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Tensile Simulation and CAE Analysis of Fibre Reinforced Polymers (FRP)

Andrei-Ionut Perdum[1],

1 Environmental Engineering and Corrosion Laboratory, Polytechnic University of Bucharest, Romania.

#Corresponding author
MSc. BEng. Andrei-Ionut Perdum
Polytechnic University of Bucharest,
Environmental Engineering and Corrosion Laboratory,
Splaiul Independentei 313, Romania.
E-mail address: andrei.perdum@gmail.com

Abstract. This paper describe, how multiple CAE Analysis Simulations were evaluated to verify the influence of the filler in polymer matrix, by checking the differences in weight, density and maximum limit on tensile analysis(MPa) for each polymer composite (PA-MWCNT & PA-CF). Fibre reinforced polymer (FRP) composites were incorporated at different loadings of 10 wt. %., 20 wt. %., and 30 wt. %. Statistical Analysis results, reveals that high tensile limit has been achieved, when the addition of 30 wt. % of CF filler in the PA66 polymer matrix has been added. This paper explore the potential for a novel type of composite material incorporating carbon fibre (CF) and multi walled carbon nanotube (MWCNT). Recent work has shown that notable improvements in mechanical performance are achievable in reinforced polymers [1].

Keywords. MWCNT, Carbon fibre, CAE, Tensile simulation, Fibre reinforced polymer, Mechanical performance.

1. Introduction

In nowadays weight reduction has been a challenge for every car manufacturer in the world. Reducing the vehicle weight is now one of the most important things that a car producer should respect when they planning to build a new concept car. The big challenge for the automobile industry is to meet the requirement of global legislation on CO_2 outputs per kilometre travelled.

In the European Union for example, from 2021 a fleet average limit will apply of 95g CO_2/ km per manufacturer and a penalty of €95 for every g of CO_2/ km in excess of this will apply for each registered vehicle. This emission level corresponds to a fuel consumption of around 4.1 l/100 km of petrol or 3.6 l/100 km of diesel [2].

Developing a new material or refreshing the information by adding contribution with new improvements in this side of engineering represents a significantly "brief" for the industry. Having the latest information in your hand will help all the manufactures to take the right decision when they want to develop a new product.

Fibre reinforced polymer (FRP) composites can play a role in vehicle light-weighting due to their excellent specific strength and stiffness. Costs for FRP may be in the range of 20 times that of the equivalent steel structure [3]. This paper explore the potential for a novel type of composite material incorporating carbon fibre (CF) and multi walled carbon nanotube (MWCNT). Recent work has shown that notable improvements in mechanical performance are achievable in reinforced polymers [1].
The aim of this work is to explore the CAE analysis for ISO 527/ 2, to show the differences in density, mass and tensile simulation, for each type of polymer composite, which were selected carefully for the study.

2. Materials and Method

2.1. Materials

Polyamide PA66 was used as a polymer matrix in this study. Input data sheet for the products used in simulation were according to the manufacturers. Plasticyl PA1501 (from Nanocyl) represent a family of carbon nanotubes, which is especially used for extrusion processes and injection molding. Neat Polyamide PA66, density is 1.14 g/cm^3 while the Young Modulus is 2910 (MPa) [4]. First considered filler was Multi Walled Carbon Nanotube (MWCNT) manufactured by Nanocyl (Belgium), and second filler was represented by Carbon Fibre (CF) supplied by GoodFellow, with a density of 1.28 g/cm^3 [5].

2.2. Methods

Fibre reinforced polymer (FRP) composites were considered at different loadings of 10wt.%. (*PA66-10MWCNT & PA66-10CF*), 20wt.%. (*PA66-20MWCNT & PA66-20CF*), and 30wt.%. (*PA66-30MWCNT & PA66-30CF*).

