The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 28, Pages 252-258

ICBASET 2024: International Conference on Basic Sciences, Engineering and Technology

# Design and Calculation of Products from Composite Materials Using Software

**Sara Srebrenkoska**
Goce Delcev University

**Vineta Srebrenkoska**
Goce Delcev University

**Marija Cekerovska**
Goce Delcev University

**Todor Cekerovski**
Goce Delcev University

**Abstract**: This article analyzes six types of composite pipes that are good replacements for corrosive steel and metal pipes for oil, gas, and water. The analysis of the six samples of composite pipes was done using the software program Hoffman Engineering, which is intended for the design and calculation of various types of products made of composite materials. For the analysis of the six composite pipes, the same diameter and the same length were taken, and variable parameters are: the type of material from which the composite pipes are made (carbon/epoxy, carbon-glass/epoxy and glass/epoxy), and the angle of winding of the fibers (10º and 90º degrees). Using the Hoffman Engineering software package, an analysis of the durability of the six differently designed composite pipes at high internal pressure was performed. The same conclusion was obtained from all analyses: the high internal pressure resistance of composite pipes is highly dependent on the fiber winding angle and the type of fibers used. Composite pipes obtained with a fiber winding angle of 90º have twice the internal pressure resistance compared to composite pipes obtained with a fiber winding angle of 10º. Composite pipes based on carbon fibers have the highest resistance to internal pressure, then composite pipes based on hybrid materials (glass and carbon fibers) and finally composite pipes based on glass fibers. Finally, a comparison was made with the obtained laboratory results for the same composite pipes. The same conclusion was obtained from all analyses: the high internal pressure resistance of composite pipes is highly dependent on the fiber winding angle and the type of fibers used. The composite pipes obtained by this process are durable and resistant to very high pressures.

**Keywords:** Composite pipes, Software program, Material type, Internal pressure, Winding angle.

## Introduction

The production of composite pipes is of great importance because it refers to standard types of composite pipes that are in direct competition with older types, such as steel pipes. The industrial importance of the process is great because the resulting composite pipes are a good substitute for corrosive steel and metal pipes for oil, gas, and water (Osanna, 2004). In addition, the pipes obtained by this process are durable, even at high pressures.

Most often, the improvements in the processes to produce composite materials, which primarily have a technological, technical, and economic effect, are seen in the more rational use of raw materials and auxiliary materials, and thus also in the waste and harmful substances that, because of the process, are either controlled or uncontrolled, thrown out, or disposed of in the environment (Chyng, 2010). If the processes to produce composites are more compact and the stages of production are related to efficiency in the use of equipment, the time cycle per unit of the product is shorter. (Chyng, 2010). It can be concluded that in optimized, improved, or advanced processes to produce composite materials, the cost of the energy consumed per unit of product is lower (Mazumdar, 2002).

Computer-aided design is a standard part of the training of today's engineer, who has at his disposal the widely available packages for modeling, optimization, and selection of materials and processes. The software package for the selection of materials and processes relies on a database of attributes of materials and processes and their mutual compatibility, which allows the search and selection of those materials and processes that best meet the requirements of an appropriate design (Boccara, 2010).

### Fiber Winding Process

Industrial processes to produce composite materials are in continuous development with a constant tendency to introduce new processes and technological solutions in them. The process of winding fibers and obtaining composite pipes is a relatively new process that presents a challenge for industrial facilities working with composite materials (Peters, 1998). The choice of procedures and processing conditions for obtaining a composite material are of particular importance because they greatly affect the properties of the obtained material and the price of the final product. The production of composite structures is often associated with obtaining products of inconsistent quality (Basu, 2004). It is typical of these types of materials that results from their anisotropic nature. Engineers who work with processes for obtaining such materials have the freedom to design the processes for obtaining composite structures depending on the final requirements for meeting certain properties (Beyreuther, 2010). Composite pipes are often used as a good substitute for corrosive steel and metal pipes for oil, gas and water, and also as tanks, and therefore the requirements they have to meet are related to their durability and resistance to high internal pressures. Obtaining composite pipes that will have unchanging (constant) quality, light weight, and at the same time will be durable and durable at high pressure and competitive with the price of the market has encouraged various activities in that area (Bernard, 1991).

