems. There are a wide range of DOE algorithms or methods available in engineering literature. These techniques all have one common characteristic: they try to locate the sampling points such that the space of random input parameters is explored in the most efficient way, or obtain the required information with a minimum of sampling points. Sample points in efficient locations will not only reduce the required number of sampling points, but also increase the accuracy of the response surface

that is derived from the results of the sampling points. By default, the deterministic method uses a Central Composite Design, which combines one center point, points along the axis of the input parameters, and the points determined by a fractional factorial design.
We used DOE method for searching the most suitable value of the angles of 3rd and 4th ply and lenghts of axes of elliptical cross section of the tube (Fig. 3).

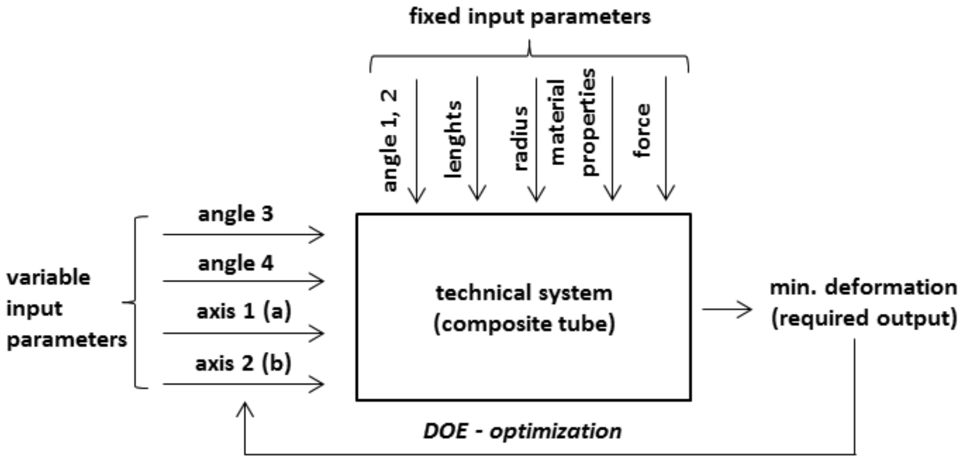


**Fig. 3** System model of the optimization task

First part of the computation was searching of correlation dependencies between particular input parameters and output parameter. Total 100 design points were generated with the use of „function specimen“ also used in (Price K., Storn R., Lampinen J., 2005).

$$\text{Specimen} = \{(type^1; Lo^1; Hi^1); (type^2; Lo^2; Hi^2) \ldots (type^D; Lo^D; Hi^D)\} \tag{1}$$

$$Dp_j = Lo^j + rand(0,1)\left(Hi^j - Lo^j\right) \tag{2}$$

Where type mean the number character (real, integer, discrete set), Lo and Hi are the lowest and highest possible value (in our case the winding angle in actual ply) and j mean nr. Of the actual design point.
The limit values of angles 3 and 4 were chosen according to manufacturing technology which do not allowed to use angles close to 0 or 90 deg. Initial and limit values of variable parameters are in the Tab. 1.

**Tab. 1** Initial and limit values of variable parameters

| Variable parameter | Initial value | Lower limit value | Higher limit value |
|---|---|---|---|
| P1 – Longer axis - ellipse (mm) | 35 | 30 | 40 |
| P2 – Shorter axis - ellipse (mm) | 20 | 15 | 25 |
| P3 – Angle of ply 3 (deg) | 45 | 20 | 80 |
| P4 – Angle of ply 4 (deg) | -45 | -20 | -80 |

After finding correlation dependencies, it was necessary to find the optimal solution using the Response surface optimization algorithm. The solution consisted of new generations totaling 1000 design points.

## RESULTS AND DISCUSSION

The correlation dependencies of input and output parameters are shown in Quadratic determination matrix (Fig. 4). The highest impact on the deformation (output parameter) has the lenght of longer axis of ellipse (absolut value of correlation coeficient lies in interval 0,4-0,6), lower impacts have angles of plies 3 and 4 (absolut value of correlation coeficient 0,2-0,4), the lowest impact has the lenght of shorter axis of ellipse (absolut value of correlation coeficient 0,1-0,2). Proportional impact of imput parameters to deformation is shown in pie chart Sensitivity of deformation on the input parameters (Fig. 4).

