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Dynamic Analysis of Carbon Woven Reinforced Epoxy Matrix Composites Used for Parts of Electric Vehicles

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Abstract. This paper deals with evaluation of mechanical properties of fibre composites using an experimental technique based on dynamic mechanical analysis (DMA). Fibre composite material are increasingly being used in various industries due to their properties. Composites excel in high strength at low weight compared to conventional materials. Carbon woven reinforced epoxy matrix composites is a very promising type of composite material. Electric vehicles are a desirable replacement for vehicles with combustion engines, and the weight is a key parameter of their usability. The low density of composite materials is very advantageous for part design of electric vehicles. Fibre composites can be used not only for visual parts but also for structural and safety elements. Three types of carbon composites, with different configuration, were used for this study. The chosen test method was three-point bending at frequency 10 Hz and variable temperature. The performed measurement shows different storage modulus of each type of sample.

Introduction

Transportation sector is using mainly fossil fuels. This sector alone consumes nearly two-thirds of global oil consumption. Transportation is responsible for 23 % of CO_2 emissions connected to energy [1]. The current trend in vehicle development puts great emphasis on reducing harmful emissions and energy consumption. Legislative regulations lead manufacturers to reduce vehicle weight and search for new ways of propulsion.

A possible solution is the development of electric vehicles. According to study of material composition of conventional passenger vehicles [2] there is 72.3 % metal of the total weight. For electric vehicles, weight is one of the key parameters, so manufacturers are forced to look for new low-density construction materials. Continuous fiber composites are becoming very attractive materials for application in many industries. Their high strength and stiffness to weight ratios are their main advantages over metallic structures. However, their low impact tolerance, easy delamination and poor damage tolerance behaviors are the main disadvantages [3]. Fiber composite materials are increasingly used also in the automotive industry. Usage of carbon fiber composites can reduce weight up to 65 % [4]. At present time, composites are used not only for visual parts but also for structural and safety elements. When composite part is properly designed, it can absorb a large amount of deformation energy. Compared to conventional metal deformation parts based on plastic deformation, composite deformation elements can show not only lower weight but also significantly higher specific absorbed energy [5]. With the gradual improvement of the production process, the properties are improved and also price of composite products is decreasing. These are other reasons for increased use of composite materials in vehicle production.

Fiber reinforced polymer is a composite material made of a polymer matrix reinforced with fibers. The polymeric matrix is most often epoxy, polyester or phenolic. The fibers are usually carbon, glass, or aramid, plant fibers are becoming increasingly popular due to ecology. Carbon fiber has been described as a fiber containing at least 90 % carbon obtained by the controlled pyrolysis of appropriate fibers. Conventional carbon fibers typically have diameter around 7 μm. The carbon fiber blanks for the composite are most often prepared by textile processing techniques of weaving, knitting and braiding. Weaving can be done in a conventional manner to produce two-dimensional fabric as well in a multilayer weaving that can create three-dimensional fabric. Braiding is suited to the manufacture of narrow width flat or tubular fabric. 3D braiding machines produce spatially shaped braiding fabrics with different shape of cross section. Fabric produced by knitting is regarded as two-dimensional, but multiaxial warp knitting machines are capable of producing multilayered fabrics with layers oriented from 0°to 90° - so called non-crimp fabrics (NCF) or multiaxial fabrics. All layers are connected using threads, which is insert using needles to form a 3D structure [6].

Dynamic mechanical analysis (DMA) is very effective method for determining the morphology and viscoelastic properties of polymers and composite material. The storage modulus (E') is typically related to the Young's modulus, determines material ability to store energy applicable for future purpose. Loss modulus (E'') is a viscous response of the material and regarded as material tendency to dissipate energy applied to it. Loss modulus is also associated with internal friction. Tan δ is mechanical damping factor defined as the ratio of loss and storage modulus (tan δ = E''/E'). A low value of tan δ shows high elasticity of material. Increasing bonding interface fiber/matrix results reduction of tan δ [7].

Materials

For experiment three type of composite with fibre reinforcement were used. Sample 1 – carbon woven fabric, standard 6K, plain weave, sample 2 - carbon woven fabric, 12K - WD, plain weave, sample 3 - carbon woven fabric, spread tow 12K, plain weave. Table 1 contains detailed specification of fabric.

Table 1: Parameters of carbon fabrics

Fabric	Weave	Weight [gm^{-2}]	Thickness [mm]	Sett 0°/0°
1	Plain 6K	200	0.55	520/520
2	Plain 12K	193	0.35	120/120
3	Plain 12K	160	0.19	67/67

Composite from one layer of carbon woven fabrics with plain and epoxy resin CHS-EPOXY 531 was made using hand lay-up moulding process (weight ratio of hardener 1:27, curing temperature +20°C and curing time 24 hours). CFRP (carbon fiber reinforced polymer) with reinforcements 1-3 you can see in Fig 1.