## Method

In this paper, the analysis of six samples of composite pipes is done using the software program Hoffman Engineering, which is intended for the design and calculation of different types of products from composite materials. The standard ISO 11439.2000-ASTM D1599 (Standards, 2000) was used in the analysis of the composite pipes. According to this standard, one of the basic characteristics that should be satisfied is the internal burst pressure as well as the tension ratio of the fibers - the reinforcement. The minimum burst pressure should not be lower than the values given in Table 1.

Table 1. Minimum burst pressure and stress ratio for pipes (Standards, 2000)

| Fiber type | Stress ratio | Crushing pressure(bars) |
|---|---|---|
| Glass Fibers | 3.65 | 180 |
| Carbon Fiber | 2.35 | 117 |
| Hybrid Fibers | 3.0* | 148 * |

*The stress ratio and the braking pressure should be calculated according to the table

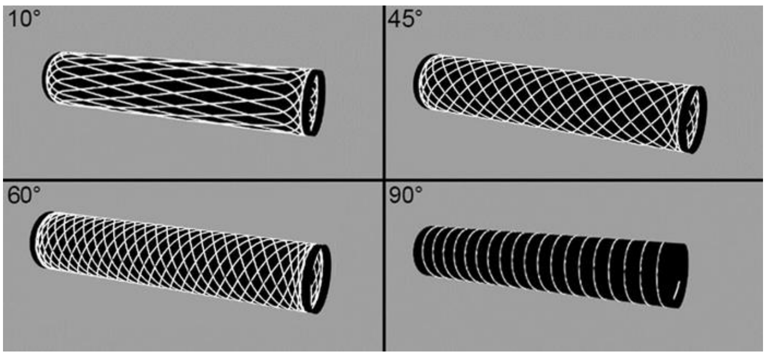


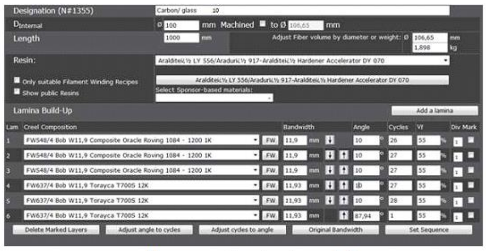

Figure 1. Graphical representation of tube winding with four different layer orientations

By applying the Hoffman Engineering software package, the wall of the composite pipe, which consists of several layers, is first designed or structured. The composite pipe is constructed from multiple layers. Each layer is made up of fibers placed at a specific angle. The fibers in the layers can be placed at the same or different angles, thus allowing the composite pipes to withstand the intended internal and external loads, as shown in figure (Figure 1). Composite pipes are rarely constructed of layers where the fibers are placed at only one angle. For a composite material to withstand different loads in different directions, a layered composite is designed with a combination of the fibers in the layers at multiple angles (Beyreuther, 2010). If a composite part must withstand internal pressure, then the stresses in the radial direction are much higher than the stresses in the longitudinal direction.

Then, in the same software, the characteristics of the composite layers are determined, and the expected internal burst pressure of the composite pipe is calculated. Through multiple calculations of different variants of the structure of the layers and their optimization, the optimal method of winding a composite pipe with characteristics that will meet the requirements of the standard is determined (Koussio, 2004). The input variables in that optimization are the types of raw materials (fibers and resin), the winding angles of the separate layers, the number of layers, and their arrangement (Boccara, 2010). Within the framework of this paper, six composite pipes were analyzed, and the same diameter and length were taken for them. The variable parameters are:

- the type of material from which the composite pipes are made (carbon/epoxy, carbon-glass/epoxy, and glass/epoxy) and
- the angle of winding the fibers (10º and 90º degrees).

a) composite pipe type 1-1

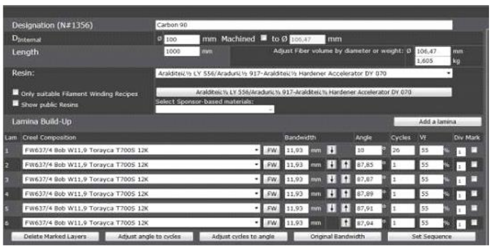


b) composite pipe type 1-2

c) composite pipe type 1-3

d) composite pipe type 2-1

e) composite pipe type 2-2



f) composite pipe type 2-3

Figure 2. Hoffman Engineering software application - creating layers of different six types of composite pipes