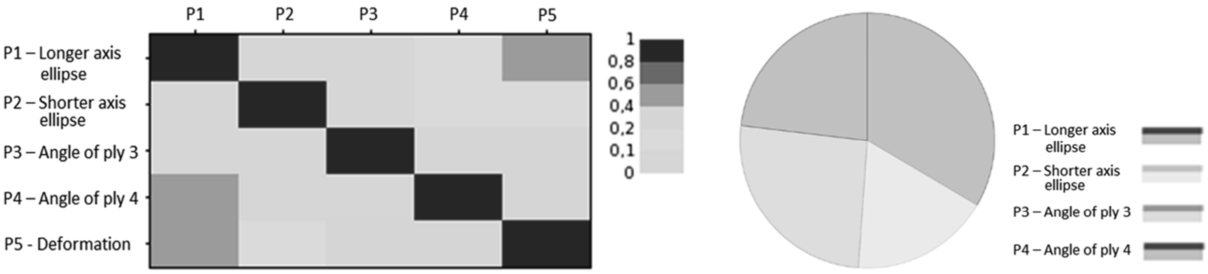


**Fig. 4** The correlation dependencies a) Quadratic determination matrix b) Sensitivity of deformation on the input parameters

The dependence of maximal total deformation on length of longer axis of ellipse is shown in the Fig. 5. Between these two parameters (the most important input parameter and output parameter) is negative correlation.

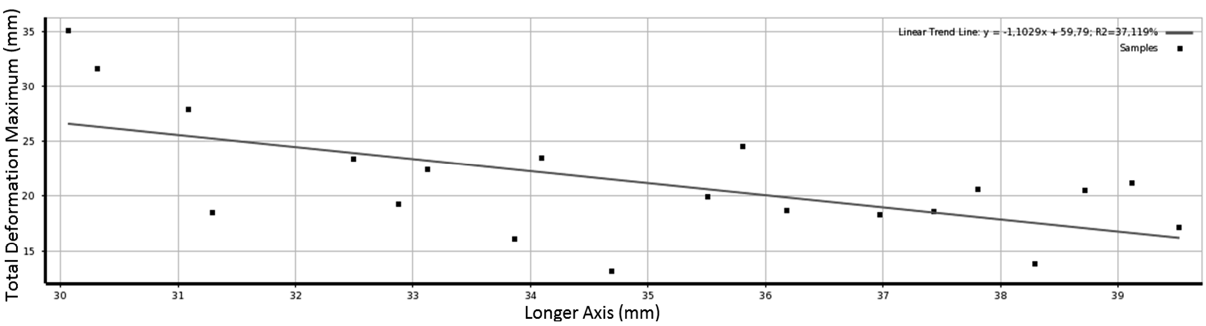


**Fig. 5** The dependence of maximal total deformation on length of longer axis of ellipse

The dependences of maximal total deformation on two variable input parameters (agles of plies 3 and 4) or lenght of longer ellipse axis and angle of ply 3 are shown in the Fig. 6. The minimum deformation occurs when the fibers are oriented at 20 degrees (ply 3) and -20 degrees (ply 4).

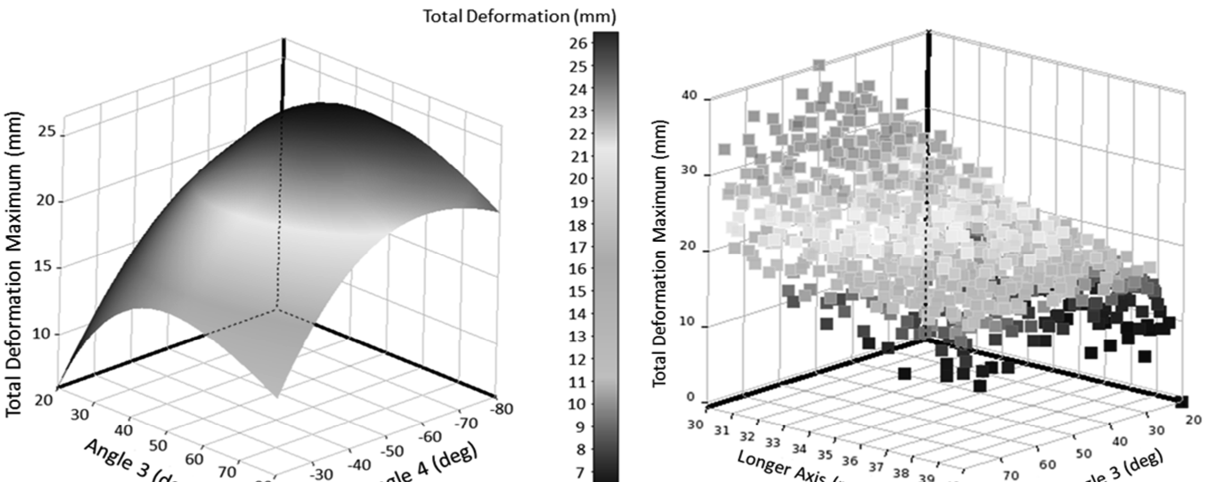


**Fig. 6** The dependence of total deformation on two variable input paremeters a) Response surface b) Sampling points

After recognition of impact of particular variable input parameters to output parameter can be find optimal combination of parameters to achieve optimal value of output parameter (minimal total deformation). The best candidates has been chosen from generated 1000 points accorting to the fitness functions in our case represented by minimal total deformation. The parameters of the best candidate are introduced in Tab. 2. The results correspond with the theoretical expectation. The directions of fibers given by angles of the plies are in sum the closest possible to the tensile loading of the fibers. The cross section of the tube achives to maximal allowed value to minimize deformation of the tube.

