INVESTIGATION OF COMPRESSIVE STRENGTH OF CARBON-FIBER COMPOSITE IN THE WING SPAR OF THE MOTOR GLIDER AOS-71

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Abstract. The motor glider AOS-71 is the first motor-glider designed and manufactured by the Institute of Aeronautics and Applied Mechanics, which is complete made of carbon-fiber composite. In order to investigate the compression strength of the wing spar, it is necessary to create specimens of this carbon-fiber composite to check its material properties. Until now the dimensions of the cross-section area of a specimen were 4x4 [mm]. The American standards dictate to investigate the compression strength on specimens, which have a cross-section area of 10x2 [mm]. The goal was to investigate which standard of the specimens gives higher results of compression strength of tested composites. The paper contains the results of experimental investigations together with the statistical analysis.

Keywords. Carbon composites , roving reinforcement, testing standards.

1 Introduction

1.1 AOS-71

The project AOS-71 is the continuation of the ULS program and is a joint project of Warsaw and Rzeszow University of Technology. It´s a two-seater motor glider with a structure made of carbon-fiber composite. The identification AOS is related to the academic center of gliding in Bezmiechowa, Poland and the number 71 is because it´s the 7th project of the Warsaw University of Technology and the 1st one of the Rzeszow University of Technology. This glider is made of the newest achievements in the aviation industry and shell give the possibility to do research in the air as a flying lab.
The structure of the wings are based on the structure of the gliders PW-5 and PW-6. It will be the 1st aircraft made completely of carbon-fiber composite in the history of both universities [1].


Fig.1 Computer simulated picture of AOS-71

With a wingspan of 16.4 [m] the forces acting on the wings are very high and so the correct design of this element is very important for this project. Beside the geometry of the wing spar, the correct choice for the material is a fundamental issue. The investigation of the material properties of the carbon-fiber composite takes an important role in the research of the project of the motor glider AOS-71. The next chapters deal with the investigation of compressive strength of the carbon-fiber composite used for the wing spar in the motor glider AOS-71.

Target of the project
The project has 2 goals: First goal is to investigate the compression strength of carbon-fiber composite (CFC), used for the wing spar of the motor glider AOS-71. The second goal is to check, if CFC specimen with dimensions 10x2 [mm], manufactured due to the American standards, show a higher compression strength than specimens with dimensions 4x4 [mm], which were used until now.

2 Part One: Preparations for the test

2.1 Creating CFC specimens

2.1.1 Investigated Material

The carbon-fiber composite is made of two materials. One is carbon-fiber and the other one is epoxy resin. The carbon-fiber roving, which is used for the wing spar, is T700G from the company Torayca. The material properties are shown in table 1 [2].

Table 1 Material properties for carbon-fiber T700G

	Values	Units
Tensile strength	4900	[MPa]
Young modulus	240	[GPa]
Fracture elongation	2	[%]
TEX	800	[g/km]
Density	1.8	[g/cm³]

The epoxy resin is L285 with the hardener 286 from the company M.G. Scheufler GmbH. The properties of the epoxy resin are shown in table 2 [3].

Table 2 Material properties for epoxy resin L285/286

	L285	286	Units
Density [20°C]	1.18-1.23	0.93-0.96	[g/cm³]
Viscosity[25°C]	600	400	[mPa·s]
Mass ratio	100	40	[g]
Volume ratio	100	50	[ml]
Processing time	-	90	[min.]
Density after heating process	1.18-1.2	1.18-1.2	[g/cm³]

2.1.2 Impregnating carbon-fiber roving with epoxy resin

In order to produce carbon-fiber composite the Institute of Aeronautics and Applied Mechanics from the Warsaw University of Technology designed a machine to impregnate carbon-fiber roving with epoxy resin with the identification symbol "PW 2009 CF". The scheme of this machine is shown in figure 2 and 3.

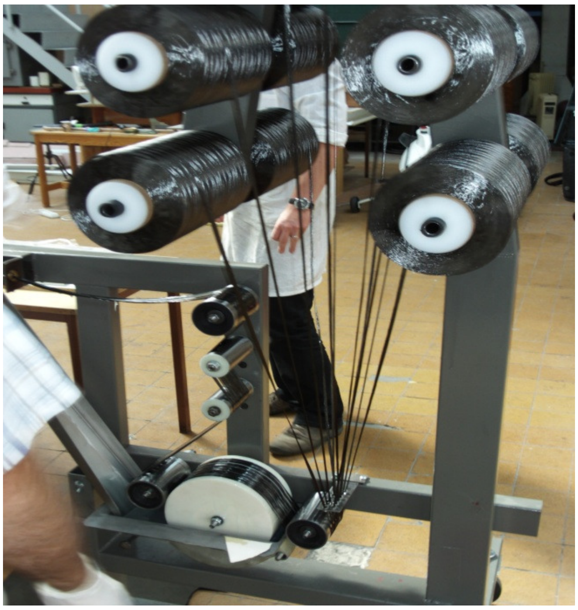


Fig.2 Photo of "PW 2009 CF"

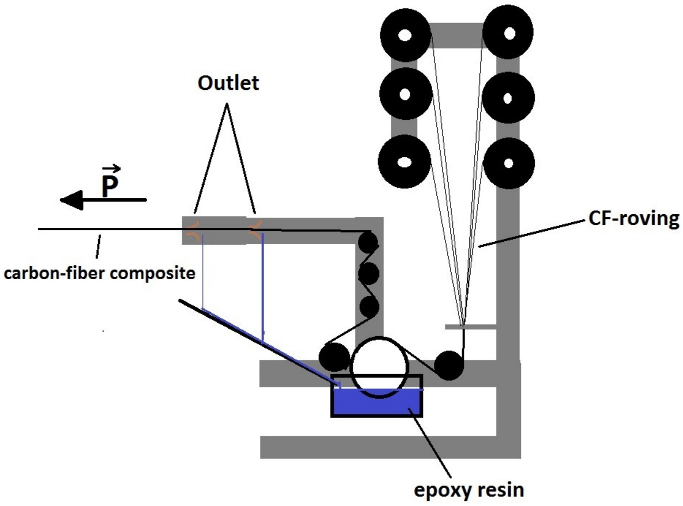
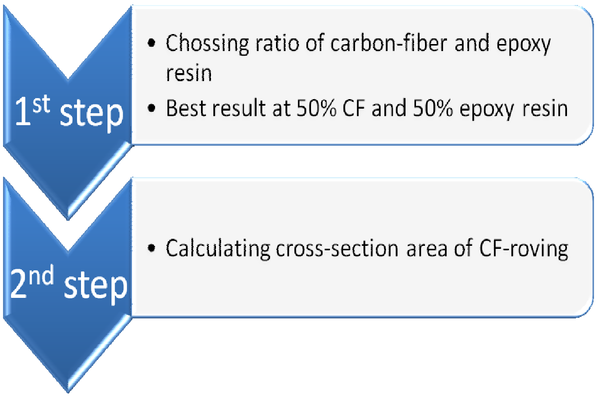


Fig.3 Roving impregnation machine

An engine is pulling the "fresh" CFC roving with a constant velocity to keep the mass ratio between carbon-fiber and epoxy resin always constant. To achieve the mass ratio between CF and epoxy resin we need to calculate the right diameter for the outlet of the machine.