In order to obtain data input for Computer Aided Engineering (CAE) Analysis, each filler loading was calculated in Microsoft Excel by using Density formula for Composite Materials according to Equation (1) and results can be found in (Table 1):

$$(1) \qquad (wt.\ \%)_a \times (\varrho)_a + (wt.\ \%)_b \times (\varrho)_b + (wt.\ \%)_c \times (\varrho)_c = (\varrho)_T;$$

Where ***(wt. %)*** represent the weight percentage for the material used, $_{a,\ b,\ c}$ represents type of material (PA66, MWCNT, CF) and ***(ϱ)*** is density [6].

Calculated data, was used as input in all simulation and weight part measurement tests, which conducted the entire simulation process.

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Table 1: Calculated density for each filler loading in polymer composite.

Materials	Calculated density (ϱ) g/ cm^3
PA66	1.14 **g/ cm^3**
PA66-10MWCNT	1.29 **g/ cm^3**
PA66-20MWCNT	1.44 **g/ cm^3**
PA66-30MWCNT	1.58 **g/ cm^3**
PA66-10CF	1.19 **g/ cm^3**
PA66-20CF	1.24 **g/ cm^3**
PA66-30CF	1.28 **g/ cm^3**

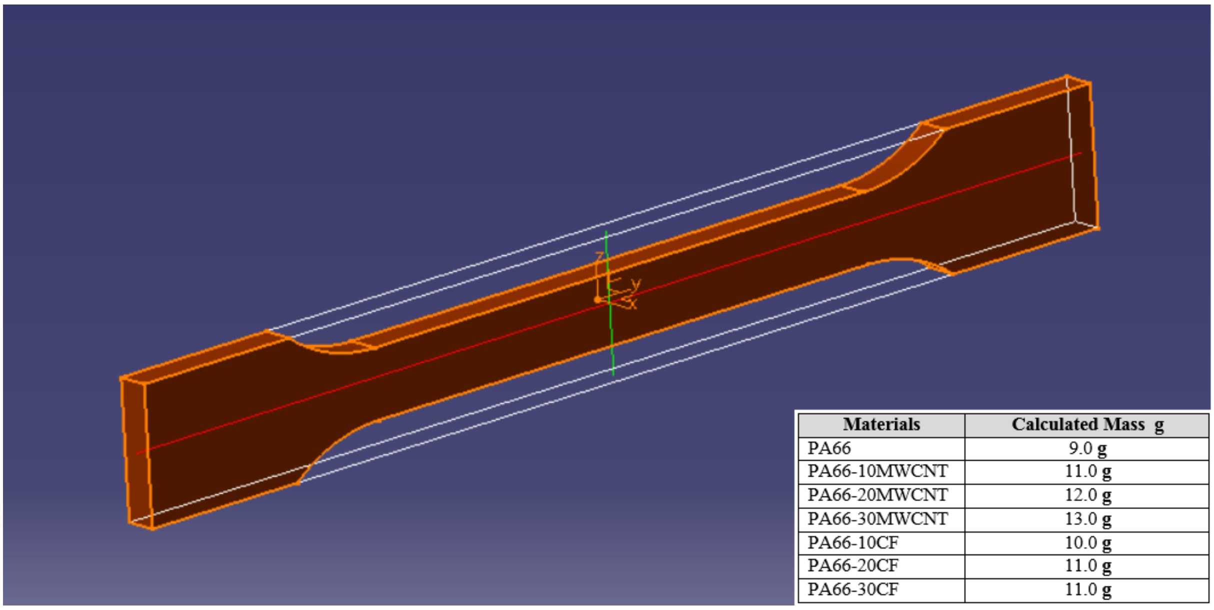
2.3. Type of test specimen

For this study has been used *ISO 527/2* - specimen type 1A, which is used for directly-molded multipurpose test specimens. This represent the test conditions to determine the tensile properties of molding and extrusion plastics [7]. Because is a simulation CAE only, there was not required any post preparation or spare parts for machine calibration.

3. Simulation program

Computer Aided Engineering (CAE) is widely accepted method to predict the performance of a studied material under specific circumstances and perform a sensitivity analysis on the variables. The properties of the materials are integrated into the 3D model, to simulate loading in tensile of the sample. Simulation is performed using CATIA -V5, software developed by Dassault Systemes [8].