**Tab. 2** The best candidate of design point generation with the highest value of fitness function

| Parameter | The Best Candidate Point (Optimized values) |
|---|---|
| P1 – Longer axis - ellipse (mm) | 40 |
| P2 – Shorter axis - ellipse (mm) | 25 |
| P3 – Angle of ply 3 (deg) | 20 |
| P4 – Angle of ply 4 (deg) | -20 |
| P5 – Maximal Total Deformation (mm) | 8,19 |

After receiving optimalized values of input paremeters the model was recalculated and results were compared (Fig. 7). Maximal total deformation of the tube was reduced from 14,8mm to 8,1mm using method DOE and Ansys for optimization of composite part design.

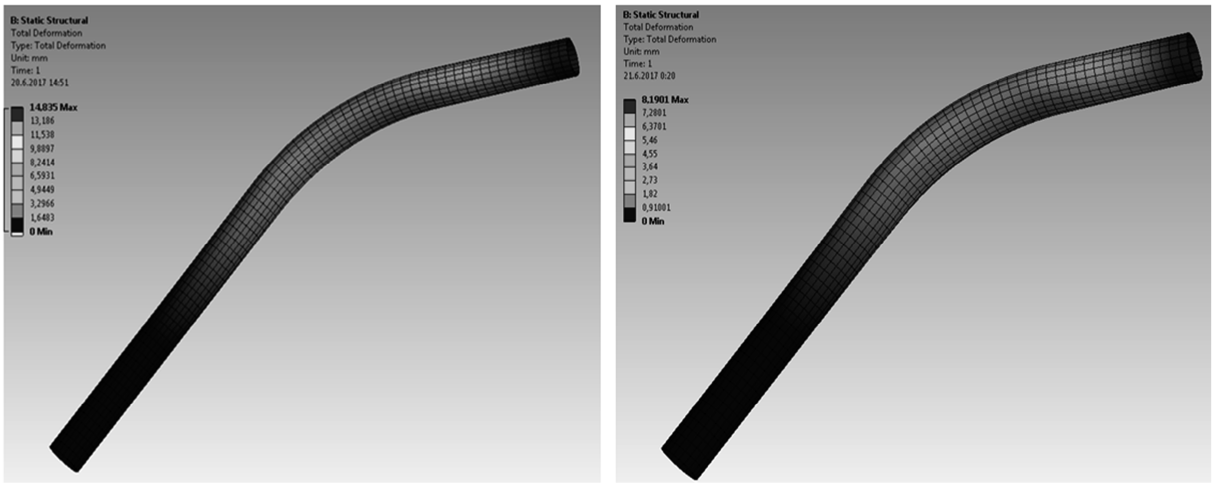


**Fig. 7** The total deformation a) original b) optimized (angles of plies 3 and 4, lenghts of axes of elliptical cross section) design of the part

## CONCLUSIONS

Designing advanced long fiber composites is not conceivable without the support of the latest computational CAD and FEM modellers today. Unlike the classical material, the parameters of the final composite part can be fundamentally influenced by the sequence and rotation of the plies from which the material is composed. Since the combination can exist theoretically countless, experimental testing is not practicaly possible. For this reason, the future is precisely the use of algorithms to search for the maximum of a given fitness function. Compared to conventional unimodal solvers, generic or evolutionary unimodal search algorithms should be used due to the complexity and amount of possible local maxima and minima of the function. Introduced study shown posibility of usage method DOE and Ansys for design optimization of long fiber carbon composite part. Optimization of parameters as orientation of particular plies and geometrical parameters of the part has led to improving of mechanical properties of the part. The benefit of this method will increase with the increasing complexity of a composite part.

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**Corresponding author:**
Ing. Petr Lepšík, Ph.D., Department of Machine Parts and Mechanisms, Faculty of Mechanical Engineering, Technical Univerzity of Liberec, Studentska 2, 461 17 Liberec 1, Czech Republic, phone: +420485353326, e-mail: petr.lepsik@tul.cz.