2.1.3 Calculating diameter of the outlet of the CFC

To obtain the necessary ratio between carbon-fiber and epoxy resin, it is important to calculate the correct diameter of the outlet.

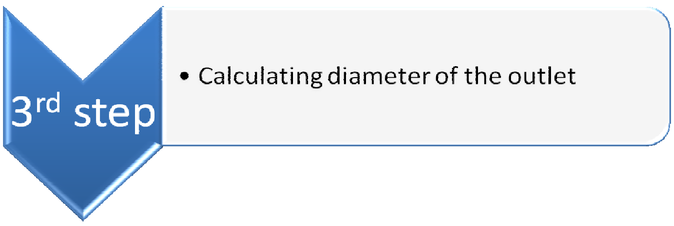


$$\boldsymbol{Ar = \frac{TEX}{1000 \cdot \rho}} \textbf{ where,} \qquad (1)$$

TEX – mass of the CF roving of a length of 1000m in [g]

ρ - density in [g/cm³]

Ar - cross-section area of CF-roving



$$\boldsymbol{D = \sqrt{\frac{4 \cdot Ar}{\pi \cdot 0.5}}} \textbf{ where,} \qquad (2)$$

D – diameter of the outlet

The machine "PW 2009 CF" has 12 strings of CF-roving each of them has a cross-section of 0.44 mm². So all 12 strings together have a cross-section of 5.28 mm². By a ratio of 50% between CF and epoxy resin, we obtain:

$$A_{CFC} = 10{,}56\ [mm^2]$$,where

A_{CFC} – cross-section of carbon-fiber composite

So the necessary diameter for the outlet is:

$D = 3.7\ [mm]$

2.1.4 Forming specimens

Due to the American standards and the European EN-ISO 14126 a specimen of carbon-fiber composite has to have the dimensions 10x2 [mm] to investigate compression strength of the material in the aviation industry. Until now it was common to use specimens with the dimensions 4x4 [mm] for the project AOS-71. To be able to compare this two ways of research it´s necessary to produce both kinds of specimens. For the 4x4 specimens the forms were used from the tests before and for the 10x2 specimens a new form has been created shown in figure 4.

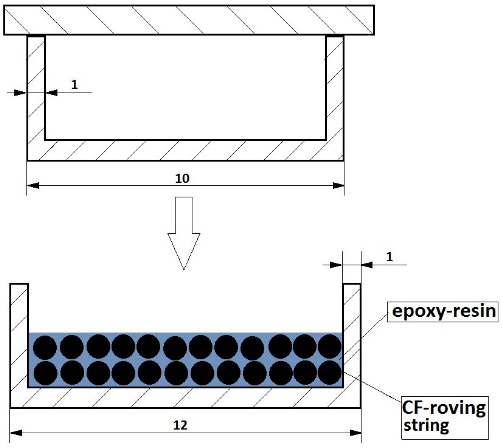


Fig. 4 Shape of 10x2 form

At the beginning it´s important clean the form and to put a separation wax on the surface to make it easier to separate the composite from the form.

Fig. 5 Form filling

In each form are coming 2 strings of carbon-fiber composite to obtain specimens with the dimensions 10x2 [mm].

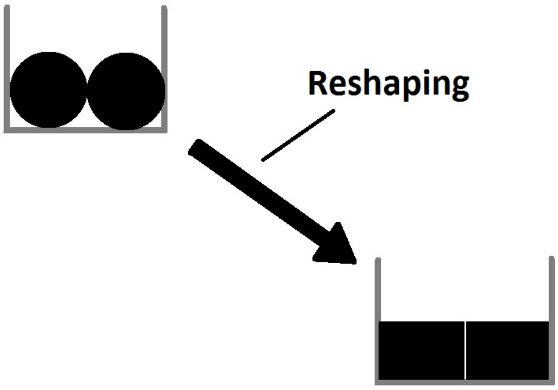


Fig.6 Idea of forming process

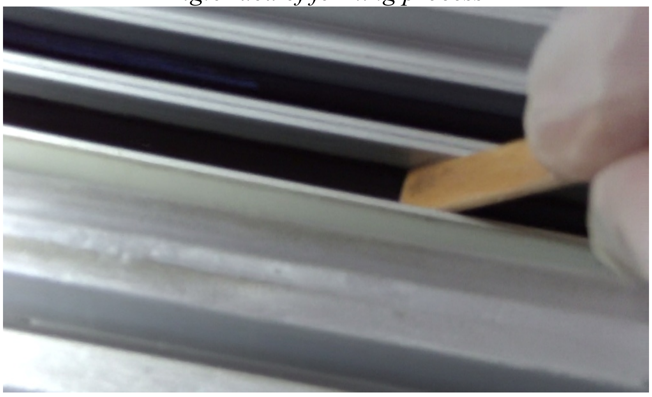


Fig.7 Operation of reshaping

The reshaping process is very important for 2 reasons: It gives the necessary geometry to the specimens and helps to share out the epoxy resin everywhere in an equivalent amount.

2.1.5 Hardening process

After reshaping the carbon-fiber composite the form the hardening process starts. The hardening process is divided in 2 parts: the pressure part and heating part [3].

