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SPECIFIC TESTS FOR COMPOSITE STEERING COLUMNS

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Abstract: *The work has a strong practical level, focusing on testing methods for composites based of carbon fiber and the results of tests for components of the steering column made by carbon fiber composites materials.*

Keywords: *composite, test*

1. INTRODUCTION

As we known, in contrast to conventional materials, properties of the composites can be controlled to a high extent by the choice of components, the percentage of fiber, fiber orientation and geometry. One of the attributes of composites is that the design engineer can choose the material properties while the optimal shape of the product, arises.

The mechanical properties depend on several variables of the composite:

• properties of the fiber
• nature of the fiber surface
• the material properties of the matrix
• properties of any other phases
• volume fraction of the second phase (and any other phase)
• spatial distribution and alignment of the two phases (including fabric material)
• the nature of the interfaces.

Processing methods - in cycles of temperature, pressure, vacuum and other factors - provide a great variability in the properties of the final product.

Ability to create a composite in its final form is effective for production, but complicates the tests. Often there is no clear relationship between the properties of test samples (specimens) and properties of the final product. Therefore, attempts should be made at different stages of manufacture to measure the properties of both constituent materials and in the final component or structure.

2. SPECIFIC TESTS FOR STEERING COLUMN

2.1 Test equipment. Typically, each component of the steering column must fulfill several functions. These multi-axial requests can be determined only by testing entire system as a whole.

According to a defined plane, are made various test measurements, listed (Table 1), in order to determine the properties of the steering column. It is perform strength tests / life and / or safety testing of vehicle collisions or other tests. After the tests of resistance / life are always performed measurements of the same kind as those before the test in order to ascertain any change in properties.

Table 1: Specific test for steering column

Preliminary measurements	**Strength tests**	**Subsequent measurements for strength testing**
Weight	2K Dynamic Test	Torque lock release lever
Force lock-release lever	Torsional wear test	Naturalfrequency horizontal and vertical
Natural frequency horizontal and vertical	Wear test of the locking mechanism	Stiffness horizontal and vertical
Stiffness horizontal and vertical		Strenght adjustment in lenght and height
Strenght adjustment in lenght and height		Maximum moment
Torsional stiffness		Full rotation
Maximum moment		Non-uniformity
Full rotation		Mass flow
Non-uniformity		
Vehicle collision tests	**Testing for incorrect use**	**Other tests**
Maintenance force	Torque from incorrect use	Universal joints extraction force
Compression tests	Incorrect use of driver lever	Breakout force joints yoke
Freefall test	Limit checking end	Cardan bushings depressing force
Bodyblock	The effort required to operate the lever	Shaker Test
Dynamic limiters end test		Climate testing
		Saline mist test

Test equipment and computer programs for data processing for testing, test conditions should enable vibration, oscillations, forces and maximum stresses, environmental, durability / reliability

The tests were made using following equipment:

- MTS Dual Rotary System (DRS)
    - Two torsional stations with single or dual rotary inputs

-160 Nm, 400º/sec capable rotary inputs

- MTS Rotary Vibration (RV)
    - 565 Nm ±45º, 50 Hz capable rotary input
    - 5 kN ±25 mm capable linear input
    - Combined linear and rotary inputs
- Tensile Machine MTS Insight 50
    - 50 kN capability
    - Column spacing of 405 mm
    - Vertical test space of 1,100 mm
- NVS (Noise,Vibration,Harshness) / BSR (Buzz,Squeak, Rattle) Testing
    - Electro-dynamic Shaker LDSv890
- Environmental Testing
    - Two environmental chambers with a soaking area of 1m x 0.9m x 0.9m
    - Soaking conditions ranging from -55º C to 155º C and 10% to 98% relative humidity
    - Soaking area can also include fixtures for testing purposes during the soak schedule – pneumatic controls available
- Instrumentation
    - Force and torque transducers
    - Digital and analog encoders
    - Pneumatic, hydraulic and electric actuators
- Data Acquisition and Data Analysis
    - MTS data acquisition system
    - Multiple computation models available to aid in system analysis

-Performance Curve Evaluation

-Torsional Rate, Lash, Stiffness and Damping Structural Lash and Bearing Hysteresis

For mechanical tests, are required some force application devices with grips and other items to transfer load applied to the test specimen (Fig. 1). Specific standard tests of composite materials are: the tensile stresses (ISO 527, ISO 14129, ASTM 3039), compressive stresses (ISO 14126, ASTM 3410), shear stress (ISO14130, ASTM D

3846), bending stress (ISO 14125, ASTM D 4476), delamination.