For this experiment, the volume fraction was not the main parameter of the composite samples. The aim was to produce composite samples with the same thickness. Samples for the experiment were prepared by the same method. Defining the differences in mechanical properties between individual samples is based on the different processing of the input roving from which the reinforcements are made (reinforcement - fabrics with plains weave, carbon roving 6K and 12K). In the first case, it is a classic roving processing - the result is a bundle of parallel-arranged fibrils, the cross section is circular. In the case of the second sample, it is a WD - flat tow adjustment; the result is an arrangement of fibrils in a tape with a rectangular cross-section. In the third case, it is a type of spread tow; the fibrils are arranged in parallel in an ultra-thin tape with a minimum achievable thickness.

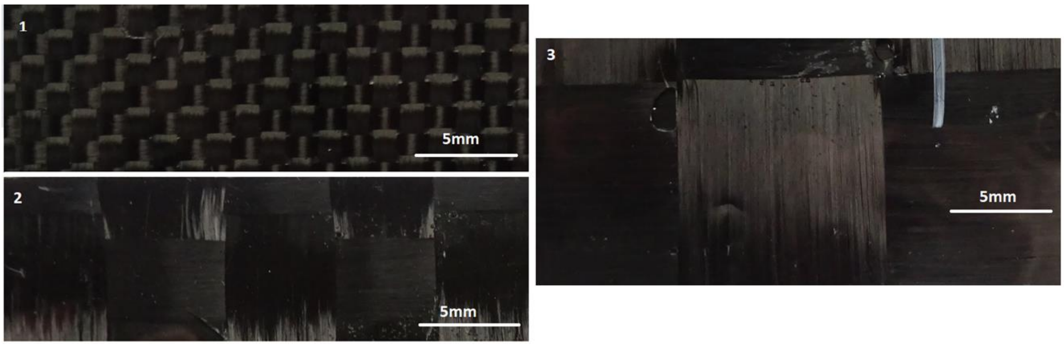

Fig. 1: Carbon composite samples

The standard prescribes a minimum sample thickness of 1 mm that is a fact. In this case, an effort was made to achieve the same minimum thickness for all samples, although the difference between the highest and lowest value of the reinforcement thickness is 0.35 mm. The same volume fraction could only be maintained by adding extra layers. In such a case, it would not be possible to monitor directly how the reinforcement parameters affect the properties of the composite. Single-layer samples were chosen to make the difference in mechanical properties depending on the processing of the input roving stand out.

Experiment

The aim of carried experiment was compare elastic behavior of different types of long fiber carbon composites under dynamic loading. For this test was use dynamic mechanical analyzer TA DMA Q800. Used method was the 3-point bending test Fig.2, that is together with the 4-points bend probably the most appropriate method useable for testing layered composites [8]. The carried experiment consists single frequency with constant strain amplitude. Because the properties of the composite material are temperature dependent, the measurements were carried out for different temperatures.


Fig. 2: DMA Q800 device with 3-point bending clamps

Before the main testing, it is appropriate to set the value of the geometry factor. For the 3-point bending clamps with rectangular samples it is possible to determine the optimal sample size according to (1):

$$GF = \frac{L^3}{4t^3W}\left[1 + \frac{12}{5}(1+\nu)\left(\frac{t}{L}\right)^2\right] \quad (1)$$

Where: L is sample length, W is width, t is sample thickness, ν is Poisson's ratio. Parameters are shown in table 2, ν is estimated value.

Table 2: Parameters of tested samples

Parameter:	Sample 1	Sample 2	Sample 3
L [mm]	20	20	20
t [mm]	0.66	0.65	0.64
W [mm]	13.42	12.64	12.29
ν [-]	0.3	0.3	0.3
GF [1/mm]	520	954	622

Obtained values of geometric factor correspond with recommended values for device DMA Q800. The recommended thickness of samples is 1/10 to 1/32 of the span (length) of the chosen 3-point bending sample supports. Used samples thickness is about 0.6 mm, which is at the limit of the recommended value for 20 mm span supports. Unfortunately supports with smaller span were not available. The thickness should be as uniform as possible across the sample because, cube of the thickness is used in the modulus calculation a 3% error in thickness becomes a 10% error in the calculated modulus. For composite samples the amplitude of 10 to 50 µm should yield good results [9]. In this measurement amplitude was set to 15 µm, preload force to 0.01 N, frequency 10 Hz and temperature in the range 30 - 50 °C.

Results

In the fig. 3 are shown results of dynamic 3-point bending test. It is possible to see dependency of storage modulus on temperature (range 30°C – 50°C). The results are shown for three different samples of carbon composites. Sample number 3 shows the highest value of storage modulus, and at the its decreasing with temperature is the most significant.