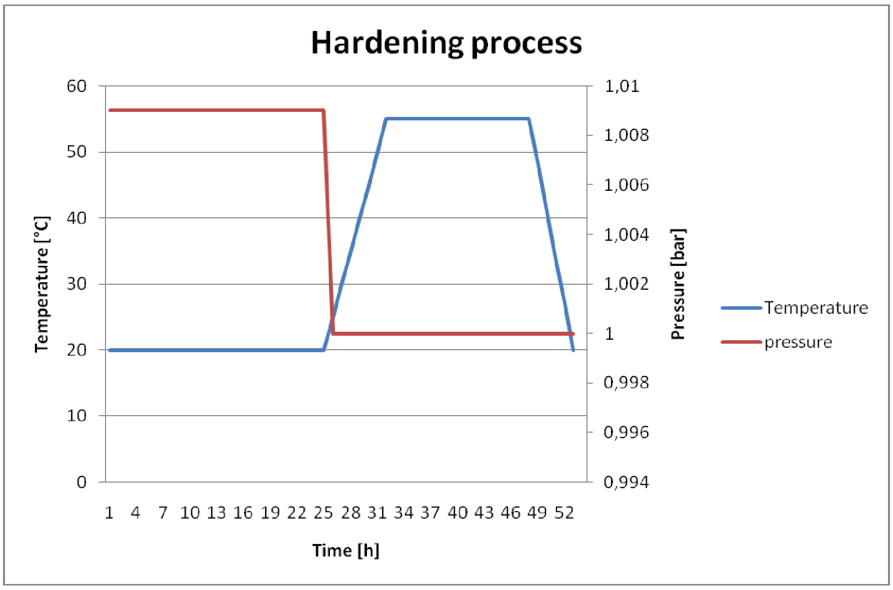


Fig. 8 Hardening process

2.1.5.1 Pressure part

In this part the form will be closed for at least 24 hours and pressed with weights together. In this case it´s a pressure of 1.009 [bar]. It´s important to obtain a constant weight along the whole form to make sure that the form doesn´t change its shape.

2.1.5.2 Heating part

To obtain the necessary strength for the composite, the specimens have to go through a heating cycle. The most important part of the heating part is to keep the correct temperature gradient, which can´t be bigger than 5°C per hour.
With the end of the heating process the specimens of carbon-fiber composite are completed.

2.2 Positioning device

To investigate the compression strength of the carbon-fiber composite it´s important that the compressive force, acting on the specimen, is perpendicular to the cross-section area of the composite like shown in fig. 9

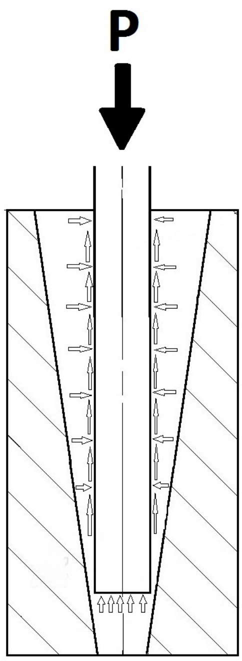


Fig. 9 Compressive force

To obtain the maximum compression strength of the material, the specimen has to be positioned vertical and exactly in the middle of the steel conical support.

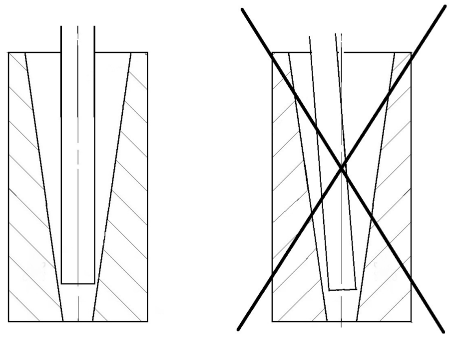


Fig. 10 Positioning of specimen

To achieve the necessary conditions, a positioning device has been constructed, which allows to place the specimens in the right position of the steel conical supports. Another function of this device is to fill up 8 steel conical supports in the same time.

2.2.1 Epoxy resin for filling up

The epoxy resin, which fills up the steel conical supports with the composite specimens in the middle is EP52 with hardener Z1. The material properties are shown in table 3 [4].

Table 3 Material properties of epoxy resin EP52/Z1

	EP52	Z1	Units
Density	1.12-1.13	-	[g/cm^3]
Viscosity	400-800	-	[mPa·s]
Mass ratio	100	13	[g]
Processing time	-	30	[min]

2.2.2 Filling up the lower steel conical supports

The steel conical supports are filled up by a dosing syringe with the epoxy resin after positioning the composite specimens in the middle of the supports like shown in figure 11.

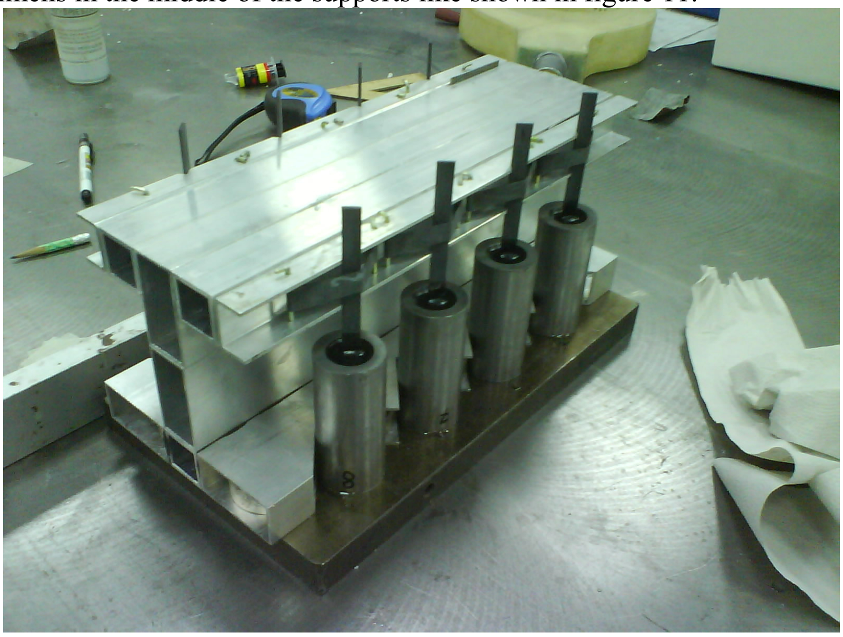


Fig.11 Photo of the positioning device

2.2.3 Upper steel conical supports

After a hardening time of 24 hours by 20°C the upper steel conical supports are filled up with the epoxy resin EP52 by a dosing syringe. In order to keep the distance between the 2 cups always 12mm, screw nuts were used.