Besides static mechanical tests, the operation and dynamic tests are made: impact test (ASTM D 7137) and fatigue test (ISO13003, ASTM D 3479).

The damages nondestructive inspection methods are microscopic, ultrasonic, radiography, thermography.

Fig. 1: Specific equipment static and dynamic mechanical testing and data acquisition software

Besides these standard tests, they can make a series of tests and experiments to explore the behavior of various composite materials and extreme environments. Test results should help the design engineer to correctly calculate different modules and resistant due to the high anisotropy of composite materials based on carbon fibers and to render a representation of the characteristics of composite materials tested.

To perform tests on specimens of composite materials were made plates 300x300mm from which specimens were cut according to the standards. To achieve the plates and specimens using RTM process, we used a standard resin produced by Hunstman standard epoxy resin XB3585 and XB3458 hardener and fiber Toray T700 and Tenax HTS40.

2.2 Test results. Reasons for traditional materials (steel), to achieve structural components of the steering column, are replaced with composite materials reinforced with carbon fiber, advantages of carbon fiber have:

-carbon fibers are very light, their density is $\rho \approx 1{,}8$ kg / dm³

-Stiffness and E modulus is high in fiber direction

-fatigue-stiffness to high dynamic loads

-acid-resistance and high biocompatibility

-stressed anisotropic behavior.

Composites steering column components must be lightweight, have a simple and cheap technology, to meet the requirements of the specifications and bring more innovation in vehicle technology.

The main requirements of the steering column extracted from the specification of the VW Golf 6 are presented below:

- Weight saving
- Natural frequency
  - Vertical > 50 Hz
  - Horizontal > 50 Hz
- Stiffness
  - Vertical ≤ 1.6 mm
  - Horizontal ≤ 1 mm
- Force control in climatic conditions of -30 to + 80 ° C
- Locking way and blocking force of action lever, including acoustic and a haptic behavior
- Maximum permissible torsional moment
- Torsional stiffness

According to DIN EN ISO 527-1 requires 5 or > 5 specimens and test results that the static tests are relevant.

In the following are shown force-displacement curves for the five specimens tested and calculation parameters characterizing composite materials:

<u>Tensile parallel on fiber EN ISO 527</u>

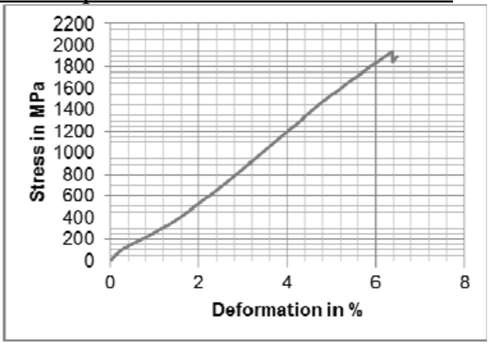

Fig. 2: Tensile stress-strain curve parallel to the fibers

Fig.3: Breaking standard specimen

After averaging measurements was made and the following parameters were calculated:

Table 2: Parameters calculated for fiber HTS40 and T700 for tensile parallel fiber

HTS40 CFK	E modul [Mpa]	Break Strenght [Mpa]	Elongation Break [%]	Pois ratio
Average	108.8	1.896	1,78	0,33
Standard deviation	7.390	54	0,11	0,05
Coefficient variation	6,8%	2,8%	6,4%	14%

T 700 CFK	E-modulus [Mpa]	Breaking Strenght [Mpa]	Elongation Break [%]	Poiss ratio
Average	98.879	1.782	1,75	0,28
Standard deviation	8.211	282	0,18	0,09
Coefficient variation	8,3%	15,8%	10,3%	35%

Composite materials are strong in axial tension, and tensile test specimen, must be gripped in some manner for testing. It is proper to calculate the minor Poisson ratio from the measured transverse modulus, the axial modulus and the major Poisson ratio.