Mass (g) has been calculated for each test specimen with *measure inertia* tool from CATIA-V5. As can be seen below, in Figure 1, adding 30% filler in the mixture, has been impacted significantly the weight of the final part, by adding 4 grams on top, taking as reference the initial part.



Materials	Calculated Mass g
PA66	9.0 g
PA66-10MWCNT	11.0 g
PA66-20MWCNT	12.0 g
PA66-30MWCNT	13.0 g
PA66-10CF	10.0 g
PA66-20CF	11.0 g
PA66-30CF	11.0 g

Figure.1: Calculated Mass (g) in Catia-V5, measured with inertia tool, for each composite material.

Based on *ISO 527/2,* CAE Tensile Analysis tests were conducted for each compounded material. In real life this test is performed on a table top universal testing machine. A 5kN or 10kN system is most usual, but as composites increase in strength, higher charge is required, such as 30kN or 50kN. For the sake of this study, has been used a Tensile Force of 35kN [9].

In real life it is mandatory also to measure each test specimen before and after tensile test, in order to get accurate data results [7]. Because this study has been entirely conducted with Simulation Software, measurement phase for each specimen was skipped, as these details were carefully checked when 3D model was created.

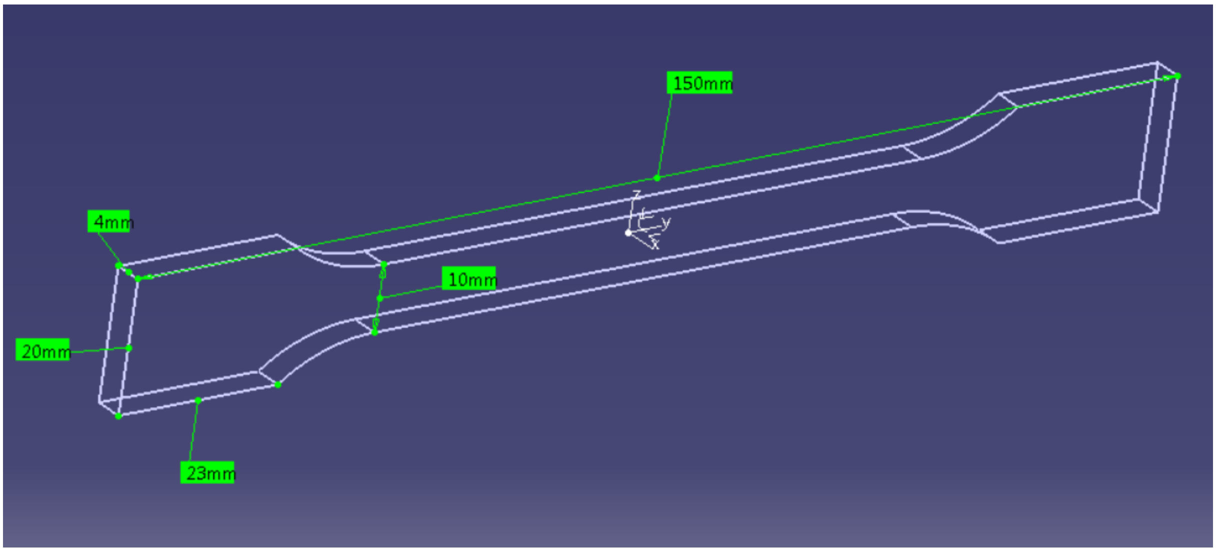


Figure 2*:* CATIA -V5 measurement for ISO 527/2 – type 1A.

Tensile Simulation tests were conducted for each type of specimen with CATIA V5, using Analysis & Simulation → General Structural Analysis Tool.

Based on below test results (Table 2, Table 3 and Table 4) can be seen how the stress has been impacted, when fibre reinforced polymers was used at different ratio loading. Also the average length specimen distortion has been observed as well before and after test (Figure 3).