2.2.4 Heating process

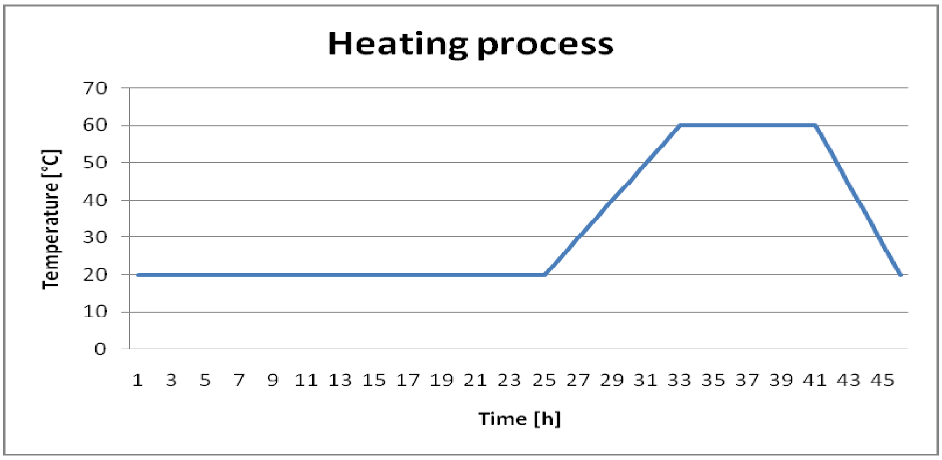


Fig.12 Heating process of epoxy resin EP52/Z1 [4]

2.2.5 Specimen

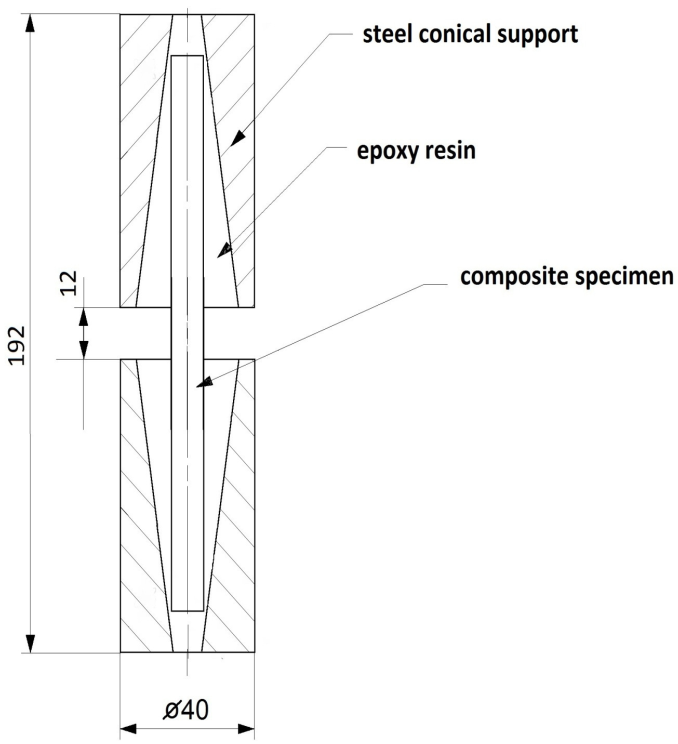


Fig.13 Technical drawing of complete specimen

It´s important that the compressive force is acting co-axial during the whole time of compression. To make sure that this condition will be fulfilled, a co-axial tube is used for the test to achieve the right conditions like shown in fig. 14 and 15.

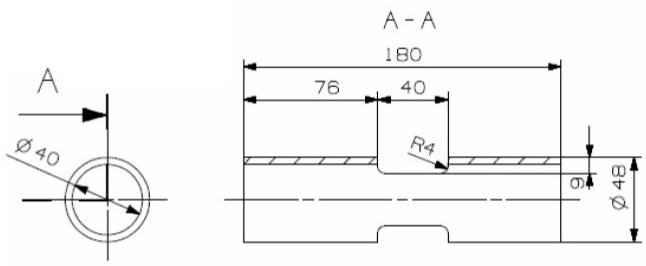


Fig. 14 Technical drawing of co-axial tube

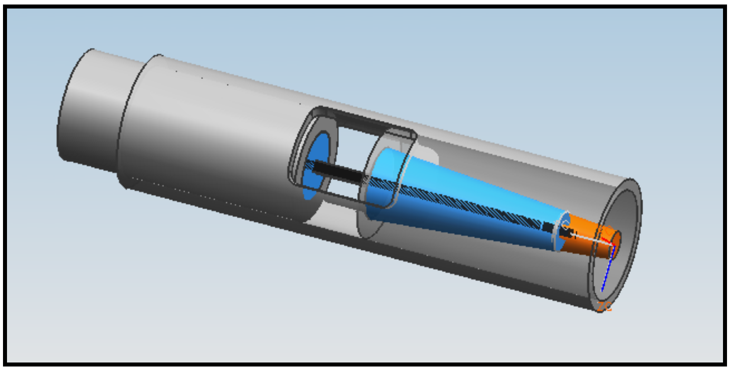


Fig.15 Assembly of specimen and co-axial tube

2.3 Types of specimens

For the investigation, 4 types of carbon-fiber composites are used:

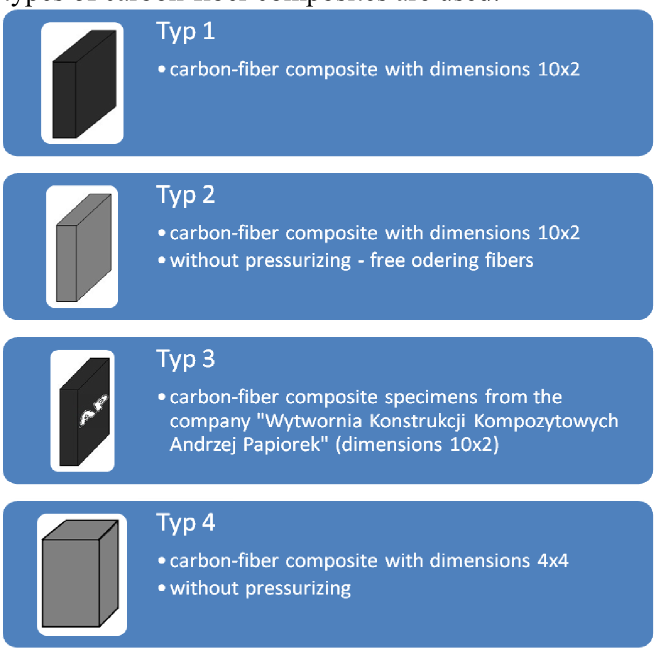
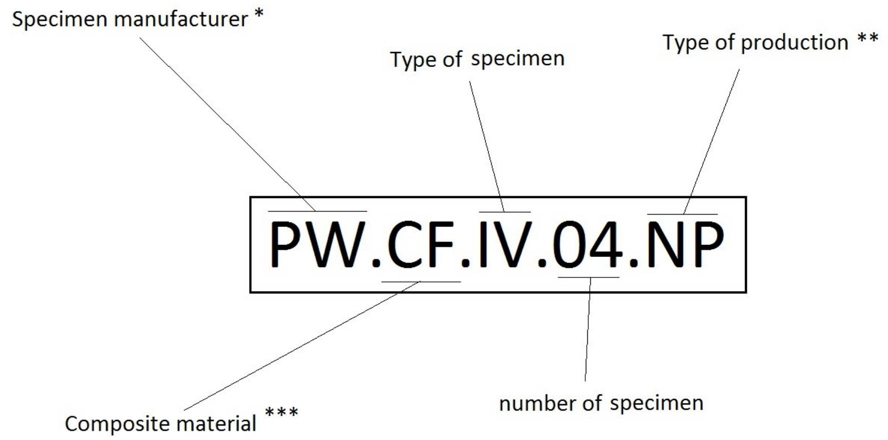