<u>Tensile perpendicular on fiber EN ISO 527</u>

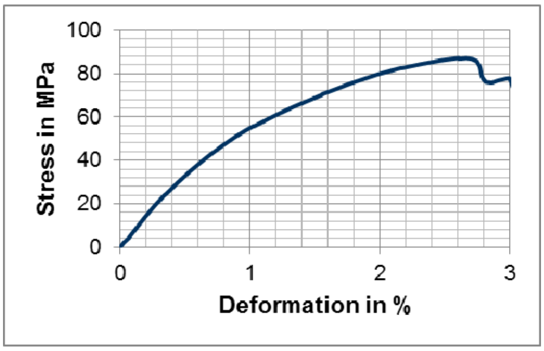

Fig.4: Tensile stress-strain curve ±45˚ fibers orientation

Fig. 5: The fracture pattern of the specimens

After averaging measurements was made and the following parameters were calculated:

Table 3: Parameters calculated for fiber TS40 and T700 for tensile perpendicular on fibers

HTS40 CFK	E-modulus [Mpa]	Break Strenght [Mpa]	Elongation Break [%]
Average	7.832	49	0,66
Standard deviation	1.017	2,3	0,05
Coefficient variation	13%	4,7%	7,6%

T700 CFK	E-modulus [Mpa]	Breaking Strenght [Mpa]	Elongation Break [%]
Average	7.137	46	0,66
Standard deviation	716	4,9	0,06
Coefficient variation	10%	10,7%	9,2%

For both carbon epoxy laminates, the axial compressive strength was nearly a constant value. The tests shows that, in case of both laminates, the values obtain are comparable and the different fiber nature, not interfere with the quality of the composite material.

<u>Tensile tests (±45˚ fibers orientation) for determining shear characteristics DIN 65466</u>

HTS, CFK	Shear-modul [Mpa]	Shear Strenght [Mpa]	Shear Elongation at Break [%]
Average	6	133	2,12
Standard deviation	678	2	0,39
Coefficient variation	10,9%	1,5%	18,4%

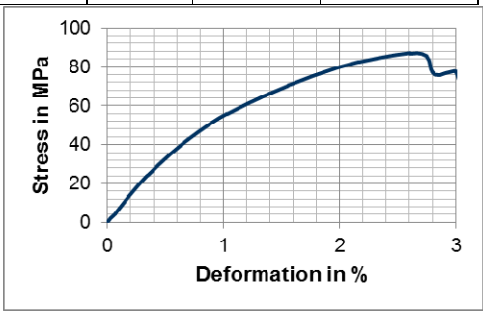

Fig.6: Tensile stress-strain curve ±45˚ fiber orientation

Compression perpendicular on fiber EN ISO 14126

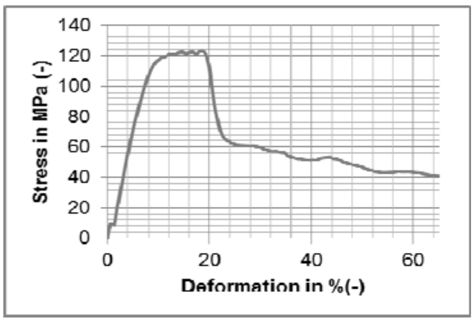

Fig.8: Stress-strain curve in compression perpendicular on fiber

Fig.7: The most common fracture pattern of specimens for ±45˚ fibers orientation

Table 4: Parameters calculated for fiber HTS40 and T700 for ±45˚ fibers orientation

T700 CFK	Shear-modulus [Mpa]	Shear Strenght [Mpa]	Shear Elongation atBreak[%
Average	5.619	121	2,15
Standard deviation	805	2,1	0,51
Coefficient variation	14,3%	1,7%	23,6%

Fig.9: The most common fracture pattern of the specimens for compression perpendicular on fibers

Table 5: Parameters calculated for fiber T700

HTS40 CFK	E-modul	Breaking Strenght	Elongation Break[%]
	[Mpa]	[Mpa]	
Average	8.016	169	3,14%
Standard deviation	901,4	4,1	0,40%
Coefficient variation	11,2%	2,4%	12,8%

and HTS40 for compression perpendicular on fibers

T700 CFK	E-modulus [Mpa]	Breaking Strenght [Mpa]	Elongation Break [%]
Average	8.265	185	3,61%
Standard deviation	1.328,6	8,5%	1,03%
Coefficient variation	16,1%	4,6%	28,6%

The existence of reliable material characteristics is an important basis for FEM calculations.