Table 2. Composite wall structure for six types of composite pipes

| Types of composite pipe | | | | | |
|---|---|---|---|---|---|
| 1-1 | 1-2 | 1-3 | 2-1 | 2-2 | 2.-3 |
| Radial 90$^o$ | Radial 90$^o$ | Radial 90$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ |
| Diagonal 10$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ | Radial 90$^o$ | Radial 90$^o$ | Radial 90$^o$ |
| Diagonal 10$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ | Radial 90$^o$ | Radial 90$^o$ | Radial 90$^o$ |
| Diagonal 10$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ | Radial 90$^o$ | Radial 90$^o$ | Radial 90$^o$ |
| Diagonal 10$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ | Radial 90$^o$ | Radial 90$^o$ | Radial 90$^o$ |
| Diagonal 10$^o$ | Diagonal 10$^o$ | Diagonal 10$^o$ | Radial 90$^o$ | Radial 90$^o$ | Radial 90$^o$ |

Next figure (Figure 2) presents windows of the software application in which data is entered for building the layers of the composite wall of all six composite pipes separately, and table (Table 2) shows the structure of the composite walls for all six samples.

The composite wall structure consists of three types of winding layers: radial layer, diagonal (or helical) layer and transition layer (Allaire, 2007). The coiling of one type of tube in production at a different angle is shown in the figure (Figure 3). The transition layer is of special importance for continuous winding with an alternating change of the winding angle of each successive layer (for example, radial with diagonal and vice versa). In this way, the entire winding process is continuous from start to finish, without the need to stop the process and manually adjust the starting position of the machine for each layer separately.

a) fiber winding angle 10 º


b) fiber winding angle 90 º

Figure 3. Production of composite pipes with different fiber winding angle

After the layers are entered into the software program, the loads that the composite pipe should withstand are entered, and then the criterion is selected according to which we want to check the resistance of the composite pipe to the predicted load, i.e., internal pressure. In the next figure (Figure 4), one of the interactive windows of the application is presented, in which part of the data needed for the analysis of the composite structure (pipes) is entered

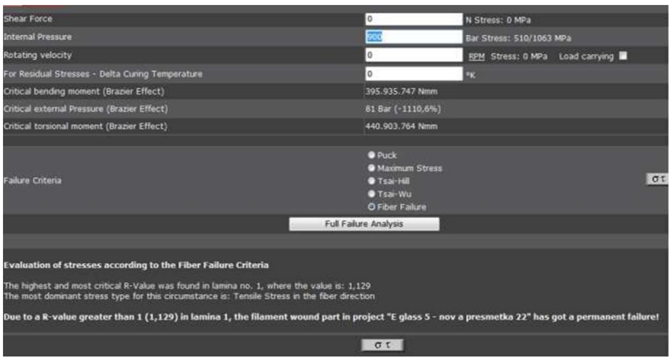



Figure 4. Hoffman Engineering software application - definition of analysis parameters

In the software application, there are several criteria by which the durability of composite pipes at high internal pressure can be checked: Puck, Maximum Stress, Tsai-Hill, Tsai-Wu, and Fiber Failure. When testing the resistance to maximum internal pressure in composite tanks and pipes, several so-called premature cracks occurred in the layered composite. Cracking of the matrix occurs at the beginning, then of the fibers that are in a direction different from the direction of the load, and then certain layers give way until complete cracking of the tube occurs, i.e., the composite. For composite pipes, the initial early cracks are not important, but the final complete crack at a given pressure is significant, i.e., burst pressure. When using glass fibers, the maximum allowable pressure is taken with a safety factor of 2.75 to 3.65 times greater than the working one for which the tube is designed, while when using carbon fibers, 2.35 times larger than the working one. However, with any software calculation for the durability of the designed composite, it is always necessary to do experimental testing to confirm the reliability of the obtained software results.

Within this paper, when applying the Hoffman Engineering software, the "Tsai Wu" criterion was chosen as a criterion for the calculation and analysis of the characteristics of the six composite pipes. This criterion was chosen based on data from practice, according to which it has been proven that it gives accurate data, that is, closest to the experimentally obtained data.

## Results and Discussion

Durability analyses of six differently designed composite pipes at high internal pressure were performed using the Hoffman Engineering software package. Namely, when designing these composite pipes, the variable parameters were the types of materials, i.e., the reinforcing fibers and the angle of fiber winding, while the length and diameter were the same for six composite tubes. Therefore, the obtained results of the six differently designed composite tubes with different fiber winding angles (10º and 90º degrees) using the Hoffman Engineering software package are shown in the next figure (Figure 4).