Fig. 16 Types and symbols of specimens

2.4 Specimen number

Each specimen has his personal identification code. The system of this coding is shown in the following figure:



* PW – composite specimen manufactured by the institute of aeronautics and applied mechanics

AP – composite specimen manufactured by the company “Wytwornia Konstrukcji Kompozytowych Andrzej Papiorek”

** NP – composite specimen manufactured without pressuring

WP – composite specimen manufactured by pressuring

T – Teflon tape around the edges of the investigated area

*** CF – composite specimen manufactured with carbon-fiber roving

2.5 Cross-section measurement

It´s important to measure the cross-section area of each specimen to be able to calculate the strength of the carbon-fiber composite.

3 Part Two: compression strength test

3.1 Machine for compression strength test

The machine ZD-20 is used for material strength tests. The technical properties are shown in table 4 [5].

Table 4: ZD-20 technical properties

Company	**VEB Werkstoffprüfmaschinen Leipzig**
Date of manufacture	1967
Serial number	281729
Max. work pressure [kp/cm^2]	350

3.2 The test

Due to the German standards the material used for a wing spar has to reach a strength of at least 690 [MPa] by an environment temperature of 54°C to be certificate for the use in aviation industry (like shown in fig. 17) [6].

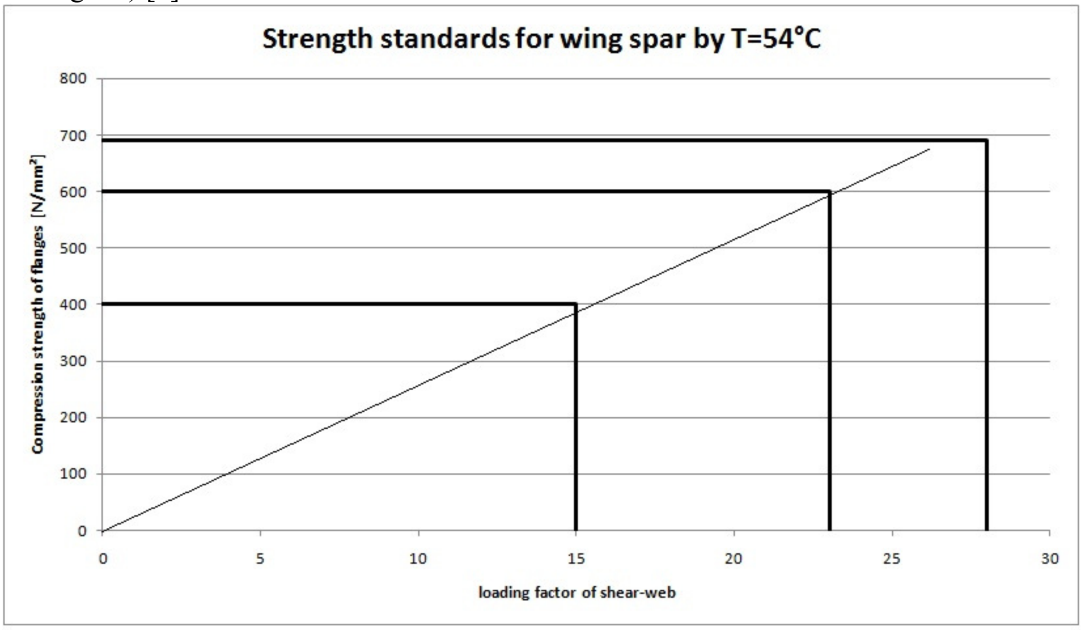


Fig. 17 Strength standards for wing spar

To fulfill the requirements the compression test has to be completed in 2 ways.
First there has to be the so called "cold" test. The composite specimens are compressed by an environment temperature of 20°C.
And second it´s necessary to do the so called "hot" test, where specimens are compressed by an environment temperature of 54°C to check if the material achieves the necessary properties.
To achieve this environment for the test, a device has been created to heat up the area around the specimen on a temperature of 54°C and to keep this temperature constant.(shown in fig. 18)