Having determined the characteristics of the material were made molds (Fig.10) to produce parts / specimens similar in structure with console steering column that we want to achieve.

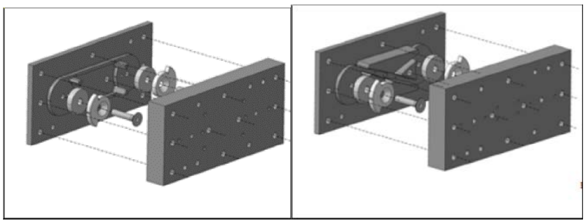

Fig.10: Right / cross molds for specimen

Specimens were made to highlight the behavior of composite materials based on carbon fiber for achieving steering column bracket.

The specimen is strained by means of a fork-like construction, which in turn is attached to the drive components of the machine. This mounting have to eliminate all movements of rotation and translation. The specimen shall apply only translation tensioning rails or to compare the effects of stress. In order to analyze as many cases of stresses and deformations, specimens required stress on three directions. Specimen mounted in the test machine, loaded after X direction, is shown in Figure 11. The image presents fork construction details.

The lengths x1 and x2 are defined analogously. The elongation of the sample results from the difference between the two lengths. This value is compared to the rate recorded for the test machine. After recording three measurements race-force it was measured for compare some of characteristic values among others for the spring constant, c.

Each specimen was mounted in the test machine, tense and removed four times and subjected to five times to a task 7'000 N for right specimen and 6'000 N for cross specimen.

Table 6 shows that the reliability of the values measured by the test machine under 10% would be acceptable but the measured values of that machine test could not be confirmed by manual measurements.

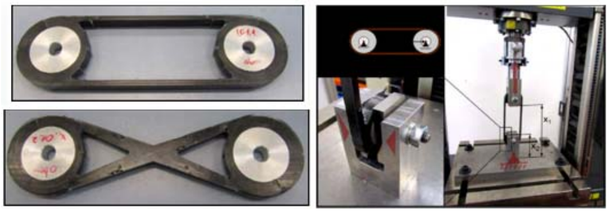

Fig. 11: Specimens for testing steering column and their test machine

In the specifications of the client is known the torque of the drive lever or driving force of drive lever.

The torque of the drive lever is made in dependence on the angle lever Force lock / unlock is determined by the length of the lever and the results recorded in a test report.

Tabel 6: Measured values

	c?[N/mm] by measuring on the test machine		c?[N/mm] by manual measuring	
Right specimen	13.133	±848	25.586	±2387
Cross specimen	10.326	±984	15.054	±3413

Tests were performed using FEM to compare simulated results with real tests and measurements.

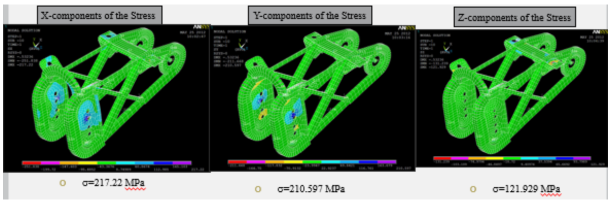

Fig.12: FEM simulation for console steering column

FEM simulation results for the steering column bracket and structural measurements and tests specimens were relatively similar.

Stiffness horizontal and vertical

A highly rigid steering column will have its own frequency higher than a less rigid column. As a measure of stiffness it is considered the ratio force / displacement [N/mm]. This report is the equivalent of elastic constant of the steering column. The value of the ratio is higher; we obtained the more rigid steering column. It is therefore desirable to achieve a high rigidity of the steering column. Radial stiffness measurement is made after the vertical and horizontal. Radial forces are applied to the end of the steering pipe. Here deflection is measured.