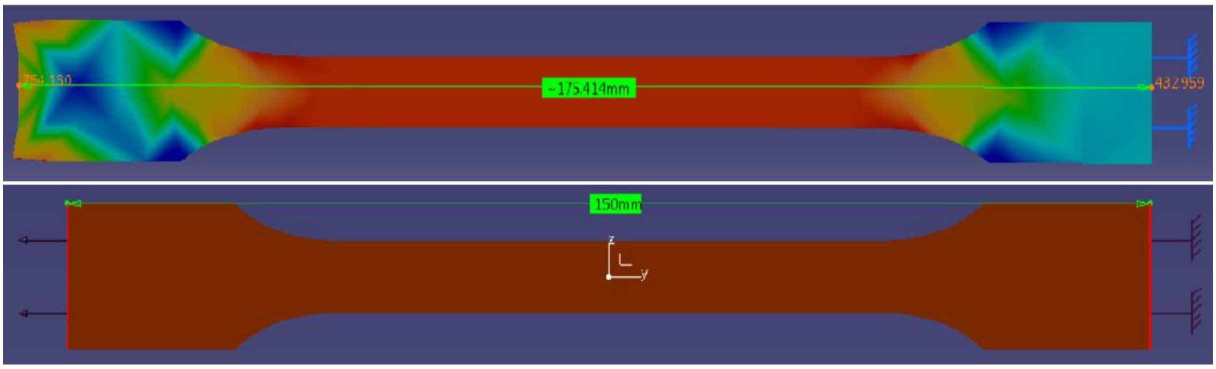
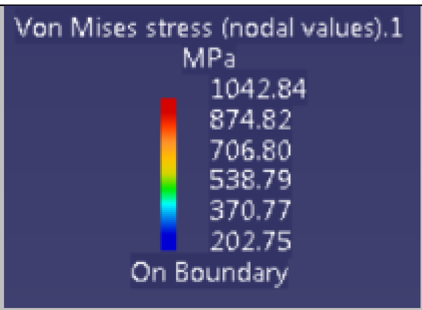
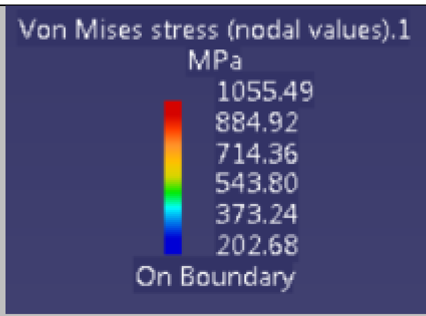


Figure 3: Test specimen view before (150 cm length) and after (175.4 cm length) tensile simulation.

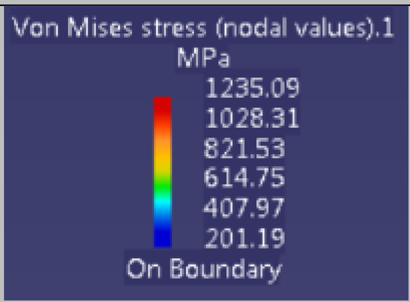
Table 2: Test results of Von Mises Stresses - volume distortion energy density and state of stress.