3.3 Composite specimens after compression

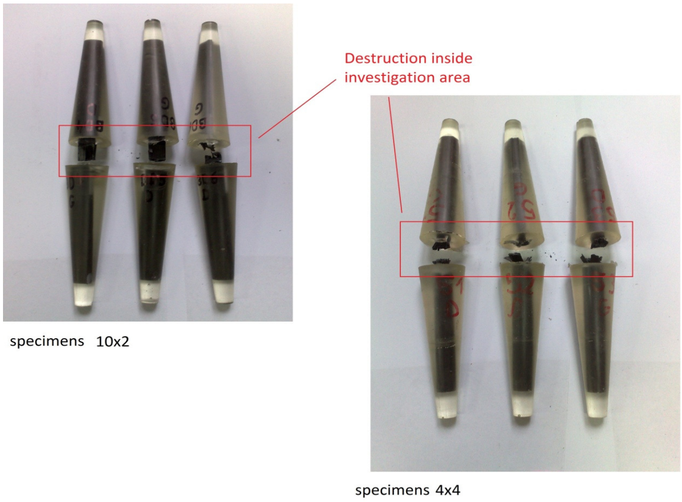


Fig. 18 Photo of specimens after compression

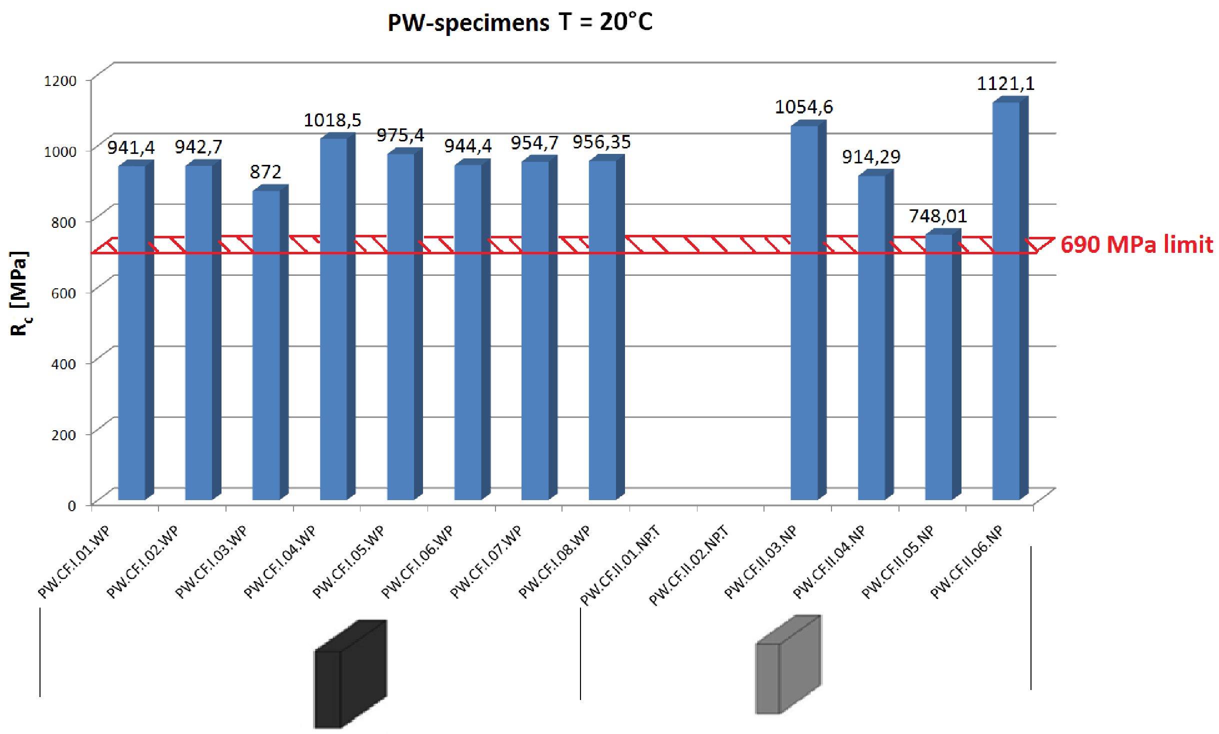
4 Part Three: Results and analysis

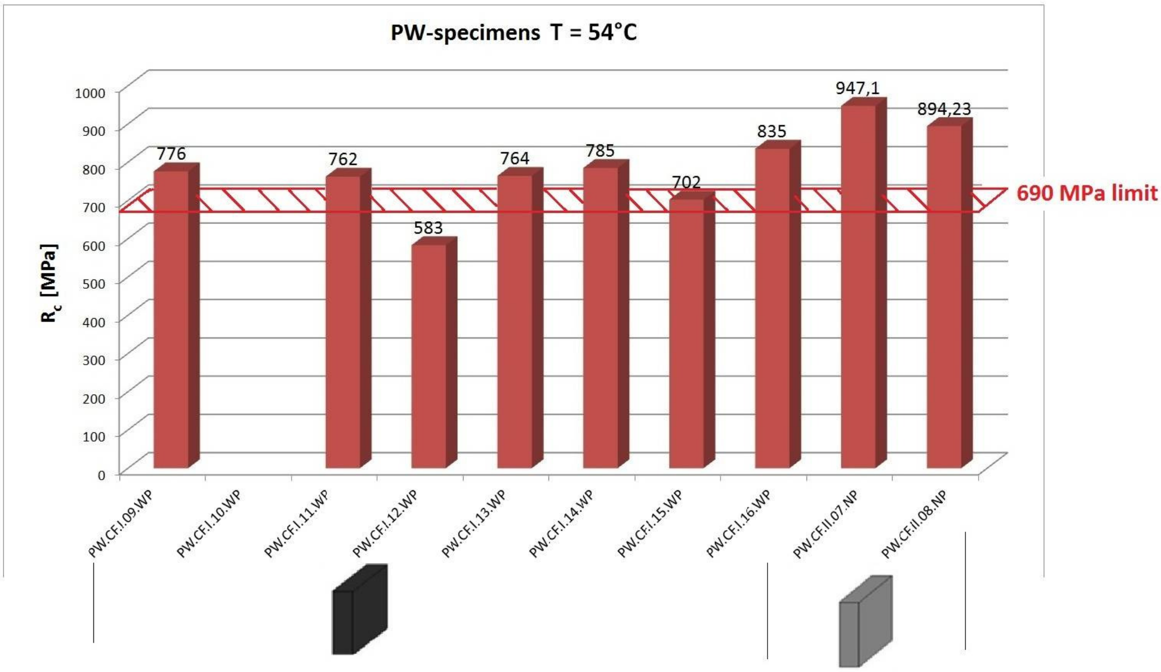
Calculating compression strength

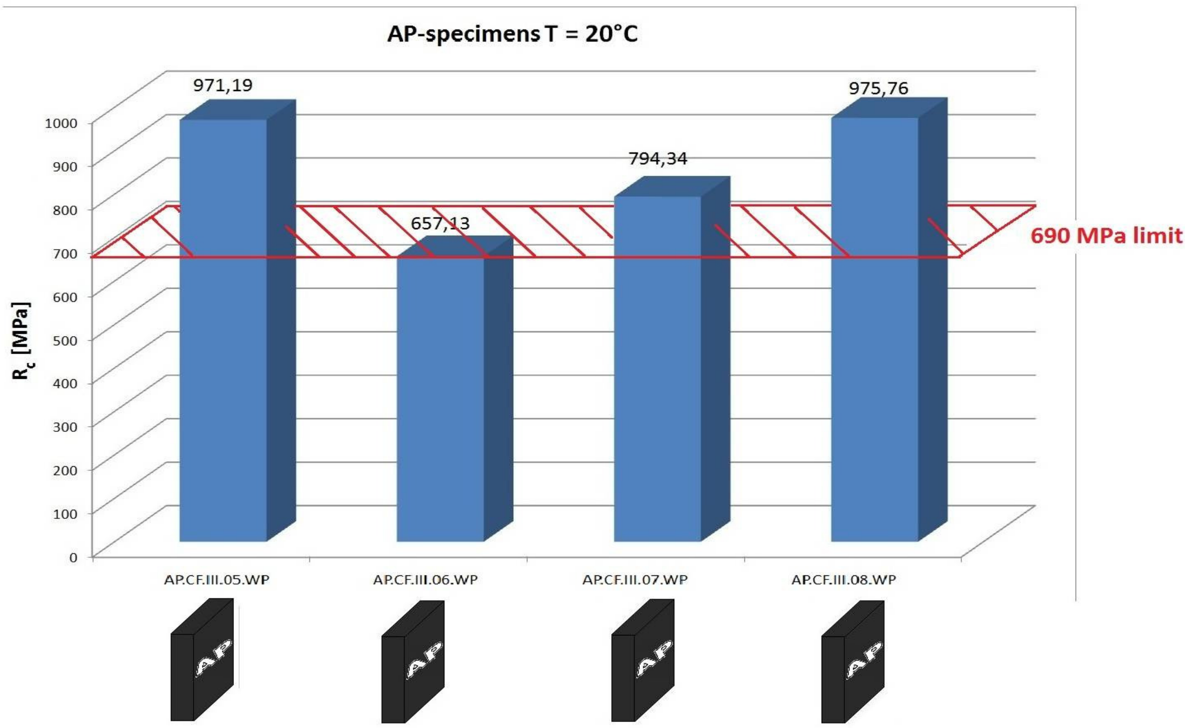