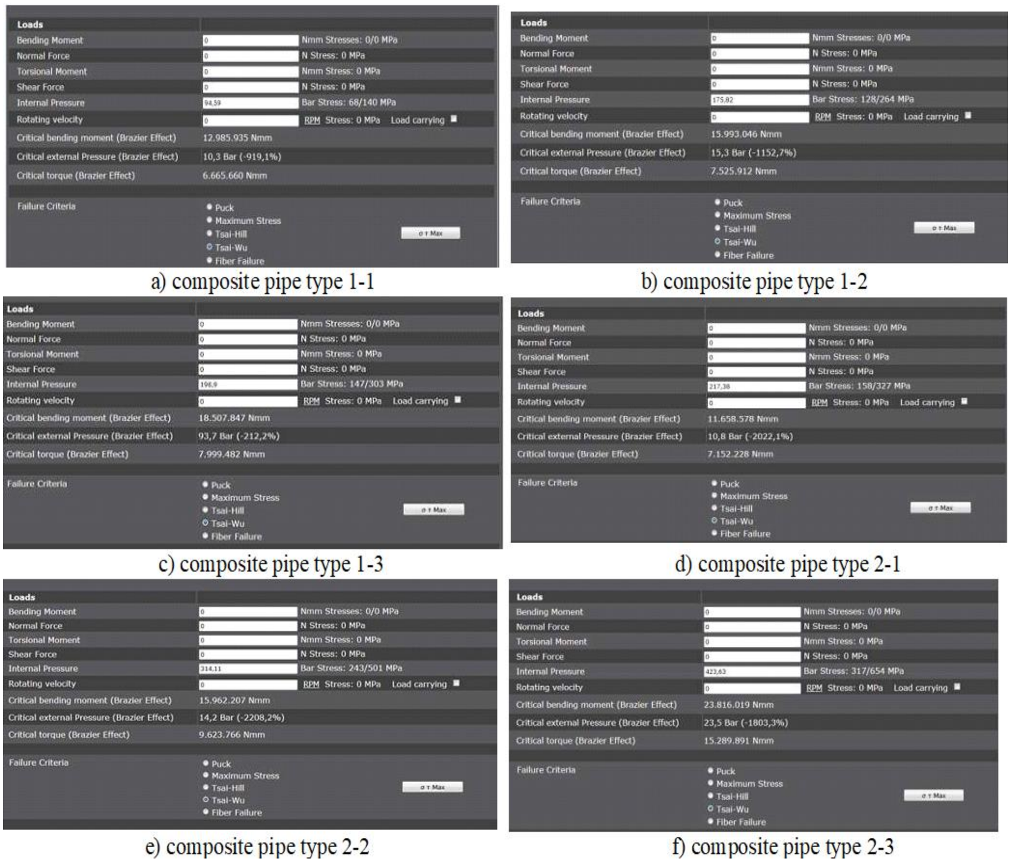


Figure 4. Results of the calculation and analysis of various types of composite pipes

After the calculations, the results of the analysis for the internal braking pressure of six types of composite pipes, which are the subject of analysis in this article, are shown in the table (Table 3). According to the table, all composite pipes meet the requirement according to the ISO 11439.2000 standard (Standards, 2000), except for type 1-1, where the winding angle of the fibers is 10º and the type of fibers is glass. This data indicates that the winding angle has the greatest effect on the durability of composite sheets at high pressure. Namely, the composite tubes obtained with a fiber winding angle of 900 show much higher internal failure pressures. From the fiber type analysis, it can then be concluded that the composite tubes obtained with carbon fibers show a much higher value of internal burst pressure than the composite tubes wound with glass fibers. Therefore, in these composite pipes, the number of layers can be freely reduced, thus reducing the thickness of the composite wall and the weight of the composite pipe while satisfying the requirements of the standard. Composite pipes obtained from a hybrid material of glass and carbon fiber show slightly lower internal pressures of endurance compared to composite pipes based on carbon fiber but are higher than those based on glass fiber. Also, with these composite pipes, it is possible to reduce the layers and reduce the thickness and weight of the composite pipe. However, for all analyzed tubes with a fiber winding angle of 10º, a lower internal burst pressure was observed compared to tubes with a fiber winding angle of 90º. For the composite pipe type 1-1 to meet the requirements of the standard, it is necessary to add more layers, which in turn will increase thickness and weight.