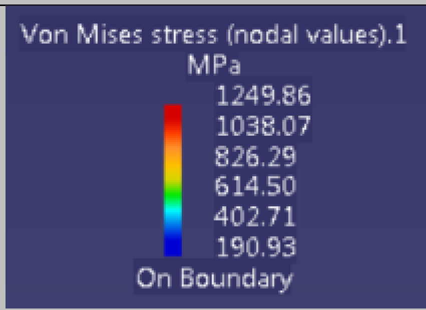
PA66-10MWCNT



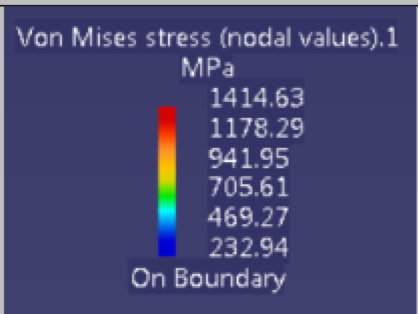
PA66-10CF



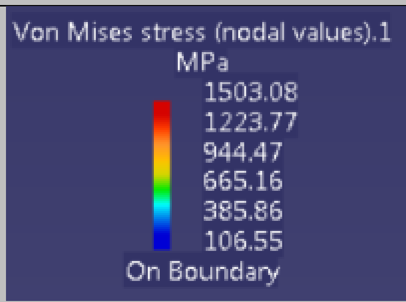
PA66-20MWCNT



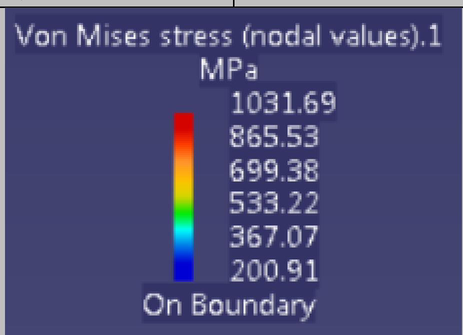
PA66-20CF



PA66-30MWCNT



PA66-30CF



PA66

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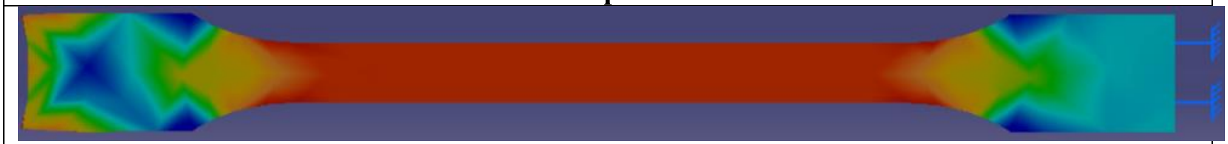
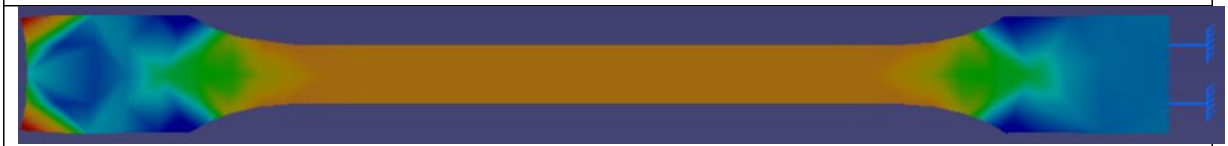
Table 3: Test specimen view of fibre reinforced polymers at different ratio loading, after tensile analysis.


Initial specimen

PA66

PA66-10MWCNT

PA66-20MWCNT

PA66-30MWCNT

PA66-10CF

PA66-20CF

PA66-30CF

Table 4: Test results of Von Mises Stresses - volume distortion energy density and state of stress, based on minimum and maximum stress limit.

Materials	Von Mises Stresses (MPa)	
	Minimum Stress limit	Maximum Stress limit
PA66	200.91	1031.69
PA66-10MWCNT	202.75	1042.84
PA66-20MWCNT	201.19	1235.09
PA66-30MWCNT	232.94	1414.63
PA66-10CF	202.68	1055.49
PA66-20CF	190.93	1249.86
PA66-30CF	106.55	1503.08

4. Conclusion

In this study, fibre reinforced polymers composites have been considered with the aim of showing the differences in density, mass and tensile simulation limit, for each type of polymer composite. Density increase has been notable observed when filler was added in the polymer matrix. Within CAE Tensile Analysis, it was observed, that adding 30.0 wt. % CF (carbon fibre) filler in the polymer matrix, the Maximum Stress limit has been increased significantly and improved material properties. This study is represented entirely by CAE simulation and no psychical parts were used; all input data were calculated based on equations in order to have a reference for the further study. All calculations and software simulations might not represent 100% accurate reference data. A physical study will be conducted in the future, in order to confirm and complete the entire case of this paper.

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