The results from the compression strength test are given as compression force P in [kG]. The compression strength can be calculated by following formula:

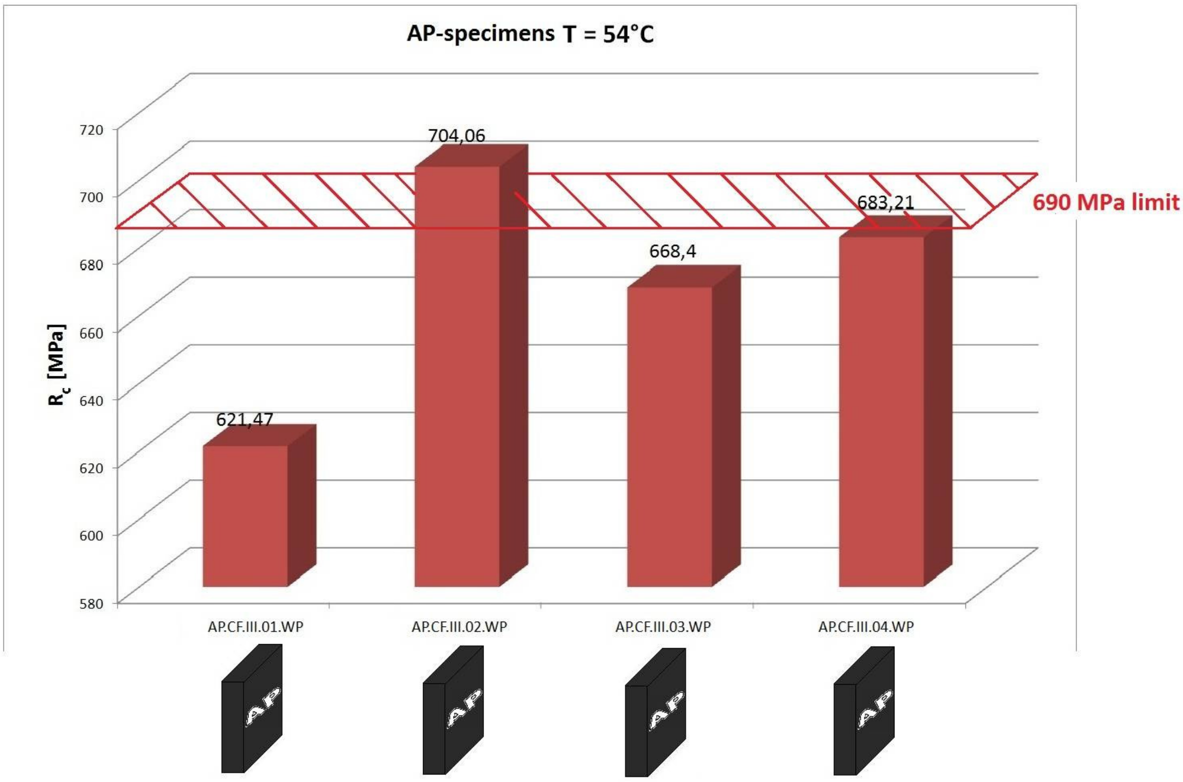
$$R_c = \frac{P \cdot g}{A} \quad (3)$$

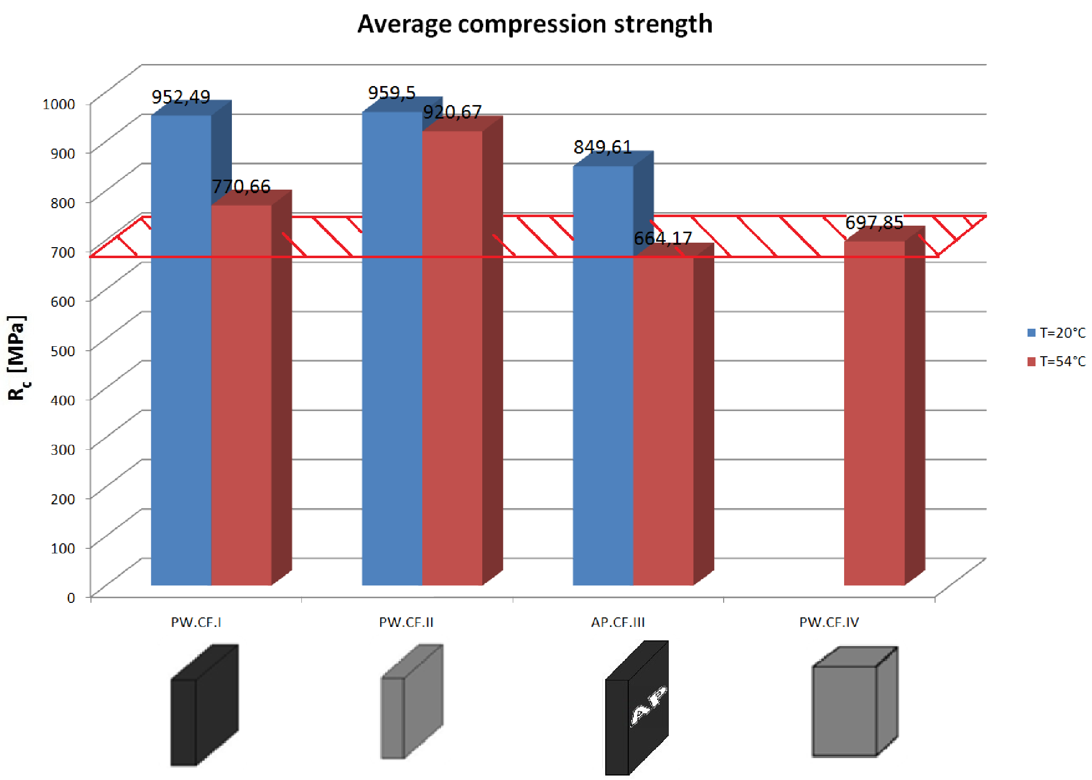
where,
P – compression force in [kG]
g = 9.81 m/s² – gravity constant
A – cross-section area of specimen in [mm²]
R_c – compression strength in [MPa]