Table 7: Real measured values of stiffness and values of simulation results

Stiffness[mm]	Real Test [mm]	FEM simulation [mm]
BS 1 Vertical (<1,6)	±1,47	±0,96
BS 1 Orizontal (<1,0)	±0,71	±0,73
BS 2 Vertical (<1,6)	±1,45	±1,02
BS 2 Orizontal (<1,0)	±0,85	±0,75

For a defined radial force, resulting deflection should not exceed a certain limit (table 7). Tangent curve force/displacement is a measure of movements. The value of tangent at any point of the curve, there should be below a certain limit value (fig.13).

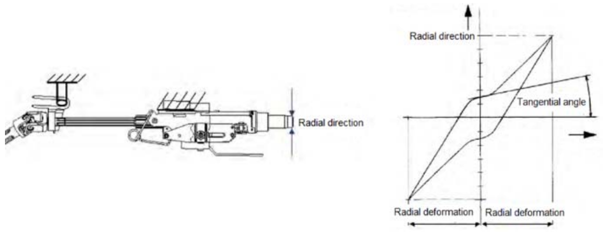

Fig. 13: Graphical representation of stiffness measurement and the resulting diagram

Natural frequency horizontal and vertical

The natural frequency of a complete steering column is measured on the vertical and horizontal. For this purpose the steering column is mounted on a rigid support. At the end piping steering column mounted a mass equivalent to multiple properties. Then, the steering column is brought into a specific position. On the board applies an acceleration transducer. The excitation frequency is effected by means of an impact hammer (Dirac pulse) in steering piping. If it is desired to measure the natural frequency in the vertical direction, the acceleration sensor is applied to the top or bottom surfaces of the equivalent mass, and the tubing is excited to vibration, to a mechanical impulse in the vertical direction. Measuring direction must correspond to the excitation.

Table 8: Frequency values and their real measured and values from the simulation results

Natural frequency[>50Hz]	Real Test [Hz]	FEM simulation [Hz]
BS 1 Vertical	47	45,6
BS 1 Horizontal	61,8	58,2
BS 2 Vertical	45,3	45,5
BS 2 Horizontal	59	57,9

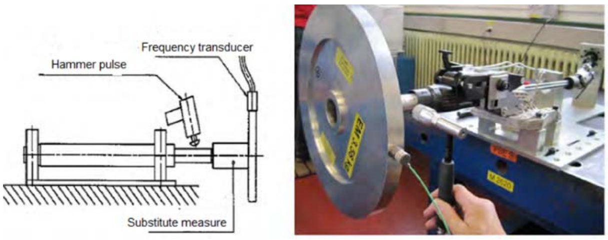

Fig. 14: Natural frequency measurement

3. CONCLUSIONS & ACKNOWLEDGEMENT

Mechanical tests are very important to describe the behavior of composite materials based on carbon fiber in various different applications and conditions.

Test results on specimens help choosing the correct material composition, mode of settlement of the fibers, their orientation, etc.

With the help of computer programs AlphaLam, LamiCens, LAP can calculate the dimensional characteristics of different stratifications. For CFK materials, transverse contraction coefficient becomes for certain angles, 0, an effect that can be exploited.

Both specimens and finished parts made of composite materials based on carbon fiber revealed that traditional materials can be successfully replaced by the new composite materials.

The quality of parts made of composite materials must be very good and constant in every section of the piece and manufacturing technology should allow the production of parts in high and very high series for automotive parts.

The next step is to optimize the production process to obtain high quality parts in a production time of less than 2 min / part for the high series production.

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REFERENCES

1. T.Heitz-*Performantele fizico-mecanice ale pieselor din materiale compozite utilizate pentru coloana de direc□ie a autovehiculului*, Teză de doctorat, 2013, Brasov,România
2. C Soutis and N A Fleck, '*Static compression failure of carbon fibre T800/924C composite plate with a single hole*', Journal of Composite Materials, 1990 **24**(5) 536–58.
3. M B Gruber, J L Overbeeke and T W Chou,'A reusable sandwich beam concept for composite compression test', Journal of Composite Materials, 1982 **16**162–71.
4. N.Iosipescu, *Journal of materials*, 1967, 537-566
5. Heitz, T. und Chiru, A. *Analysis of using CFK material for steering columns components in passenger vehicles* - Part 2. Valancia : FISITA, 13th EAEC Automotive Congress, 2011. C54