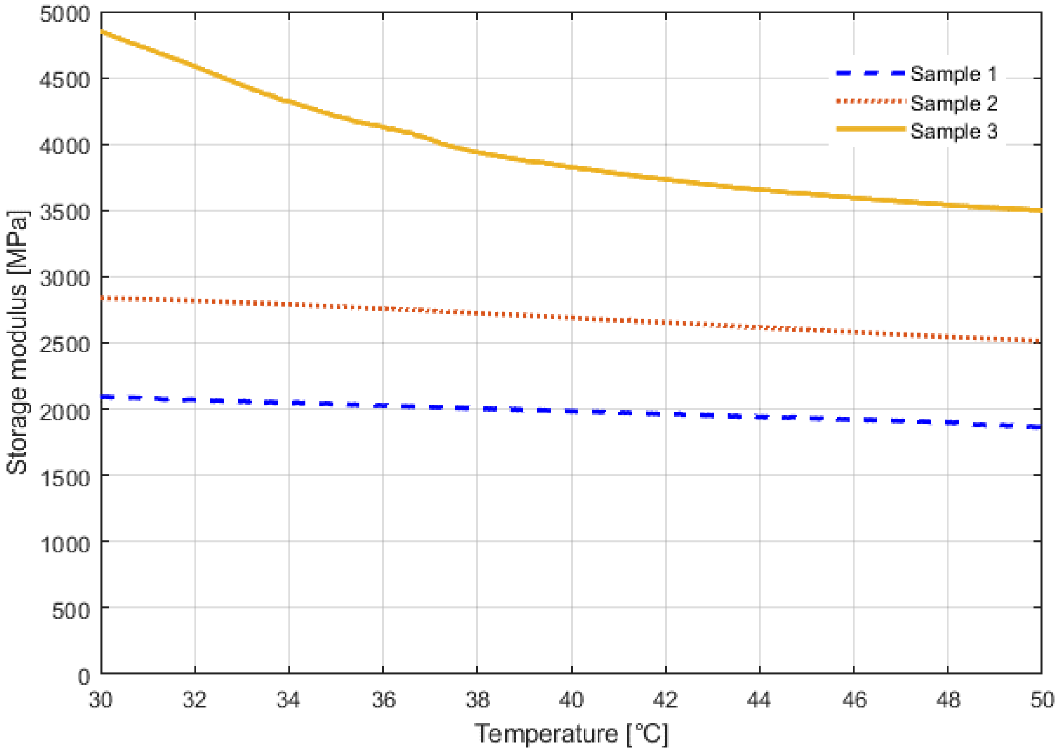

Fig. 3: DMA Q800 device with 3-point bending clamps

Conclusion

Mechanical properties of three types of carbon composite were compared using a dynamic mechanical analyzer. The measurement shown different characteristics at different temperatures. Storage modulus values were obtained at a frequency of 10 Hz for a temperature range of 30°C – 50°C. The parameters found can help for selection suitable composite material for a particular application.

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References

[1] K. Habib, S. T. Hansdóttir, H. Habib, Critical metals for electromobility: Global demand scenarios for passenger vehicles 2015–2050, Resources, Conservation and Recycling, Volume 154, 2020, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2019.104603.

[2] J. Sullivan, J. Kelly, A., Elgowainy, Vehicle Materials: Material Composition of Powertrain Systems. Argonne National Laboratory, Argonne, 2015

[3] E. Selver, Tensile and flexural properties of glass and carbon fibre composites reinforced with silica nanoparticles and polyethylene glycol. Journal of Industrial Textiles, 49(6), 809–832. https://doi.org/10.1177/1528083719827368, 2020

[4] S. Balakrishnan, H. Seidlitz, Potential repair techniques for automotive composites: A review. Composites Part B: Engineering, 145, 28-38. doi:10.1016/j.compositesb.2018.03.016, 2018

[5] JM. Hormann, M. Wacker. Simulation of the Crash Performance of Crash Boxes based on Advanced Thermoplastic Composite. 5th European LS-DYNA Conference :DYNAmore, 2005

[6] M. A. Masuelli Introduction of Fibre-Reinforced Polymers − Polymers and Composites: Concepts, Properties and Processes, Fiber Reinforced Polymers - The Technology Applied for Concrete Repair, Martin Alberto Masuelli, IntechOpen, DOI: 10.5772/54629. January 23rd 2013. Available from: https://www.intechopen.com/books/fiber-reinforced-polymers-the-technology-applied-for-concrete-repair/introduction-of-fibre-reinforced-polymers-polymers-and-composites-concepts-properties-and-processes

[7] N. Saba, M. Jawaid, Othman Y. Alothman, M.T. Paridah, A review on dynamic mechanical properties of natural fibre reinforced polymer composites, Construction and Building Materials, Volume 106, 2016, Pages 149-159, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2015.12.075.

[8] P. Kulhavý, V. Fliegel, P. Lepšík, P. Srb, Dynamic analysis of 3D printed and moulded composites with carbon microfibers, Experimental Stress Analysis - 56th International

[9] QDMA Manual, TA Instruments - Waters LLC, New Castle, DE 19720, 2006