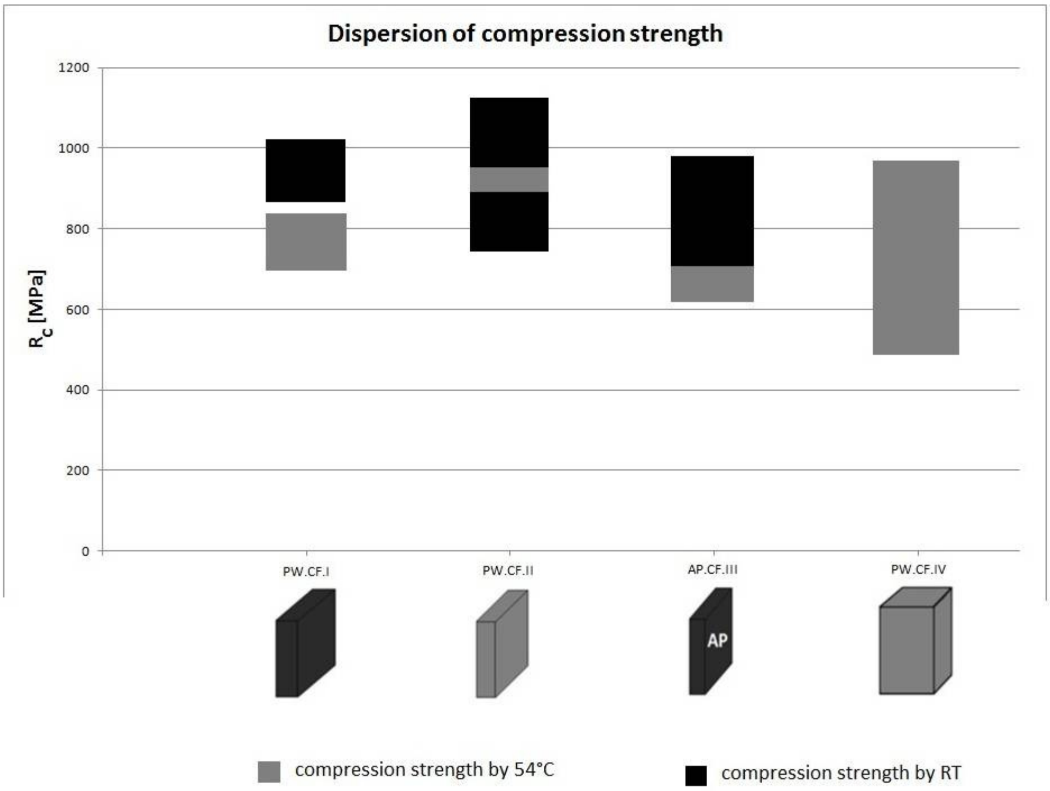



PW-specimens T = 54°C
R_c [MPa]
1000
900
800
700
600
500
400
300
200
100
0
776
762
583
764
785
702
835
947,1
894,23
690 MPa limit
PW.CF.I.09.WP
PW.CF.I.10.WP
PW.CF.I.11.WP
PW.CF.I.12.WP
PW.CF.I.13.WP
PW.CF.I.14.WP
PW.CF.I.15.WP
PW.CF.I.16.WP
PW.CF.II.07.NP
PW.CF.II.08.NP


AP-specimens T = 20°C
R_c [MPa]
1000
900
800
700
600
500
400
300
200
100
0
971,19
657,13
794,34
975,76
690 MPa limit
AP.CF.III.05.WP
AP.CF.III.06.WP
AP.CF.III.07.WP
AP.CF.III.08.WP
AP
AP
AP
AP


AP-specimens T = 54°C
720
700
680
660
640
620
600
580
Rc [MPa]
621,47
704,06
668,4
683,21
690 MPa limit
AP.CF.III.01.WP
AP.CF.III.02.WP
AP.CF.III.03.WP
AP.CF.III.04.WP


Average compression strength
1000
900
800
700
600
500
400
300
200
100
0
Rc [MPa]
952,49
770,66
959,5
920,67
849,61
664,17
697,85
T=20°C
T=54°C
PW.CF.I
PW.CF.II
AP.CF.III
PW.CF.IV



5 Conclusion

Most of the specimens, which were manufactured in the Institute of Aeronautics and Applied Mechanics at Warsaw University of Technology, fulfill the requested properties of at least 690 [MPa], which satisfy the first target of the project.
The specimens with the dimensions 10x2 [mm] don´t show a significant higher compressive strength than the 4x4 [mm] ones. But the results of the 10x2 specimens are very close to each other and aren´t so scattered like the 4x4 specimens during the "hot" tests. This means that the 10x2 specimens have a higher probability to reach the maximum compressive strength than the other specimens. Because of this observation the 10x2 specimens are more proper for the investigation of compressive strength in carbon-fiber composites than the 4x4 specimens. An explanation of this observation could be that the fibers in the middle of the 4x4 specimens aren´t often working during compression what cause a drop of compressive strength during the test. The geometry of the 10x2 specimens distributes more carbon-fibers at the edges to utilize the full strength of the carbon-fibers.
Another observation is that the specimens, which were manufactured without pressuring, show a higher compressive strength than the ones with pressuring.
The carbon-fiber roving T700G fulfill the requirements for the wing spar of the motor glider AOS-71.

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Ph.D. Mirosław Rodzewicz

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