Table 3. Results of calculated internal pressure endurance of six types of composite pipes

| Composite tube type | Calculated internal burst pressure (bar) | Minimum burst pressure according to ISO 11439.2000 (bar) | Evaluation of satisfaction of requirements from the Standard |
|---|---|---|---|
| 1-1 | 94.59 | 180 | It doesn't fulfill |
| 1-2 | 175.82 | 148 | Fulfills |
| 1-3 | 198.9 | 117 | Fulfills |
| 2-1 | 217.38 | 117 | Fulfills |
| 2-2 | 314.41 | 180 | Fulfills |
| 2-3 | 423.63 | 180 | Fulfills |

The obtained results confirm our previous research (Srebrenkoska, 2023), where it was obtained through experiments that the winding angle has the most influence on the durability of composite pipes at high pressure. The same conclusion is reached, which is that optimal results would be obtained for composite pipes with a fiber winding angle greater than 10º and less than 90º. It is expected that composite pipes will have optimum characteristics when the winding angle is about 50º.

## Conclusion

With the help of the Hoffman Engineering software package, six types of composite pipes were analyzed, where the following parameters were considered: the constituent materials and the winding angle of the fibers. Whereas the composite pipes obtained with a fiber winding angle of 90º have two times higher resistance to internal pressure compared to the composite pipes obtained with a fiber winding angle of 10º. Composite pipes based on carbon fibers have the highest resistance to internal pressure, followed by composite pipes based on hybrid materials (glass and carbon fibers), and finally, composite pipes based on glass fibers. Based on all the analyses made, i.e., laboratory tests and the software package, it was concluded that the resistance to the high internal pressure of composite pipes is highly dependent on the fiber winding angle and the type of fiber applied.

## Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

## Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Basic Sciences, Engineering and Technology (www.icbaset.net) held in Alanya/Turkey on May 02-05, 2024.

## References

Akkus, N., Genc, G., & Girgin, C. (2008). Control of the pretension in filament winding process. *Acta Mechanica et Automatica*, *2*(3), 5-10.

Allaire, G., & Craig, A. (2007). *Numerical analysis and optimization an introduction to mathematical modelling and numerical simulation.* Oxford University Press.

Bernard, E. (1991). *Path generator for filament winding of asymmetric fibre composite components*. University of Ottawa.

Basu, R. (2004). *Implementing quality – a practical guide to tools and techniques.* UK, Thomson Learning.

Boccara, N. (2010). *Modeling complex systems*. Springer Science+Buisness Media LLC.

Beyreuther, R., Brunig, H. (2010). *Dynamics of fiber formation and processing*. Berlin: Springer.

Chyng, D., L. (2010). *Composite materials.* London: Springer-Verlag Limited.

ISO -International Standards. (2000). *ISO 11439.2000* (2nd ed.). Retrieved from https://www.iso.org/

Koussio, S. (2004). *Filament winding: a unified approach*. DUP Science.

Mazumdar, S., K. (2002). *Composites manufacturing - materials, products and process engineering*. CRC Press LLC.

Osanna, P., H., Durakbasa, M., N., Afjehi-Sasat, A. (2004). *Quality in industry*. Vienna University of Technology, TU AuM.

Peters. S., T., Tarnopol'skii, Yu., M., Beil, A., I. (1998). Handbook of composites*.* In *Filament winding*, (pp.456-475). US: Springer.

Srebrenkoska, S., Kochoski, F., Srebrenkoska, V., Risteska, S., & Kotynia, R. (2023). Effect of process parameters on thermal and mechanical properties of filament wound polymer-based composite pipes. *Polymers*, *15*(13), 2829.

## Author Information

**Sara Srebrenkoska**
Faculty of Mechanical Engineering - Goce Delcev University, Stip, I Krste Misirkov 10-A, Stip 2000
Republic of North Macedonia
Contact e-mail: *sara.srebrenkoska@ugd.edu.mk*

**Vineta Srebrenkoska**
Faculty of Technology - Goce Delcev University, Stip, Krste Misirkov 10-A, Stip 2000
Republic of North Macedonia

**Marija Cekerovska**
Faculty of Mechanical Engineering - Goce Delcev University, Stip, Krste Misirkov 10-A, Stip 2000
Republic of North Macedonia

**Todor Cekerovski**
Faculty of Electrical Engineering, Goce Delcev University, Stip, Krste Misirkov 10-A, Stip 2000
Republic of Macedonia

**To cite this article:**

Srebrenkoska, S., Srebrenkoska, V., Cekerovska, M. & Cekerovski, T. (2024). Design and calculation of products from composite materials using software. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 28,* 252-258.